Comprehensive review of ORTHOPTICS AND OCULAR MOTILITY

THEORY, THERAPY, AND SURGERY

SECOND EDITION

HURTT • RASICOVICI • WINDSOR

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TO

HERMANN M. BURIAN, M.D.

for his many contributions to the field of
ocular motility and his devotion to further
the liaison between orthoptics and ophthalmology

Preface

We would like to thank our critics for the helpful suggestions made with regard to the first edition of our book. Most of them have been covered in this second edition.

An attempt has been made to review the salient factors involved in the diagnosis and management of diseases of ocular motility: medical and surgical therapy, new instruments, and tests and syndromes lately described. New information has been included on the use of miotics, prism therapy, the faden operation, the nystagmus blockage syndrome, and penalization therapy. Some of the material from the first edition has been abbreviated and placed in an appendix rather than as a separate chapter.

It is our feeling that the question and answer format used provides the reader with an easy method of obtaining information on either a specific subject or on a more general aspect of a particular entity.

For those who think we may have ignored their suggestions, permit us to say that the material covered is primarily based on the *Syllabus of Orthoptic Instruction* published by the American Orthoptic Council in 1962 and revised in 1969. We have included not only the material a candidate for the Orthoptic Board Examination will need for certification or recertification but also such material as may be useful for the beginning ophthalmic resident, the orthoptist, or the practicing clinician who may wish to use this text in solving specific motility problems.

Although we do not claim to present all the diverse opinions about this very complex subject, we hope this book will be useful.

Jane Hurtt
Antonia Rasicovici
Charles E. Windsor

Contents

1/Optics

■ What is light?

Light is a form of electromagnetic energy. Two theories have been applied to explain its properties. The quantum theory states that light is made of particles of energy called photons that are transmitted through space until they are absorbed. The wave form theory states that light consists of wave forms of energy that radiate in a concentric fashion from its source, such as the wave forms created when an object is thrown into the water.

■ What is monochromatic light?

Visible light from the sun is made up of wavelengths of light from 400μ to 800μ. Each wavelength represents a slightly different color. Monochromatic light represents light rays of the same wavelength and color.

■ What is a light ray?

A light ray is a term used in geometric optics to describe the radius of the concentric wave forms. It is a line drawn perpendicular to the surface of the wave form. A pencil of light is a group of light rays. A beam of light is a group of parallel rays of light (Fig. 1-1).

■ What three events can occur to a ray of light striking a surface?

The light ray can be *absorbed, transmitted,* or *reflected.* When light passes from one medium to another, some of the light may be absorbed by the medium and the light energy is converted into heat energy. The light can be transmitted through the medium and exit as light, but in so doing the rays may change direction (refraction). Finally, the rays may be *reflected* from the surface as they would be from a mirror. Depending on the nature of the two media, various proportions of all three events usually occur.

■ Explain focus, diopter, and vergence.

The point in space or in a geometric optics diagram at which light rays intersect is called the focus or focal point. Vergence is the term that describes direction and power of light. For purposes of geometric optics, light is always assumed to travel from left to right. Light emitted from a point source produces divergent pencils of light rays (negative [−]). Light rays coming to a focus are called

Fig. 1-1. A light ray is a line drawn perpendicular to a wave front of light emitted from a source. Parallel pencils of light rays form a beam.

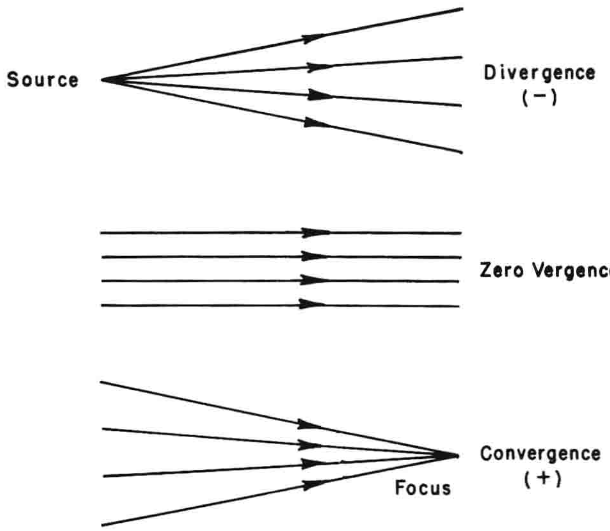

Fig. 1-2. Vergence of light rays.

