BERNHARD SCHMIDT AND HIS COMA-FREE REFLECTOR

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The Schmidt telescope is now so well known that its wide use in astronomy and in engineering is almost taken for granted. It probably may be said without exaggeration that Schmidt's invention ranks high among the most important advances in optics made during the past fifteen years. His invention is another example of a development in "pure" science finding ready and almost unexpected application in the more "practical" pursuits of industry. It is surprising that so little is known in this country about the inventor himself, and therefore translations of R. Schorr's biographical sketch of Schmidt and of Schmidt's original report are presented here, with the hope of making more widely known the life and works of a man who has contributed so significantly, and yet so modestly, to the advancement of optical science.

BERNHARD SCHMIDT*

On December 1, 1935, the astronomical optician Bernhard Schmidt died in Hamburg. He was a voluntary colleague of our observatory who had acquired considerable distinction by the construction of an astronomical reflecting telescope of unrivaled perfection.

Born on March 30, 1879, on Nargen Island (Esthonia), he as a boy attempted to make, on the beaches of Nargen, a concave mirror by grinding together sea sand and the flattened lower parts of bottles. He studied engineering in Götenburg and Mittweida, and in the latter town he began in about 1900 the systematic manufacture of astronomical mirrors up to nearly 20 cm [7.9 in.] in diameter, which were widely distributed in amateur circles, and which created a sensation because of their perfection. In 1905 he made a mirror of 40 cm [15.8 in.] aperture with the large aperture ratio of 1 to 2.26 for the Astro-

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* Translation of an article by R. Schorr, *Astr. Nachr.*, **258**, 45, 1936. *Nachr.*, **258**, 45, 1936.

physical Observatory at Potsdam (see H. C. Vogel, *On a Reflecting Telescope with Relatively Short Focal Length,* Berlin, 1906) which showed extraordinarily small zonal errors, and which at that time far surpassed in quality other existing astronomical mirrors. With the Cassegrain mirrors that Schmidt made, he generally used a spherical mirror as the primary, and removed the spherical aberration by suitable deformation of the secondary.

Schmidt was not only an outstanding optician, but he was also an enthusiastic astronomical observer. Around 1909 he constructed in Mittweida for his own observing purposes a new kind of horizontal telescope mounting. This consisted of a parabolic mirror of 40 cm [15.8 in.] aperture and 11 m [36 ft. 1 in.] focal length, which was set outdoors and placed vertically on a pier, with the axis of the mirror lying in the north-south direction, and of a plane mirror movable about two axes perpendicular to each other. As the drive for this reflecting instrument, later named the "Uranostat" (see Hartmann, *Astr. Abh. Bergedorf,* Bd. **4**, No. 1), Schmidt used a "water clock-work," with a lever transmission on the polar axis.

In 1920 Schmidt constructed for our observatory in Bergedorf a horizontal mirror-mounting of similar design, with a plane mirror of 61 cm [24 in.] aperture, and two parabolic mirrors of 55 and 60 cm [21.6 and 23.6 in.] aperture, and of 11 and 30 m [36 ft. 1 in. and 98 ft. 6 in.] focal length, respectively. After he moved to Bergedorf in 1926, he took some quite remarkable photographs of the larger planets with it, especially of Jupiter and Saturn, and of the moon (*Jahresbericht Bergedorf,* 1928). Later he supplied the Breslau Observatory with a similar mirror arrangement.

My desire to obtain for our observatory a mirror of 60 cm [23.6 in.] aperture, with an aperture ratio of at least 1 to 2, and also having a large field, led him to the construction of his coma-free mirror system *(Zentral Zeitung für Optik und Mechanik,* **52** Jahrgang, and *Mitt. d. Hamb. Sternw. in Bergedorf,* No. 36). In an ingenious manner, he used for the avoidance of coma and astigmatism a spherical mirror with an aperture stop in its center of curvature, and for the removal of spherical aberration he took as aperture stop a quite weakly-curved toroidal correcting plate (see B. Strömgren, *Vierteljahrsschr. d. A. G.,* **70** Jahrg., p. 65). A mirror system made according to this principle, with a spherical mirror of 44 cm [17.3 in.] aperture and 62.5 cm [24.6 in.] focal length and a correcting plate of 36 cm [14.2 in.] diameter, showed the extraordinary significance which this Schmidt construction had for astronomical purposes. The photographs (*Jahresbericht Bergedorf,* 1930) taken on curved film with this reflector of aperture ratio 1 to 1.75 gave completely round images over a field 16° in diameter.

