THE SIGNIFICANCE OF STURM'S INTERVAL IN REFRACTION

AVERY DEH. PRANGEN, M.D.
Rochester, Minnesota

The phenomenon of Sturm's astigmatic interval has long been known in the field of physiologic optics. So far as I know, however, very little concerning its clinical application to the problems of refraction has been taught. One of the main difficulties in refraction is the diagnosis, interpretation, and treatment of astigmatism. The phenomena exhibited by Sturm's astigmatic interval illustrate a fundamental theme in the problems of astigmatism. I have referred to this theme in a previous paper.* The ability of the ophthalmologist to keep clearly in mind a picture of the phenomena of Sturm's interval is of the greatest aid to an understanding of the various problems that arise in treating astigmatism.

Sturm's interval (fig. 1) is the distance represented in the conoid of Sturm between the two focal lines of the two principal planes of an astigmatic lens system. As rays of light pass through an astigmatic lens system they come to a focus at each of these two principal focal distances. In the interval between these two focal lines there is formed a series of imperfect or distorted images of the object or source of light, and these images are representative of the images seen by an astigmatic eye when it is viewing an object. One of these distorted images is more nearly perfect than the remainder and is called the "circle of least confusion" (fig. 1, *4*). This is situated near the middle of the interval.

The clinical problem in astigmatism is to replace these

* Prangen, A. DeH.: "Some Problems and Procedures in Refraction," Arch. Ophth. **18**: 432–447, 1937.

distorted images of Sturm's interval with a corrected image by obliterating the interval by means of correcting lenses; in other words, to bring the two principal focal lines together. This would be a full correction of astigmatism, an ideal situation that it is not always possible or feasible to achieve, as will be discussed later.

The concept of Sturm's interval is an aid to understanding the optics of the astigmatic lens systems or astigmatic eyes. It aids in visualizing how and what astigmatic eyes see,

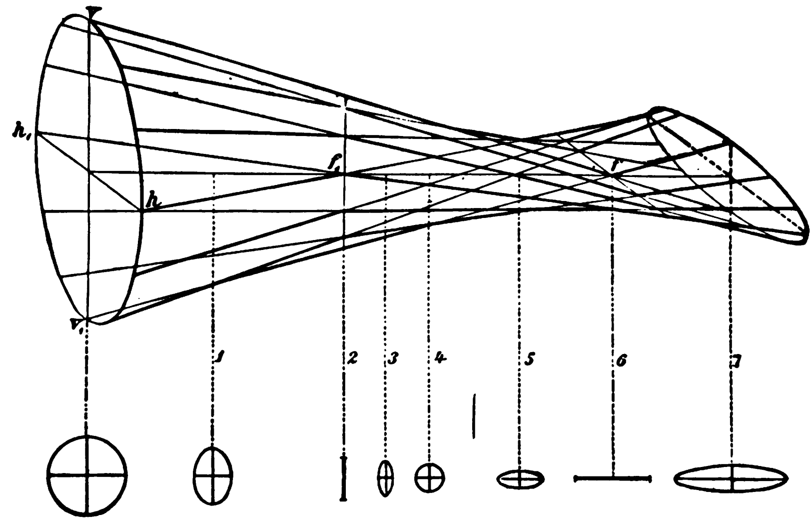

Fig. 1.—Sturm's astigmatic interval (after Fuchs).

whether they be uncorrected, partially corrected, overcorrected, or fully corrected. It visualizes for ophthalmologists what is occurring in the patient's mind's eye, and also what is occurring as a result of the ophthalmologist's manipulations when he attempts to correct astigmatic eyes by subjective methods; that is, by lenses and cross cylinders. When the ophthalmologist is subjectively refracting astigmatic eyes with lenses or cross cylinders, he is progressively shifting or changing the images of the interval as seen by the patient's eyes, and attempting to find a combination of lenses that will obliterate the interval; in other words, he tries to find a lens combination that will bring the two principal focal lines to the same plane and produce a correct image of the object that is being looked at.

