CNR - Istituto Nazionale di Ottica
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MISURE DI POTERE OFTALMICO: LENTI I.O.D.A. SERIE 085

MEASUREMENTS OF OPHTHALMIC POWER: LENSES I.O.D.A. SERIES 085

Relazione tecnica n. 3/16

Technical report n. 3/16

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FOREWORD

This report contains the results of the measurements performed on a series of 12 lenses submitted by:

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The series is made of 5 negative spherical lenses of nominal power -5, -10, -15, -20, -25 dioptres (symbol D), 5 positive spherical lenses of nominal power +5, +10, +15, +20, +25 D, 1 cylindrical lens of nominal power Cyl +5 D, and 1 prismatic lens of nominal power 5 prismatic dioptres (symbol Δ). The spherical lenses are made of K5 glass, 25 mm in diameter; they are mounted in a plastic frame where the identification mark is engraved. The cylindrical lens is made of B23-59 glass, 60x40 mm^2 in size; the mark is engraved on the glass. The prismatic lens is made of K5 glass, 26x50 mm^2 in size; the mark is engraved on the glass.

The lenses are identified one by one by means of their nominal power in dioptres and their serial number, as detailed below:

power	series	identification	power	series	identification
-5 D	085	-5 / 085	+5 D	085	+5 / 085
-10 D	085	-10 / 085	+10 D	085	+10 / 085
-15 D	085	-15 / 085	+15 D	085	+15 / 085
-20 D	085	-20 / 085	+20 D	085	+20 / 085
-25 D	085	-25 / 085	+25 D	085	+25 / 085
5 Δ	085	PRISM5 / 085	Cyl +5 D	085	Cyl +5 / 085

The samples were received at the measuring laboratory with accompanying document n. 419 of 30 October 2015; and were tested on 14 - 23 Dicember 2015.

This report consists of n. 18 pages, numbered consecutively. Copy of the same is filed in the archive of the CNR - Istituto Nazionale di Ottica under the registration number 73 of 8 January 2016.

Firenze, 8 January 2016

Dott. Vincenzo Greco *P. I. Andrea Sordini*

METHOD AND MEASURING INSTRUMENTS: LENSES

The ophthalmic power is obtained from the geometrical and physical characteristics of the lenses. The following symbols are used:

N	*refractive index of the glass*
R_1	*first radius of curvature (*)*
R_2	*second radius of curvature (*)*
T	*axial thickness of the lens*
f	*focal length of the lens*
ϕ	*power of the lens* $(\phi = 1/f)$
BFL	*Back Focal Length*
Φ	*ophthalmic power* $(\Phi = 1/BFL)$

(*)It is assumed by convention that the light travels from left to right; the radii of curvature are named first and second according to their order along the optical path; a radius is positive if the centre of curvature lies to the right.

As well known (e.g., see W.J. Smith, "Modern Optical Engineering", 2nd ed., McGraw-Hill, New York 1990, p. 38, eqs. 2.36a - 2.37), basic equations are:

$$\phi = \frac{N-1}{R_1} - \frac{N-1}{R_2} + \frac{(N-1)^2}{N}\frac{T}{R_1 R_2} \tag{1}$$

$$BFL = \frac{1}{\phi}\left(1 - \frac{N-1}{N}\frac{T}{R_1}\right) \tag{2}$$

thus:

$$\Phi = \frac{N(N-1)}{NR_1 - (N-1)T} - \frac{N-1}{R_2} \tag{3}$$

$$\frac{\partial \Phi}{\partial R_1} = -\frac{N^2(N-1)}{[NR_1 - (N-1)T]^2} \tag{4}$$

$$\frac{\partial \Phi}{\partial R_2} = \frac{N-1}{R_2^2} \tag{5}$$

$$\frac{\partial \Phi}{\partial T} = \frac{N(N-1)^2}{[NR_1 - (N-1)T]^2} \tag{6}$$

$$\frac{\partial \Phi}{\partial N} = \frac{(2N-1)[NR_1 - (N-1)T] - N(N-1)(R_1 - T)}{[NR_1 - (N-1)T]^2} - \frac{1}{R_2} \tag{7}$$

TABLE 1. Performing scheme of the computations. Capital are the magnitudes, lowercase the values measured (in the case of n, the values taken from the specifications); the overline indicates the operation of average.

magnitude	*estimate*	*std. uncert.*	*sens. coeff.*	*uncert. contrib.*
R_1	$\overline{r_1}$	$\sigma(r_1)$	$\left.\frac{\partial\Phi}{\partial R_1}\right\vert_{R_1=\overline{r_1}}$	$\left\vert\frac{\partial\Phi}{\partial R_1}\right\vert\sigma(r_1)$
R_2	$\overline{r_2}$	$\sigma(r_2)$	$\left.\frac{\partial\Phi}{\partial R_2}\right\vert_{R_2=\overline{r_2}}$	$\left\vert\frac{\partial\Phi}{\partial R_2}\right\vert\sigma(r_2)$
T	$\bar{t}$	$\sigma(t)$	$\left.\frac{\partial\Phi}{\partial T}\right\vert_{T=\bar{t}}$	$\left\vert\frac{\partial\Phi}{\partial T}\right\vert\sigma(t)$
N	n	$\sigma(n)$	$\left.\frac{\partial\Phi}{\partial N}\right\vert_{N=n}$	$\left\vert\frac{\partial\Phi}{\partial n}\right\vert\sigma(n)$