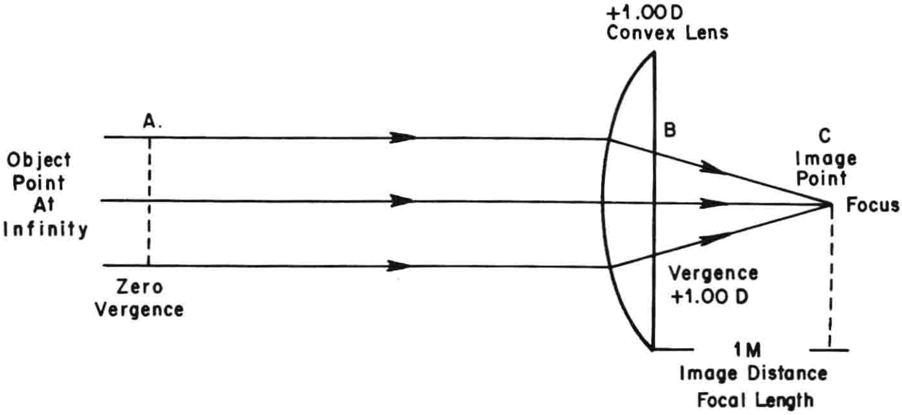

Fig. 1-3. Convergence of parallel light rays from an object at infinity to a focus by a +1.00D lens. The vergence of rays leaving the back of the lens is +1.00D.

convergent rays (positive [+]). Parallel light rays are said to have zero vergence (Fig. 1-2).

■ **Describe the normal to a surface point, angle of incidence, and angle of reflection.**

The normal to a surface point is a perpendicular line to that surface. Light striking the surface of another medium at the normal (perpendicular) is either transmitted through the medium or is absorbed. The *angle of incidence* describes the angle between the incident rays striking a surface and the normal. A reflected ray leaves the surface of a medium at an angular direction formed by the angle of the reflected ray and the normal. The *angle of reflection* is equal to the angle of incidence. The incident ray, the normal, and the reflected ray all lie in the same plane.

■ **Explain refraction, index of refraction, and angle of refraction.**

When a light ray enters another medium at an angle other than the perpendicular, the light ray is transmitted through the medium but its direction is changed. This change in direction, *refraction,* is caused by the fact that light travels at different velocities in different media. To quantitate the speed of light in one medium as compared with another medium, the term *index of refraction* is used. The velocity of light in a vacuum is approximately 300,000 km/sec. In the atmosphere it is 299,930 km/sec. This difference is so small that by choice the relative index of refraction of air is considered to be 1.0. In crown glass, for example, the speed of light is only 200,000 km/sec and the index of refraction of crown glass thus is 1.5.

When a light ray enters a denser medium, it is bent toward the normal. When a light ray leaves a denser medium to enter a less dense medium, it is bent away from the normal. The angle of refraction is the angle formed by the incident ray entering the medium and the refracted ray either within the medium or leaving the medium. The angle of incidence and the angle of refraction for any two media are related so that their sines are equal; index of refraction equals sine i (incident angle) divided by sine r (refractive angle).

■ **Describe the change of vergence of light rays by lenses.**

The function of most optic systems is to change the vergence of light rays. A lens is a piece of transparent material (glass or plastic) that is usually shaped so that one or both surfaces may be considered part of a sphere. Convex (+) lenses converge parallel rays of light, increase the convergence of convergent light rays, or decrease the divergence of divergent light rays. If the lens changes the vergence by 1 diopter, it is said to have a power of + 1.00D. A +1.00D lens brings parallel rays of light to a focus at 1 meter behind the lens (Fig. 1-3).