In order to use the principle of the Schmidt coma-free system for a larger reflector having greater image scale, I allowed Schmidt to make a coma-free mirror system of 60 cm [23.6 in.] aperture and 3 m [9 ft. 10 in.] focal length, and had this reflecting telescope mounted together with a parabolic mirror of 60 cm [23.6 in.] aperture and 3 m [9 ft. 10 in.] focal length, made at the same time by Schmidt, as a double reflector in an English mounting at our observatory (see *Jahresbericht Bergedorf,* 1934). In the case of the mechanical construction of this instrument, Schmidt likewise contributed in a very skillful way; he designed and constructed a new kind of drive in place of the ordinary clockwork. This consisted of a fixed spindle which was driven by a motor provided with a seconds control, and of a lever arm 2.4 m [7 ft. 10 in.] long which could be clamped to the polar axis and which rested freely against a worm on the spindle. Schmidt was occupied with the adjustment of this instrument during his last days.

Although the making of accurate telescope mirrors was the principal field of Schmidt's work, he also carried out other outstanding optical and mechanical jobs, acquiring considerable fame by the correction of existing large objectives. By refiguring the 50 cm [19.7 in.] objective of the Potsdam Astrophysical Observatory, the 60 cm [23.6 in.] photographic objective of the Hamburg Observatory in Bergedorf, and the 30 cm [11.8 in.] photographic objective of the Leipzig Observatory, the performance of these objectives was quite appreciably improved.

In other engineering and scientific fields, such as aerodynamics, gastrophotography, manufacture of large micrometer screws of great precision, and the making of spectrohelioscopes, Schmidt also was eminently successful.

Schmidt carried out all his work with the simplest means, without large mechanical apparatus. The frequently expressed opinion that Schmidt had used special or unknown techniques in order to make his astronomical optics masterpieces is not, to my knowledge, a correct view of his work. The fundamental principle of his work was to examine each optical surface during its production, either with an artificial star by the Foucault method, or by interference methods. His sharp eye recognized immediately every slightest deviation of the surface from the ideal form, and his complete comprehension of the problem together with his long years of experience permitted him to decide in what way and to what degree these deviations should be removed. Here it was a case of great skill in the working of the optical surfaces, combined with the fine touch which he possessed in his left hand—his only hand. He lost his right arm in an accident in his early youth. Perhaps there may be a significant hint in the fact that Schmidt always used relatively thin glass disks for fine grinding and polishing, never iron, and also used them only with his hand and not with machines.

In personality, Schmidt was an odd character, unmarried, a somewhat reserved person, but, on the other hand, one who could also be cheerful in pleasant company. In relations with our observatory he was a beloved and ever-helpful fellow worker.

The Hamburg Observatory deeply regrets the death of this highly gifted, ingenious man, who still could have provided astronomical research with many valuable tools.

A RAPID COMA-FREE MIRROR SYSTEM*

If losses of light of a mirror and of a lens system are compared with each other, then for the same aperture ratio the mirror shows a smaller loss of light than the lens system. A freshly silvered mirror reflects at least 90 per cent of the incident light, while a two-lens system transmits at most 80 per cent, and

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* Translation of an article by Bernhard Schmidt, *Zentral Zeitung für Optik und Mechanik,* **52** Jahrgang, Heft 2; *Mitt. d. Hamb. Sternw. in Bergedorf,* **7**, 15 1931–32 (No. 36).

a three-lens system at most 70 per cent of the incident light. In the case of large lenses, the situation is still more unfavorable because of the stronger absorption of short wave lengths by the glass.