If the patient's eye can be made to accept the fully corrected image with comfort, the situation will be excellent. Astigmatic eyes may or may not do this. When they are satisfactorily relaxed by a cycloplegic, most eyes will do this, for they have little opportunity to do otherwise when the accommodation is suspended. With manifest, fogging or at postcycloplegic examinations, however, these eyes, as is well known, often refuse to accept full astigmatic correction. Since many eyes are accustomed to vision with an uncorrected and distorted image situated somewhere in Sturm's interval, astigmatic eyes often resist stubbornly the ophthalmologist's attempt to substitute a new image, even if it is more nearly accurate and correct than the old one. Such eyes function tenaciously according to the old image to which they are accustomed, and resist the substitution of a new image. I am referring, of course, to those adult astigmatic eyes in which the astigmatism has never been corrected. Youthful eyes usually will accept full astigmatic correction, as will also those older eyes which have already grown accustomed to partial astigmatic correction.

If a clear understanding of Sturm's interval is borne in mind, it is possible readily to comprehend the marked variations in subjective acceptance by these astigmatic eyes when the accommodation is active, as contrasted to the situation obtaining when the accommodation is suspended. When the accommodation is active there is a constant shift or change occurring in the nature and character of the image in the interval. This changing state naturally interferes with accurate subjective refraction. This variation in the subjective acceptance of correcting lenses applies likewise to presbyopic eyes, for in the presence of presbyopia at no time is the accommodation entirely inactive. Therefore, presbyopic astigmatic eyes can readily refuse part or all of an astigmatic correction in favor of their old, accustomed, uncorrected image. To use a figure of speech, this image is to presbyopic astigmatic eyes as is an old friend or an old shoe to some persons; it is perhaps not of the best, but the eyes are accustomed to it.

The employment of the cross cylinder for determining the amount and axis of astigmatism is a method of producing a quick and marked shift of sharply contrasted images in Sturm's interval of astigmatic eyes—first in one direction of the interval and then in the opposite direction. The patient is given a choice as to which of these two new markedly different images is the sharpest and clearest, distorted though the images may be. The use of the cross cylinder is a play on the interval of Sturm. If Sturm's astigmatic interval is kept in mind, it will help greatly to an understanding of the use of the cross cylinder and the interpretation of its results. When the cross cylinder leads the ophthalmologist astray in a determination of the amount of the astigmatism present, it usually does so because the spherocylindrical relationship is not correctly balanced, and because a change of sphere is needed instead of an alteration in the cylinder. This error in cylinder strength acceptance is a phenomenon of Sturm's interval. In using the cross cylinder to determine the strength of cylinder, the ophthalmologist should keep in mind the fact that the cross cylinder affects both the sphere and the cylinder. Visualization of the dual optical effect of the cross cylinder by the examiner as he uses this device is most helpful, and aids in avoiding the pitfalls that arise during its use. An incorrect spherocylinder combination causes a distortion of Sturm's interval, and the patient may be forced to elect cylindrical change when in reality it is the sphere that should be altered. Unless the sphere is correct, the patient is forced to decide between two images occurring in an artificially exaggerated interval. When the proper sphere is employed, a normal interval relationship is then created and is ready for correction by the true cylinder. This same theme probably accounts for the selection of wrong axes by the cross cylinder when the spherocylindric relationship is incorrect.

In general it may be said that, when astigmatic eyes are not corrected or will not accept full astigmatic correction, the image of the circle (fig. 1, *4*) of least confusion on the retina, or close to it, is the one most acceptable to them. This image is more acceptable because it is least distorted, which explains why many simple astigmatic and equal mixed astigmatic eyes see so well, about 6/10, without correcting lenses. Their circle of least confusion is already close to the retina. For example, this would be true of an eye with a refractive error of $-0.75 \supset +1.50$ cyl. ax. 90°. Such was the situation in Case 1 of the series to be presented here.

It is often advisable to provide the eye with a compromise image, or with partial correction of the astigmatism, by partly obliterating the interval or by bringing the focal lines closer together instead of completely together. In initial attempts to correct higher degrees of astigmatism the eye, being accustomed to a distorted image or a wide interval, may accommodate itself more readily to a gradual adjustment of the interval by partial or compromise corrections of the astigmatism, gradually accommodating itself later to full correction. There seems to be no logical reason why all eyes should be required to adjust themselves to immediate full correction of astigmatism. The patient and the ophthalmologist often will be much happier if the astigmatism is corrected gradually over a prolonged period instead of at once. The tendency of American ophthalmologists—myself included—is to insist on full correction for astigmatism as a routine measure. In the case of young persons and of those already provided with partial correction, this procedure works well; but in that of older persons who are unaccustomed to correction for astigmatism there are, I believe, many whose astigmatism should be corrected partially and gradually, for the reasons previously mentioned.