In the laboratory, R_1, R_2, T are measured; the corresponding uncertainties are of the type A. The value for N is taken from the specifications of the glass; the uncertainty for N is of the type B. The ophthalmic power is computed from Eq.(3). Eqs.(4)-(7) are the sensitivity coefficients required to work out the uncertainty balance. In Table 1 the scheme for the computation is given, in accord with the indications of the document EA-4/02.

The result is expressed in the form

$$\Phi = \Phi(\overline{r_1}, \overline{r_2}, \bar{t}, n) \pm 2\sigma(\Phi) \tag{8}$$

where $\sigma(\Phi)$ is the combined uncertainty, given by

$$\sigma(\Phi) = \left[\left|\frac{\partial\Phi}{\partial R_1}\right|^2 \sigma^2(r_1) + \left|\frac{\partial\Phi}{\partial R_2}\right|^2 \sigma^2(r_2) + \left|\frac{\partial\Phi}{\partial T}\right|^2 \sigma^2(t) + \left|\frac{\partial\Phi}{\partial n}\right|^2 \sigma^2(n)\right]^{1/2} \tag{9}$$

To measure the central thickness of the lenses, a 0.001-sensitivity comparator is used (Mitutoyo Mod. ID-F125 "Digimatic indicator", identified with n. 2918 of the inventory CNR-INO), mounted on a stand with a reference plane.

The values for N are taken from the catalogue of the firm producing the glass [Schott K5 (melt): $n(d) = 1.52272$, $n(e) = 1.52482$; Corning B23-59 (catalog): $n(d) = 1.52300$, $n(e) = 1.52509$]. For the uncertainty on $n(d), n(e)$, on K5 (grade 2) it is assumed $\sigma(n) = 0.0003$ (standard deviation), and $\sigma(n) = 0.001$ on B23-59.

To measure the radii of curvature of the spherical lenses, an interferometer is used (Zygo Mark IVxp, identified with n.2778 of the inventory CNR-INO), according to the procedure of the manual OMP-0325 Zygo described in Appendix 1.

The calibration conditions are verified prior to each series of measurements. The average and the standard deviation are computed over 10 measurements.

The determination of the back focal length (BFL), and then of the ophthalmic power Φ, is made according to the orientation specified in Fig. 1. In the case of the sferical lenses, the BFL is referred to the surface towards the engraved side of the frame; in the case of the cylindrical lens the BFL is referred to the plane surface.

Used as test lenses for calibration of focimeters, the lower surface is put on the support of the instrument to be calibrated, as shown in the figure.

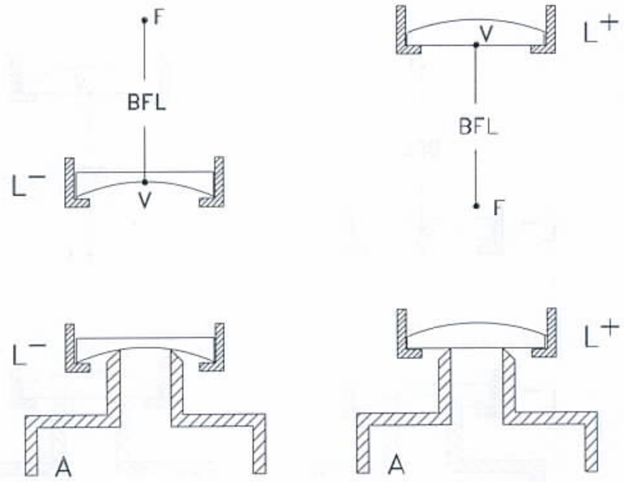

Figure 1: Specification of orientation for measuring the ophthalmic power. F, focus; V, vertex; L^-, negative lens; L^+, positive lens; A, focimeter.

METHOD AND MEASURING INSTRUMENTS: PRISM

A glass prism is considered, with apical angle A and refractive index n. A beam of collimated light belonging to the principal section of the prism that is incident at an angle I on the entry face undergoes a deflection D expressed by

$$D = I - A + \arcsin\left(\sqrt{n^2 - \sin^2 I}\,\sin A - \cos A\,\sin I\right) \tag{10}$$

The definition of ophthalmic power Φ_Δ in prism dioptres (symbol Δ) is given as

$$\Phi_\Delta = 100\tan D \tag{11}$$

supplying the incidence conditions as well. In the measurements reported here the incidence condition on the prism is that of perpendicularity to the entry face ($I = 0$).