The power at any place along a pencil of light is the reciprocal of the distance in meters of this point from the focus or source. The unit of measurement of vergence is the *diopter* (D). Diopter (D) = 1/d (distance in meters). Fig. 1-4 demonstrates the vergence power of a pencil of divergent light rays emitting from a light source *O*. At 0.25 meter it has a vergence of −4.00D. At 0.5 meter the

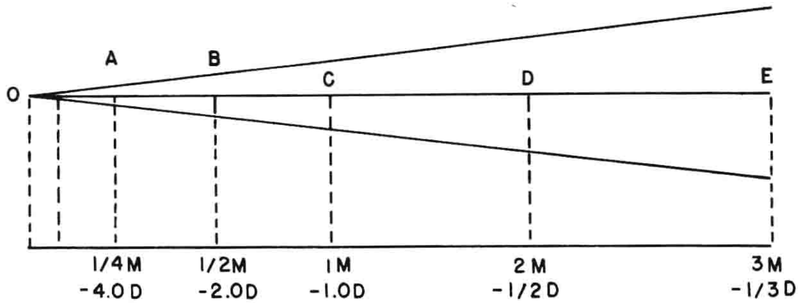

Fig. 1-4. Vergence of light rays divergent from source (O).

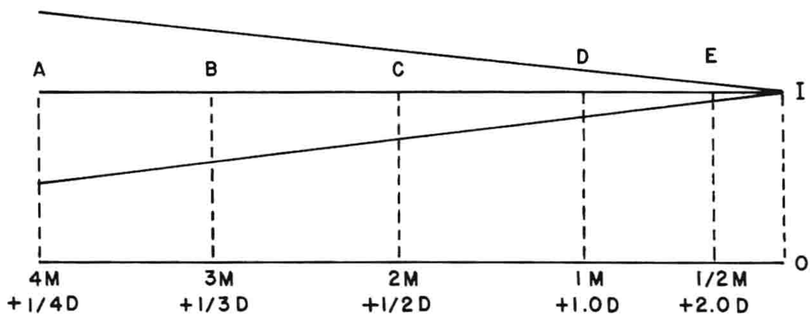

Fig. 1-5. Vergence of convergent light rays relative to distance from focus (*I*).

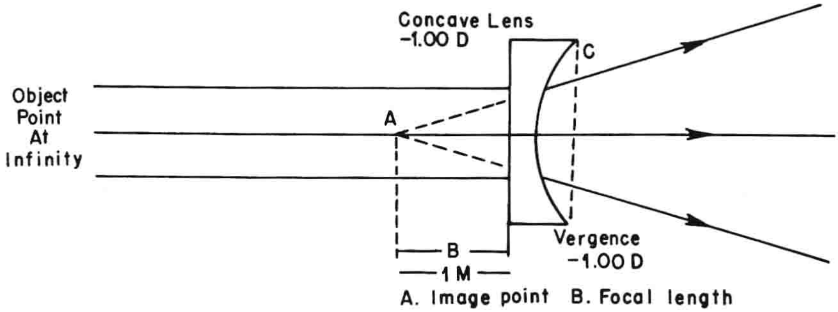

Fig. 1-6. Divergence of parallel light rays from an object at infinity by a −1.00D lens. Image point (*A*) is 1 meter in front of the lens. The vergence of rays leaving the back of the lens (*C*) is −1.00D.

vergence is −2.00D, at 1 meter the vergence is −1.00D, and at 2 meters the vergence is −0.50D.

Similarly, when the light rays are convergent to a point *O* (Fig. 1-5) the pencil of light may be intersected at any given distance from the focus point and the positive (+) vergence powers can be determined.