I know of no rule by means of which the ophthalmologist can ascertain how much to deduct when the full astigmatic error is known and he wishes to correct it partially. This is a point that the ophthalmologist must decide for himself. There is, however, a rule governing spherical and spherocylindric equivalents of formulas for the correction of astigmatism which is a great help. The spherical equivalent to or use of any spherocylindrical formula is equal to the value of the spherical lens plus half the value of the cylindrical lens, added algebraically. There exists, therefore, a series of equivalent formulas for any given formula for the correction of astigmatism. If the cylinder is reduced by any given amount, half of this reduction should be added algebraically to the existing sphere. This furnishes or gives a formula that is equivalent in visual effect to the original formula. This original formula and all equivalent formulas keep the circle of least confusion or area of best vision in the uncorrected interval, focused on or close to the retina. In other words, the eye is kept an equal mixed astigmat with the two principal focal lines equidistant from the retina. Of course, the farther the focal lines are from the retina, the larger the circle of least confusion will be, and, consequently, with each reduction of cylinder the lower the vision will be. By trial of a series of cylindric reductions in their equivalent formulas one formula can be found that will provide the patient with vision comparable to full correction. This procedure is, of course, based on another variation of Sturm's interval. The patient is allowed to select a compromise formula, or an image which obliterates the interval partially instead of completely. This procedure provides the eye with a new image that is not too unlike the image to which it has been accustomed. The image represented by full astigmatic correction may be so different from the accustomed image that the patient's mind's eye will not accept it. For eyes that have difficulty in accepting full astigmatic correction I have found it better to use these equivalent formulas rather than merely to reduce the cylinder and make no change in the sphere.

The ophthalmologist will also find it helpful to form the habit of thinking in terms of equivalents when he is comparing and evaluating lenses and formulas. Often, when lenses worn by a patient are compared with the ophthalmologist's findings, they appear to differ. Closer examination, however, may disclose the fact that they are equivalents, and that the one may be as useful to the patient as the other. As an example in the consideration of equivalent formulas, the full acceptance with a manifest test or a postcycloplegic test could be: For the right eye, a −2.00 D. sph. ⊃ + 5.00 D. cyl. ax. 90°. The patient may be thirty-nine years old and may never have worn glasses. The equivalent formulas are:

(1)	−2.00 D. sph. ⊃ +5.00 D. cyl. ax. 90°	= equivalent	+50 D. sph.	
(2)	−1.75 D. sph. ⊃ +4.50 D. cyl. ax. 90°	= equivalent	+50 D. sph.	
(3)	−1.50 D. sph. ⊃ +4.00 D. cyl. ax. 90°	= equivalent	+50 D. sph.	
(4)	−1.25 D. sph. ⊃ +3.50 D. cyl. ax. 90°	= equivalent	+50 D. sph.	
(5)	−1.00 D. sph. ⊃ +3.00 D. cyl. ax. 90°	= equivalent	+50 D. sph.	Equivalent = sphere + ½ cylinder (added algebraically)
(6)	−0.75 D. sph. ⊃ +2.50 D. cyl. ax. 90°	= equivalent	+50 D. sph.	
(7)	−0.50 D. sph. ⊃ +2.00 D. cyl. ax. 90°	= equivalent	+50 D. sph.	
(8)	−0.25 D. sph. ⊃ +1.50 D. cyl. ax. 90°	= equivalent	+50 D. sph.	
(9)	0 D. sph. ⊃ +1.00 D. cyl. ax. 90°	= equivalent	+50 D. sph.	
(10)	+0.50 D. sph. 0 D. cyl.	= equivalent	+50 D. sph.	

On testing these formulas, Nos. 3, 4, or 5 are likely to be accepted, with the resultant vision being comparable to full correction. One formula—preferably No. 5—may well be worn with comfort by the patient. For illustrative purposes, a high degree of mixed astigmatism was selected, because it shows perhaps the theme of equivalent reduction more strikingly than do other types of astigmatism. High degrees of either compound myopic or compound hyperopic astigmatism may be equivalently reduced in the same manner. Equivalent reduction of cylinders is most useful in mixed astigmatism and myopic astigmatism and less useful in hyperopic astigmatism. In the presence of hyperopic astigmatism in younger persons, if the cylinder is reduced, the active accommodation may make up or balance the spherical component in reduced formula.