In large telescopes, the parabolic mirror thus would be more advantageous, in general, than a lens system, but unfortunately with large aperture ratios the usable field of view is very limited by coma. For an aperture ratio of 1 to 3, the spreading due to coma amounts to 37 seconds of arc for a field diameter of only 1 degree; moreover, the spreading due to astigmatism becomes 5 seconds of arc. Coma increases in direct proportion to the field diameter, astigmatism quadratically. As a result, astigmatism in the vicinity of the axis is negligibly small and almost pure coma is present, while at greater distances from the axis it is modified by astigmatism.

Nevertheless, a parabolic mirror of aperture ratio 1 to 8 or 1 to 10 surpasses the ordinary two-lens objective as regards image sharpness, which is due to the fact that chromatic aberration is entirely absent in the mirror. But it is a disadvantage that the light-distribution in the aberration disk of the mirror image is one-sided, for this condition can produce systematic radial displacements in measurements of such images.

But it will be shown below that even a purely spherical mirror of aperture ratio 1 to 8 or 1 to 10 is still quite usable. If the aperture stop were brought directly in front of the mirror, then there would be no advantage over the parabolic mirror, since the spherical mirror has exactly the same aberrations; besides, spherical aberration would be present, which increases the existing aberrations over the whole field of view. However, if the aperture stop is brought to the center of curvature, the spherical mirror no longer has any but longitudinal aberrations, for coma and astigmatism are zero. The image surface lies on a sphere whose radius is the focal length and which is concentric with the mirror surface, so that the image surface is turned with the convex side to the mirror.

The aberration of a spherical mirror of 1 to 8 or 1 to 10 ratio amounts to 12.5 or 6.4 seconds of arc at the paraxial image point, and the smallest possible aberrations are only one-fourth of that, 3.1 or 1.6 seconds of arc.[1] In practice, even sharper pictures can be obtained if the focus is set between these two positions. Under normal conditions these aberrations are smaller than the spreading inherent in the photographic layer. Therefore, even with the use of flat plates, the image quality at the edge of the field is better than with a parabolic mirror of corresponding aperture ratio; the star images are round everywhere, with a symmetrical light-distribution.

Moreover, if a round, flat film is curved by pressing it with a ring over a spherical surface corresponding to the image surface, which is easily possible without wrinkling, then the confusion disks are of the same size over the entire field. The same thing can be accomplished with a sharp-edged plano-convex condenser lens in front of a flat photographic plate (plane side of the lens toward the plate).

If the aperture ratio is greatly increased, however, then the spherical aberration becomes very large, since it increases with the third power of the aperture ratio. For 1 to 3, or 1 to 2, the aberrations at the paraxial image point are 240 or 800 seconds of arc. The smallest possible confusion disk has a diameter of 60 or 200 seconds of arc. With a focal length of 1 meter [39.4 in.], the paraxial disks then would be 1.2 or 4 mm [0.047 or 0.157 in.], or the smallest possible ones 0.3 or 1 mm [0.012 or 0.039 in.]. In this case, therefore, the spherical mirror no longer would be useful.

I shall now show how completely sharp images can be obtained with a spherical mirror of large aperture ratio.

In order to produce a parabolic mirror from a spherical mirror, the latter's edge must be flattened, that is, be given a greater radius of curvature. However, a concentric curved glass plate (of the same thickness everywhere) can be placed on the spherical mirror, and one of its surfaces deformed. But now the curvatures must be reversed, and its edge must be more strongly curved than its center. Also, the amount of the deformation must be about twice as great, because now the deviation

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[1] TRANSLATOR'S NOTE: The pair of larger figures refers to the size of the aberration disk at the focus for paraxial rays, the pair of smaller ones to the size of disk at the focus for rays from the outermost zone.

results from refraction. In general, in order to obtain the same deviation by refraction as by reflection, about four times as great inclinations have to be given, but in this case, since the rays go through the glass surfaces twice, only twice as large deformations are necessary.