A concave (−) lens diverges parallel rays of light, increases the divergence of divergent rays of light, and decreases the convergence of convergent light rays. If parallel light rays (zero vergence) are diverged by the lens so that they appear to have an object point not at infinity but at 1 meter in front of the lens, the lens has effected a change in the vergence of light of −1.00D (Fig. 1-6).

■ **Discuss the object-image relationship of lenses.**

If an object point is located on the principal axis of a lens, rays from that point have a divergent or negative value at the lens surface. This value is dependent on the distance of the object from the lens (object distance). The lens changes the vergence of light by an amount of its power (the inverse of its focal length 1/f). The resulting vergence of light rays leaving the lens can be expressed by the formula U + D = V, where *U* is the vergence of rays from the object point at the lens surface, *D* is the dioptric power of the lens, and *V* is the resulting vergence of rays leaving the back of the lens. Thus, if an object is located 0.33 meter in front of a +5.00D lens, U = −3.00D, D = +5.00D, and the resulting vergence of rays leaving the back of the lens V= −3.00D +5.00D = +2.00D. The convergent rays leaving the back of the lens having a vergence of +2.00D will form a real image located 0.5 meter behind the lens (Fig. 1-7).

If the object was located 0.2 meter in front of the +5.00D lens (anterior focal point), the rays would have a vergence of −5.00D at the lens and the resulting vergence of rays leaving the back of the lens would be −5.00 (U) +5.00 (D) = 0 (V). Thus, the rays leaving the lens have zero vergence and are parallel. The image point is at infinity (Fig. 1-8).

If the object point is located at 0.5 meter (vergence −2.00D lens), the resulting vergence from the lens is −2.00 + (−2.00) = −4.00D. Rays having a vergence of −4.00D would appear to come from a source 0.25 meter in front of the lens. The image thus formed is a virtual image (Fig. 1-9).

■ **Using the preceding information, discuss the object distance, image distance, image size, and image character for any lens system.**

The points to be remembered in any geometric construction of such optic systems are:

1. Rays of light passing through the optic center of a lens pass through the lens unrefracted.
2. Rays of light from an object above or below the principal axis of the lens and parallel to that axis pass through the lens and are focused at the second focal point of the lens (in back of convex lenses, in front of concave lenses).
3. Rays of light from an object point located off the principal axis that pass

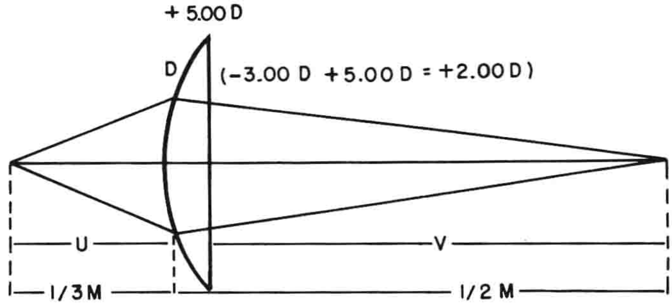

Fig. 1-7. Vergence of light from a source located 0.33 meter in front of a +5.00D lens is −3.00D (*U*). The lens changes the vergence by +5.00D (*D*). The resulting vergence of light leaving the lens is +2.00D (*V*). The rays focus 0.5 meter behind the lens. $U + D = V$; −3.00D + (+5.00D) = 2.00D.

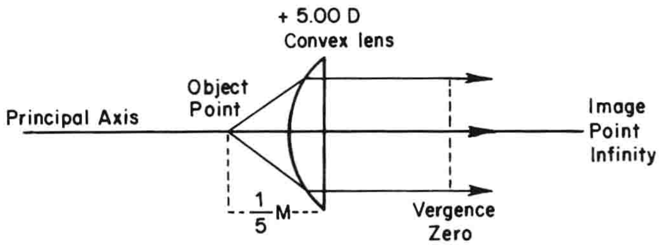

Fig. 1-8. When an object point is located at the anterior focal point of a convex lens, the resulting vergence of light rays from that point passing through the lens is zero. −5.00D + (+5.00D) = 0.