I do not advocate routine partial correction for astigmatism. In selected troublesome cases, however, it is advantageous partially to correct the astigmatism, especially when the correction is performed in the manner previously described.

REPORT OF CASES

CASE 1.—A woman, aged forty-seven years. Her visual condition was an example of equal mixed astigmatism that had provided satisfactory distant vision without making it necessary for the patient to wear glasses. Several refractions had disclosed the presence of mixed astigmatism which was equal in each eye. The patient's vision for distance was: O.D. 6/10 and O.S. 6/15+ without correction. Cycloplegic refractions had showed her refractive error to be O.D. −1.00 ⊃ +2.00 cyl. ax. 90° with distant vision of 6/6, and O.S. −1.00 ⊃ +2.00 cyl. ax. 100° with distant vision of 6/6. She had never felt the need for distance lenses and hence had never worn them. More recently she complained of presbyopic symptoms, and it was necessary to add +1.00 sph. in both eyes to her distance correction in order to provide satisfactory near vision. Since she had no desire for distance lenses, she was given a correction for near vision only.

In this patient is seen an instance of equal mixed astigmatism in which the circles of least confusion were naturally at focus on the retinas. She was content with her equivalent distance vision and sought relief only for presbyopia. She was rendered comfortable when provided with full spherocylindrical correction for presbyopia. It was not necessary to reduce the cylinder.

CASE 2.—A man, aged fifty-five years, came to the clinic complaining of poor near vision. He was wearing O.D. +3.00 sph., with distant vision of 6/12, and +2.25 sph. added in the bifocal; O.S. +2.50 sph. with distant vision of 6/12, and +2.25 sph. added in the bifocal. Near vision, especially in the left eye, was poor. Manifest refraction showed: O.D. +3.50 ⊃ +0.25 cyl. ax. 180° with distant vision of 6/5 and near vision of 14/21, with an addition of +2.25 sph. Manifest refraction showed O.S. +3.25 ⊃ +2.00 cyl. ax. 165° with distant vision of 6/6 and near vision of 14/24, with +2.25 sph. added. Full correction was prescribed for the right eye, including a bifocal lens. For the left eye it was believed best to reduce the cylinder by one-half, *i. e.*, to +1.00 cyl. ax. 165°. One-half of this reduction, that is, +0.50 D., was added to the original sphere, +3.25, making the new sphere +3.75. By this equivalent reduction and change of both sphere and cylinder the prescription for the left eye was +3.75⊃+1.00 cyl. ax. 165°, which gave vision for distance of 6/7 instead of 6/6, which had been the full correction, and bifocal of +2.25, which gave near vision of 14/24, the same as it had been under full correction. The patient wore these glasses with comfort for a year, and was then given full astigmatic correction for both eyes. It is believed that he was more comfortable in his initial correction with partially corrected astigmatism for the left eye.

CASE 3.—A woman, aged forty-two years, whose complaint was of poor near vision, or presbyopia. Her visual condition was an example of compound myopic astigmatism with equivalent reduction of cylinder in her first bifocal lenses. The lenses she was wearing showed O.D. −2.50⊃−2.25 cyl. ax. 30°, with distant vision of 6/20 and near vision of 14/28; O.S. −1.25⊃−2.25 cyl. ax. 147°, with distant vision of 6/15 and near vision of 14/28. Cycloplegic refraction, carried out with the aid of homatropin, showed: O.D. −4.00⊃−3.25 cyl. ax. 35°, with 6/12+ distant vision, and O.S. −1.50⊃−3.25 cyl. ax. 150° with 6/7 distant vision. Postcycloplegic examination showed acceptance of full correction with the same axes and distant vision, for near vision adding +2.00 sph. in both eyes with 14/24 vision in both eyes. Since these lenses would be her first bifocal lenses, and since she was a high-strung, nervous person, it was deemed best partially to correct the astigmatism, thereby making it easier for her to adjust herself to her new glasses. The cylinder was reduced by −1.25 D. in both eyes, and one-half of this reduction, approximately −0.50 D., was added to the original sphere in both eyes. The final prescription was: O.D. −4.50⊃−2.00 cyl. ax. 35°, with distant vision of 6/12+, a bifocal addition of +2.00 sph., with 14/28 near vision, and O.S. −2.00⊃−2.00 cyl. ax. 150°, with distant vision of 6/7−, and bifocal addition of +2.25 sph., with 14/24 near vision. It was observed that both distant and near vision were practically equal with both the full and the reduced equivalent formulas.