This plate can also be optically "sagged" to such an extent that one side becomes plane again, while the other then has a pure deformation curve. That is to say, a plane-parallel plate, instead of a zero-power meniscus, can be deformed just as well from the beginning. Almost the same effect is thus obtained optically with this correction plate as with a parabolic mirror.

A suitably shaped cover plate of this kind for a spherical mirror[2] also has the practical advantage that the silver coat of the mirror is well protected. It is a disadvantage in that, owing to the passage of light twice through the glass plate, the loss of light reaches about 20 per cent.

The correcting plate can also be placed in another position in the optical path. If it is located beyond the focal surface, then the light goes through the plate only once. The plate then obviously must have twice as much deformation as in the first case. The loss of light is then only 10 per cent.

If the correcting plate is now brought to the center of curvature of the mirror, then there result the same relationships as before in the case of the spherical mirror with aperture stop in the center of curvature, but with the difference that now the spherical aberration is abolished, even over the whole field. Thus it is possible to use aperture ratios of 1 to 3 or 1 to 2, and to obtain freedom from coma, astigmatism, and spherical aberration.

If the inclination of the incident rays is very large, then the correcting plate is projected as an ellipse, and the deformation is not projected on the correct places of the mirror, so that the correction is variable and even introduces an overcorrection in the radial direction.

However, large inclinations do not need to be considered at

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[2] TRANSLATOR'S NOTE: One form of this optical system is known as the Mangin mirror; it is described in Czapski-Eppenstein, *Grundzüge der Theorie der Optischen Instrumente,* 3d ed., pp. 110–11, 1924.

all, since the photographic plate soon would become greater than the clear aperture. In practice, photographic plates greater than one-fourth to one-third the aperture can hardly be used, the inclination aberrations then being negligibly small.

The case is somewhat different for the chromatic aberrations of the correcting plate. In order to keep these as small as possible, the correcting plate is so shaped that the central part acts like a weak condensing lens, and the outer parts have a divergent effect. If the neutral zone is placed at 0.866 of the diameter, then the chromatic aberration is a minimum. If the point of inflection of the curve is at 0.707, then the thickness of the edge is equal to the central thickness. The remaining difference in thickness between the thickest and thinnest parts of the plate is very small, only several hundredths of a millimeter, so that a disturbing color effect does not occur; in any case, the effect usually is much smaller than the secondary spectrum of a corresponding objective.

This chromatism is identical with the so-called "chromatic difference of the spherical aberration."

If the mirror has the same diameter as the correcting plate, then the incident cylinder of rays for outer images falls eccentrically on the mirror, and there is a part of it left out, so that the outer portions of the plate obtain somewhat less light. If this is to be avoided, the mirror must have a greater diameter than the clear aperture, and of course it must be greater by about twice the plate diameter. In a mirror of 50 cm [19.7 in.] clear aperture (diameter of the correcting plate) and of 1 m [39.4 in.] focal length, the photographic plate for a field of 6 degrees has a diameter of 10.5 cm [4.1 in.], and accordingly the mirror must have a diameter of 71 cm [28 in.].

The rapid coma-free mirror system described here offers, according to the preceding considerations, great advantages in regard to light-gathering power and aberration-free imagery. There is assumed, however, a technically complete understanding of the correcting plate.

Addendum by R. Schorr: B. Schmidt has attached to a spherical mirror of 44 cm [17.3 in.] aperture and 62.5 cm

[24.6 in.] focal length, which was available at our observatory, a correcting plate of 36 cm [14.2 in.] aperture. With this system (1 to 1.75) Schmidt has taken a series of experimental photographs with a horizontal mounting and an attached guiding telescope, in combination with the 60 cm [23.6 in.] coelostat mirror; several of the photographs obtained on curved film are reproduced in Plates I and II. It may be seen from these that the mirror system, in spite of the large aperture ratio, gives a completely coma-free field of 15° diameter, which represents a great advance for many astronomical investigations. It is planned to construct an especially stable camera tube for this mirror system and to set this up equatorially, in order to carry out further experimental photography.