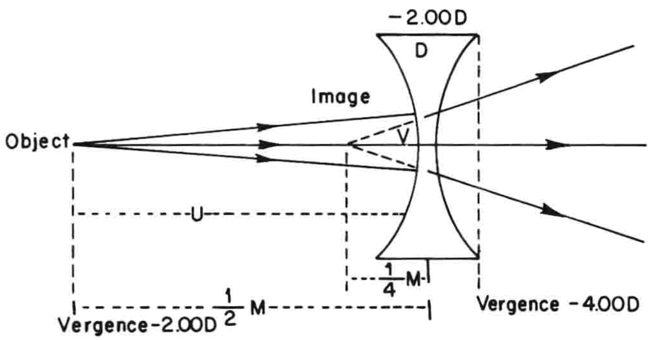

Fig. 1-9. An object is located 0.5 meter in front of a —2.00D lens. The resulting vergence (*V*) of light rays passing through the lens is −2.00D (*U*) + −2.00D (*D*) = −4.00D (*V*). Such divergent rays appear to arise from a source 0.25 meter in front of the lens. A virtual image is formed.

through the anterior focal point of the lens emerge from the lens parallel to the principal axis.

In convex lenses, the image formed by an object located in front of the anterior focal point is real, inverted, and smaller than the object (Fig. 1-10).

An object located at the anterior focal point of this lens will not form an image since the resulting rays are parallel and have an image point at infinity. An object located closer to the lens than the anterior focal point produces an image point in front of the lens. This image is upright, virtual, and larger than the object. In this case, the lens serves as a magnifying glass (Fig. 1-11).

There will always be an erect, virtual image that is closer to the lens than the object, and smaller in size, in any lens system in which an object is located in front of a concave lens (Fig. 1-12).

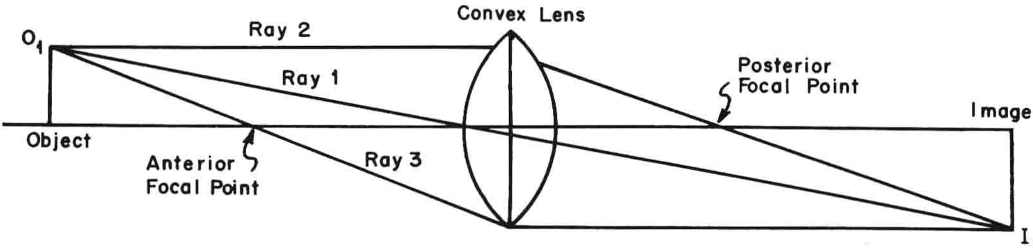

Fig. 1-10. Three rays of light passing through a convex lens drawn to locate and describe the image of the object. Ray 1 is parallel to the principal axis and is refracted through the posterior focal point of the lens. Ray 2 passes through the optic center of the lens unrefracted. Ray 3 passes through the anterior focal point and is refracted parallel to the principal axis. The intersection of the three rays is the location of the image point. The image is real and inverted.

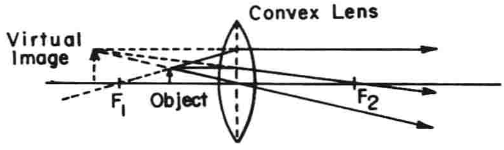

Fig. 1-11. An erect, virtual, and magnified image is formed by an object located within the principal focal point of a convex lens. F_1, Anterior focal point; F_2, posterior focal point.

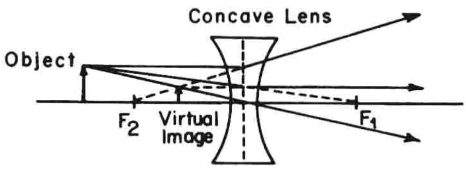

Fig. 1-12. An erect, virtual minified image is produced by an object located closer to a concave lens than its second focal point. F_1, First focal point; F_2, second focal point.

■ Discuss the refraction of light by a prism.