CASE 4.—A man, aged twenty-one years. This was an instance of marked mixed astigmatism in a young person who had never worn glasses. Distant vision was O.D. 6/30 and O.S. 6/20 and near vision was 14/24 in both eyes, with accommodative near points of 16 cm. Refraction under homatropin cycloplegia gave O.D. −1.25○+3.25 cyl. ax. 100°, with 6/10+ distant vision, and O.S. −3.75○+4.25 cyl. ax. 85°, with distant vision of 6/10+. Postcycloplegic examination gave acceptance of full cycloplegic findings with the same vision as before. Since, as has been stated, these were the patient's first glasses, it was considered best partially to correct the astigmatism. After a trial of several equivalently reduced formulas, vision most comparable to that given by full correction was found when the cylinders were reduced by +1.75 D. in the right eye and by +2.00 D. in the left eye. One-half of this reduction was added algebraically to the postcycloplegic spheres, resulting in a prescription of O.D. −0.50○+1.50 cyl. ax. 100°, distant vision of 6/12, and O.S. −2.75○+2.25 cyl. ax. 85°, or transposed, −0.50○−2.25 cyl. ax. 175°, distant vision of 6/12. Near vision with this reduced correction was satisfactory. It is seen that the difference in distant vision with full and with reduced correction is only one line on the test chart.

CASE 5.—A man, aged forty years, complaining of poor vision for distance and headaches. This was an instance of mixed astigmatism and antimetropia in a middle-aged man who had never worn glasses. Distant vision was: O.D. 6/20− and O.S. 6/60−. Refraction under homatropin cycloplegia showed O.D. +1.00○−3.25 cyl. ax. 180°, with distant vision 6/7, and O.S. −1.75○−3.00 cyl. ax. 180°, with distant vision of 6/10−. Postcycloplegic examination showed acceptance of O.D. −3.25 cyl. ax. 180°, with distant vision of 6/7, and O.S. −2.50○−3.00 cyl. ax. 180° with distant vision of 6/7. Near vision with correction was 14/21 in both eyes and good range. Inasmuch, as stated, these were to be the patient's first glasses at the age of forty, it was considered best to reduce the cylinders. A trial of several reduced formulas showed vision comparable to that obtained with full postcycloplegic correction, when the cylinders were equivalently reduced by −1.50 D. One-half of this reduction of cylinder was added algebraically to the postcycloplegic spheres. The prescription was O.D. −0.75○−1.75 cyl. ax. 180° with distant vision of 6/10, and O.S. −3.25○−1.50 cyl. ax. 180°, with distant vision of 6/12+. Again it is observed that the vision with equivalently reduced formulas is but one line less on the test chart than that obtained with full correction.

SUMMARY AND CONCLUSIONS

The phenomena incident to and illustrated by Sturm's astigmatic interval have a broad and varied clinical application to the problems of astigmatism in refraction. By visualizing or keeping in mind these phenomena of Sturm the ophthalmologist is aided in his work. Such visualization makes refraction a much more vital procedure and a much less routinely mechanical process. The employment of equivalently reduced formulas is most useful for astigmatic eyes, concerning which difficulty is anticipated in the patient's wearing fully correcting cylinders. Partial correction of astigmatism is advocated only for such selected eyes as those in which the adaptation to full correction is likely to be difficult.

DISCUSSION

DR. W. B. LANCASTER, Boston, Mass.: I wish to add a word of approval for Dr. Prangen's insistence on the importance of the conoid of Sturm. The experience of the American Board of Ophthalmology shows that the candidates who come up for examination do not understand astigmatism. For example, they do not understand the use of astigmatic charts, for they have not been taught. I am, therefore addressing myself especially to the teachers and the heads of departments who are members of this Society.

What would Dr. Prangen and others who discuss this paper say to the student who brings Gullstrand's statement to their attention? If they read Helmholtz's "Physiological Optics," which every student should be required to read, they will discover that Gullstrand says: "The path of the rays in the human eye does not even approximate the conoid of Sturm."

What are the reasons for Gullstrand's statement that the astigmatic eye does not correspond to the conoid of Sturm? The reason is that the eye has so many aberrations. Here is the simplest aberration of the spherical lens: The axial rays—those adjacent to the axis of the lens—come to a focus here (illustrating) and the marginal rays come to a focus at a distinctly different point nearer the lens. Sturm takes no account of that. The formulae of Sturm, and those of most of the writers on theoretic optics, are valid for an infinitely small area at the very center of the lens. They take no account of the peripheral rays. The human eye, of course, must take care of the rays in the whole area of the pupil; hence students should be taught the practical application of spherical aberration, especially with dilated pupils.

In asking my question I should give my own answer, which is that the lenses which we use to correct errors of refraction—spheres and cylinders—refract light precisely according to the conoid of Sturm, and therefore the best we can do in correcting errors of refraction is to use these simple regular lenses, selecting that combination which corrects the largest possible part of the mixed errors of the eye. Students could make these experiments on one another and on themselves, and so study the effect of the different lenses on the image.

I should like to show the effect of accommodation on the conoid of Sturm as demonstrated by the projection lantern: First, the image of a "point" of light is projected on the screen, appearing as a tiny luminous dot; next a cylindric lens is inserted in front of the projection lens of the lantern. This changes the image of the "point" to a line—a luminous line; next, instead of the point, a slide with two lines at right angles is inserted—first without the cylinder (a sharply defined image of the lines is thrown on the screen); second, with a −0.25 cylinder in front of the projection lens, with its axis parallel to one of the lines. Now one line remains sharp, because every point in it is a narrow line parallel to the line itself. The other line is blurred, because every point of it is imaged as a line at right angles to the line itself. What I wish to demonstrate is the effect of accommodation on this image of one sharp line and a very much blurred line at right angles to it. As the lantern operator focuses the instrument a point where both lines are alike is found. There is no visible astigmatic effect. Of course, the lantern lens system can change its focus only as a whole—not more in one meridian than in another. In other words, there is no possibility of what is called in the eye astigmatic accommodation—greater action of the ciliary muscle in one meridian than in another, thus compensating or correcting the astigmatism by an unequal contraction of the ciliary muscle. The neutralization of the astigmatism must be accomplished in another way, as it is by so focussing the lantern that the image is at the interfocal circle of the conoid of Sturm. The lines are all alike, but all are slightly blurred.

Lastly, a slide showing an astigmatic dial is inserted first without the −0.25 cylinder—all the lines are clear and equal; next, with the −0.25 cylinder—now a small group of lines is clear, whereas the others are blurred. If the cylinder is rotated, the group of clear lines is rotated, showing how easy it is to locate the axis of the cylinder. If a +0.25 cylinder were inserted with its axis parallel to the −0.25 cylinder, all the lines would be alike again. Without adding a + cylinder to neutralize or correct the −0.25 cylinder, but merely by focusing (accommodating), all the lines are made absolutely equal but slightly blurred.

The importance of this clinically is very great. It has never been demonstrated that unequal accommodation is a function of the normal eye. The normal eye neutralizes astigmatism by normal accommodation. The latter is best prevented by fogging, since this avoids the confusing and misleading aberrations introduced when the pupil is widely dilated. It is to be regretted that this art is not more widely taught.