A prism is a triangular form of a lens made of glass or plastic. At least two of its surfaces are flat and form an angle between them. Light passing through these two surfaces will be deflected from its course as a result of refraction. The amount of deflection is dependent on the angle between the two surfaces (apex of the prism). A light ray striking the front surface of the prism is deflected toward the normal entering the prism and away from the normal leaving the prism (Fig. 1-13).

The amount of deflection is called the *prism power* and is expressed in prism diopters (Δ). A prism having the power of 1Δ deflects a beam of parallel light rays 1 cm at a distance of 1 meter. At 1 meter a 5Δ prism deflects light 5 cm. A 1Δ prism deflects light 2 cm at 2 meters (Fig. 1-14).

When looking through a prism, objects will appear to be displaced in the direction of the apex of the prism. For a given prism, the amount of deflection is not constant but depends upon the angle that the incident ray makes with the anterior surface of the prism. The minimal deviation or deflection occurs when the ray inside the prism is parallel to its base.

■ Discuss the prismatic power of a spherical lens.

The concept of prismatic power of lenses is based on the ability of the lenses to refract light. A ray of light striking the margin of a convex lens will have to be refracted (or deflected) more than a ray of light striking the lens closer to its optic center. In fact, rays passing through the optic center are not deflected or refracted at all. Thus the convex lens can be considered a group of prisms with the bases oriented toward the optic center of the lens. A concave lens can be considered to be made up of a group of prisms with the bases oriented away from, and their apices toward, the optic center of the lens. The amount of prismatic power induced by the lens depends on the refractive power of the lens and the distance from the optic center through which the ray passes. If a ray of light

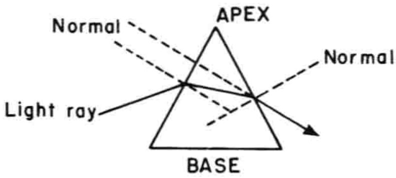

Fig. 1-13. Refraction of a light ray striking the surface of a prism.

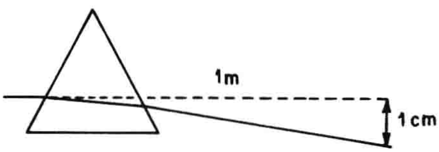

Fig. 1-14. A prism of 1Δ power deflects a beam of light 1 cm at a distance of 1 m.

enters a +10.00D lens 10 mm above its optic center, a base-down prism effect is induced. The amount of prismatic effect is determined by multiplying the distance (*h*) in centimeters and the power (*D*) in diopters. In Fig. 1-15 the amount of prismatic effect induced is 1 cm × 10.00D = 10Δ.

If the distance from the optic center of a −5.00D lens is 4 mm above the center of the lens, a base-up prism of 0.4 cm × −5.00D = 2Δ is induced. The prismatic effect of lenses becomes clinically important when the distance between the optic centers of the lenses in a pair of spectacles is different than the interpupillary distance. Under these conditions when the patient looks straight ahead, a prism effect is induced and uncomfortable symptoms may result.

■ **Discuss the principles of cylindrical lenses.**

Cylindrical lenses have one of their surfaces curved in such a manner that they form a part of a cylindrical surface (Fig. 1-16). A cylindrical lens has its full power of refraction only in one meridian; in the meridian perpendicular to this (its axis), it has no refractive power. The refractive power of the other meridians lies somewhat between these two extremes. Parallel light rays passing through a cylindrical lens will be refracted so as to form a focal line instead of a focal point. This line will also be parallel to the cylindrical axis. Convex cylindrical lenses converge light and concave cylindrical lenses diverge light. A cylindrical lens combined with a spherical lens is called a spherocylindrical lens.