DR. ALFRED COWAN, Philadelphia, Pa.: In teaching optics at the University of Pennsylvania we always endeavor to show how the theory of optics may be applied to our every-day practical work. The students do the experiments themselves and, having actually set up an optical system on a bench, they are able to visualize Sturm's conoid and know exactly what it means. They must realize that Sturm's conoid is a figure composed of a series of diffusion images of a point object by a spherocylindric optical system. In such a figure as we have here the first focal line by the refraction of one meridian of this system, and the second focal line at the focal distance of the other meridian, are at right angles to each other. Between these two lines we have what is commonly known as the circle of least confusion. The distance between the two focal lines indicates the amount of astigmatism of the two systems. If they coincide, there will be no astigmatism; therefore, the greater the distance between the two focal lines, the greater the amount of astigmatism. The circle of least confusion is not a circle except when the aperture is a circle, so that the term "circle of least confusion" applies only to a system which has a circular aperture. If the aperture were square, the diffusion image at this place would be square. However, in every system of this kind every image is a diffusion image. There is no point mage of the object point anywhere in the system. In applying this to the eye we may place the retina here, there, or anywhere, and, depending on where we place it, we have a given type of astigmatism; simple hypermetropic astigmatism if it were at the first focal line, myopic astigmatism behind the second focal line, compound hypermetropic astigmatism in front of the first focal line, and mixed astigmatism between the two focal lines.

What do we accomplish with lenses? We may shift the whole figure with spherical lenses, bringing it forward or backward. When we use spherical lenses, the distance between the two focal lines which indicates the amount of astigmatism is never affected. Only a cylindric lens can approximate or further separate those two lines.

What Dr. Prangen has said about equivalent lenses is important to a certain extent, but only quantitatively, not qualitatively. Quantitatively, we may assume very roughly the amount of curvature in a two diopter cylinder approximates the total amount of curvature of a one diopter sphere, but qualitatively there is no such equivalence as the table indicates. I believe that the first to use these equivalents was Dr. Jackson, who described them in a paper published some time ago. For his purpose it was excellent. A very good example of what I mean is in a cross cylinder. A plus 50 crossed with a minus 50 is nothing but a spherocylinder with a plus 50 and a minus 1 or a minus 50 and a plus 1. If we have a half-diopter of sphere of one denomination plotted against a whole diopter of cylinder of the opposite denomination (using the equivalent table), we see that a half-diopter of sphere would neutralize exactly one diopter cylinder of the other denomination. Here you have an example of a lens from the equivalent standpoint which is neutral, or probably would be called plano, from the quantitative standpoint, but qualitatively it is still a one diopter cylinder. It is one of our reasons for using the cross cylinder. When the patient, by accommodation or otherwise, chooses a point in Sturm's conoid, he chooses a place where there is the least amount of astigmatic distortion. At best he still has a diffusion image of the type which is found with a spherical error. His visual acuity should not be better than would be indicated by the amount of spherical error from the first or second focal line to the circle of least confusion.

In the eye we have a different type of optical instrument from the ordinary ones. We have a dynamic instrument that can change its focal power and select a place for itself. As Gullstrand says, in the eye we have not such a fixation of rays as Sturm's conoid, but a small amount of aberration that would make the lines form a figure so complicated that it can hardly be drawn on a plane surface; but the eye, by its ability to accommodate, chooses the proper place and while it may receive an image that has quite a wide area of aberration around it, by its ability to ignore the peripheral portion of the image and to select and interpret the image, it is still able to see distinctly even with the aberration which Gullstrand has shown.

DR. F. H. VERHOEFF, Boston, Mass.: I shall try to present this situation from a different point of view. I would say that the conception of Sturm's interval is a very important one, and every one who undertakes refraction tests should pass through the stage of this conception. I may say that it represents an embryonic stage in the development of knowledge of refraction of the eye, and some persons never get beyond this embryonic stage. After the conception is thoroughly understood, we must realize to what extent it cannot be applied. To understand certain phenomena, the conception must be modified. To explain certain things, aberrations must be considered in addition. For example, simple spherical aberration combined with astigmatism, when considered in the light of Sturm's interval, will explain many cases of monocular diplopia. Similarly, consideration of aberrations in addition to Sturm's interval is necessary to explain the cases of so-called aphakic accommodation. If we go still further, we must consider also chromatic aberrations, diffraction, and even polarization to explain certain phenomena. We meet this problem in every field. But because we say it is not exactly true, does not mean that the conception is not a most valuable one.

DR. EDWARD JACKSON, Denver, Colo.: We have had an interesting and instructive discussion of optical theory, but perhaps the subject has not been carried into the realm of ordinary practice. After Sturm and Helmholtz had written their articles, skiascopy was introduced as a means of measuring refraction of the eye. With skiascopy and a dilated pupil, the fact that impresses us most is that the refraction is unequal in different parts of the pupil. Also astigmatism varies in different parts of the pupil, in meridians and in amount. The so-called linear shadows are not lines. They are, rather, areas of light and shadow that move in different directions in different parts of the pupil. These aberrations disappear with a contracted pupil. For that reason subjective refraction of the eyes should be tested in a relatively strong light for the final determination. The ciliary muscle may or may not be completely relaxed. The habits of the patient are to be considered. I find the most useful rule is never to prescribe a spherocylindrical correction on one determination, but on another day to make a second determination, starting with what I found before, and correcting the errors I made in my first examination. I have seen one pair of eyes five times before satisfying myself that I have the correction for the contracted pupils that would be of the greatest service.

Then the obliquity of the glass makes a difference. Sometimes, when a patient asks, "What is astigmatism?" I take a spherical lens and hold it up, perhaps with the sun shining in the window, and get a very small circular image of the sun; then I turn that spherical lens a little obliquely and immediately introduce the interval of Sturm. At one distance you get a vertical line, and at another distance, the horizontal line. That goes on when the patient looks through different parts of his glasses, and it grows worse the larger the glasses are made. The patient looking obliquely will get a different interval of Sturm from that which he will if he were looking exactly perpendicular to the glasses. I advise college and high school students at the end of the semester, before going up for examinations not to use the eyes constantly for an hour's reading, but for short intervals only, perhaps every minute, and to close the eyes and consider what they have just read, so that the eyes may rest. On first opening them the image is most distinct. At such times we catch the relaxed eye. We see the eye that theoretically we have corrected with the lens; and in this way quickly overcome the difficulties that Dr. Prangen has graphically depicted.

DR. H. M. LANGDON, Philadelphia, Pa.: To all who are practising ophthalmology this is an important subject, for 75 per cent. of our work is dependent on it. There are two points I should like to discuss especially. The first is about Dr. Lancaster's suggestion of the knowledge of the astigmatic dial for the study of the effect of Sturm's conoid as a help to students in refraction. I agree with him, and believe that the astigmatic dial is very useful for students of refraction, but I don't regard the ordinary astigmatic dial as of great service. The dial made by Herbert Ives is the most useful. Take out one grating, however, and use merely the lines. You can arrange this so that the size of the lines is exactly the visual angle of your subject.

The second point I wish to bring out has not been mentioned this morning, and that is the comfort of the patient, for that is one of the things he comes for. He wants to see, and he wants to be comfortable. I tell students at the University that they have not done a successful refraction of the patient unless they achieve good distance vision, a good near-point, and the relief of symptoms. Now as to the partial correction of astigmatism. That depends, I believe, entirely on the conditions that Dr. Prangen has described. There will be only a small fraction of 1 per cent. that will not take the correction if the error is measured accurately and due allowance is made for the play of the ciliary muscle afterward for changes in the spherical lens. I do not believe in changing the cylinder. As I said, the patient desires comfort. We have seen persons with a 1½ D. of astigmatism with normal vision and a good near-point and no symptoms. There is no reason for urging such patients to wear a correction if they are comfortable without it. The correction of astigmatism depends on the subjective symptoms that are present, and this covers a very wide field.

THE LENS IN SECONDARY GLAUCOMA*

PARKER HEATH, M.D.
Detroit, Michigan

Practically all the tissues of the eye are capable, in some manner, of causing secondary glaucoma. Increased intra-ocular pressure is anticipated, with rupture of the capsule and lens matter streaming into the anterior chamber. The same is true of the lens luxated into the anterior chamber with capsule intact. This tissue in the vitreous, it is well known, is also a cause of recurring iridocyclitis and associated glaucoma. Other mechanisms by which the lens induces glaucoma are, however, clinically less common and less well known. Without actual conclusive proof the lens may frequently be suspected of being the indirect or direct factor producing abnormally high intra-ocular pressure. Clinical records have been reviewed, and material of the pathologic laboratory has been studied, in the hope of constructing a lens-glaucoma classification. This classification is made up of two groups: 1. The lens in position suspended by the zonule. 2. The lens out of position partly suspended or luxated.

The Lens in Position

1. Defectively developed lens and iris with vascular strand remnants; or partly absorbed lens and persistent vascular

* From the Department of Ophthalmology, College of Medicine, Wayne University, Detroit, Michigan.