The modern spherocylindrical lens has one toric surface and one spherical surface. A toric surface (a section of a barrel) has two principal meridians that correspond to the two surface powers of the toric surface. A spherocylindrical lens does not change the vergence of light in the simple way that a spherical lens does. Instead of causing refractive rays to pass through one point (the image of an object point), the spherocylindrical lens deforms the bundle of refracted rays into the so-called conoid of Sturm (Fig. 1-17). A study of this conoid reveals that two focal lines perpendicular to each other are separated by an interval called Sturm's interval. These are two line images of the object. The location is determined the same way as the location of an image point produced by a spherical lens. The dioptric powers of the two principal meridians of the lens

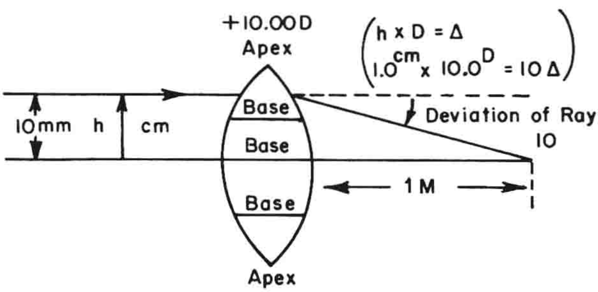

Fig. 1-15. Prismatic effect of a light ray striking a +10.00D lens 10 mm above its optic center. The amount of deviation is calculated by the formula h(cm) × D (diopters) = Δ = 1.0 × +10.00D = 10Δ.

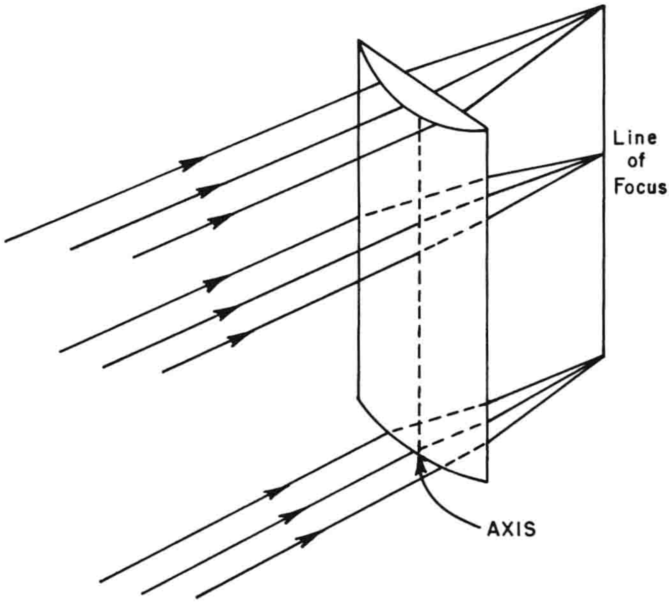

Fig. 1-16. Light rays striking the cylindrical lens are refracted to a focal line rather than to a point.

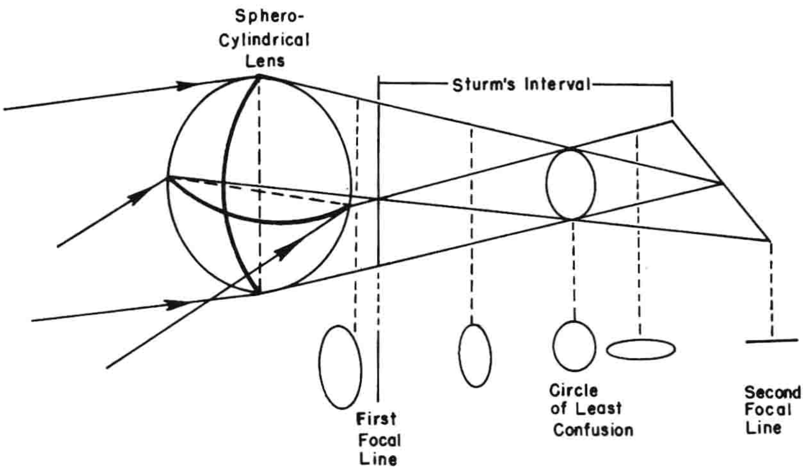

Fig. 1-17. Conoid of Sturm.