The measurement is performed with a spectrogoniometer, measuring the angle D and computing Φ_Δ by means of Eq. (11) with $I = 0$.The source in use is a mercury vapour spectral lamp at the line e (wave length 546.07 nm); in Appendix 2 it is shown how, knowing the glass type, the power at the line d (587.56 nm) is computed.

Measurements are performed after verification of the calibration conditions. The prism is then mounted on a rotation stage at the centre of the spectrogoniometer and is aligned. A central region of 10 mm in diameter is inspected. The deviation angle is measured as difference of readings between the zero position and the position of the deflected beam. The measurement is repeated 10 times, computing the average. A standard deviation of $\sigma_D = 10''$ is attributed to the single measurement; for $D \ll 1$ rad, Eq. (11) yields $\sigma_\Phi = 100\,\sigma_D = 0.005\,\Delta$.

The instrument used for the measurements is "Spettrogoniometro Officine Galileo" Mod. 040 c 00110, identified with n. 3039 of the inventory CNR - INO. The calibration conditions are verified prior to each series of measurements.

EXPERIMENTAL DATA (Units: mm)

Lens	$\overline{r_1}$	$\sigma(r_1)$	$\overline{r_2}$	$\sigma(r_2)$	$\bar{t}$	$\sigma(t)$
-5 D	*130.71*	*0.01*	*57.72*	*0.01*	*4.015*	*0.010*
-10 D	*262.05*	*0.02*	*43.607*	*0.001*	*4.037*	*0.010*
-15 D	∞		*34.998*	*0.001*	*3.784*	*0.010*
-20 D	∞		*26.109*	*0.001*	*3.827*	*0.010*
-25 D	∞		*20.887*	*0.001*	*4.358*	*0.010*
+5 D	*53.028*	*0.001*	*99.82*	*0.01*	*6.094*	*0.010*
+10 D	*42.653*	*0.001*	*186.93*	*0.02*	*5.833*	*0.010*
+15 D	*34.844*	*0.001*	*525.00*	*0.1*	*5.999*	*0.010*
+20 D	*29.112*	*0.001*	∞		*7.571*	*0.010*
+25 D	*24.065*	*0.001*	∞		*9.099*	*0.010*
Cyl +5 D	*106.33*	*0.01*	∞		*5.521*	*0.010*

RESULTS OF THE MEASUREMENTS

The results are expressed in dioptres; the uncertainty refers to a coverage factor of 2 (uncertainty 2σ), which, for a normal distribution corresponds to a confidence level of 95 %.

Lens	$\Phi\,[n = n(d)]$	$\Phi\,[n = n(e)]$
-5 D	*-5.01* $\pm$ *0.01*	*-5.03* $\pm$ *0.01*
-10 D	*-9.98* $\pm$ *0.01*	*-10.02* $\pm$ *0.01*
-15 D	*-14.94* $\pm$ *0.02*	*-15.00* $\pm$ *0.02*
-20 D	*-20.02* $\pm$ *0.02*	*-20.10* $\pm$ *0.02*
-25 D	*-25.03* $\pm$ *0.03*	*-25.13* $\pm$ *0.03*
+5 D	*5.03* $\pm$ *0.01*	*5.05* $\pm$ *0.01*
+10 D	*10.06* $\pm$ *0.02*	*10.10* $\pm$ *0.02*
+15 D	*14.95* $\pm$ *0.02*	*15.01* $\pm$ *0.02*
+20 D	*19.72* $\pm$ *0.03*	*19.80* $\pm$ *0.03*
+25 D	*24.96* $\pm$ *0.04*	*25.07* $\pm$ *0.04*
Cyl +5 D	*5.01* $\pm$ *0.02*	*5.03* $\pm$ *0.02*
Prism 5 Δ	*4.95* $\pm$ *0.01*	*4.97* $\pm$ *0.01*

Appendix 1

To measure the radius of curvature of the spherical surfaces, an interferometer equipped with a reference sphere is used. The operation is schematically indicated in Fig. 2. In practice, the surface under test is translated from the position where the surface is at the focus of the reference sphere to the position where the surface is concentric with the reference sphere. The translation undergone is equal to the sought radius of curvature.

The two positions of interest are determined with high resolution by looking at the interference fringes displayed on the screen of the interferometer; the surfaces should be quite regular, however. The main scale is provided as basic equipment of the interferometer (0.01-sensitivity scale Mitutoyo Mod. 572-427); for ranges smaller than 50 mm, a 0.001-sensitivity micrometer Mitutoyo Mod. 164-161 is used.

The aperture of the reference sphere in use for the measurements is f/3.3. A central disk is inspected, whose size varies with the value of the radius of curvature of the surface. The useful diameter to which the measurements here reported refer to, is specified in Table 2.

TABLE 2. Useful measuring diameter of the spherical lenses (mm).

lens	*diameter*	*lens*	*diameter*
-5 D	*17.5*	*+5 D*	*16.0*
-10 D	*13.2*	*+10 D*	*12.3*
-15 D	*10.7*	*+15 D*	*9.9*
-20 D	*7.9*	*+20 D*	*7.9*
-25 D	*6.3*		

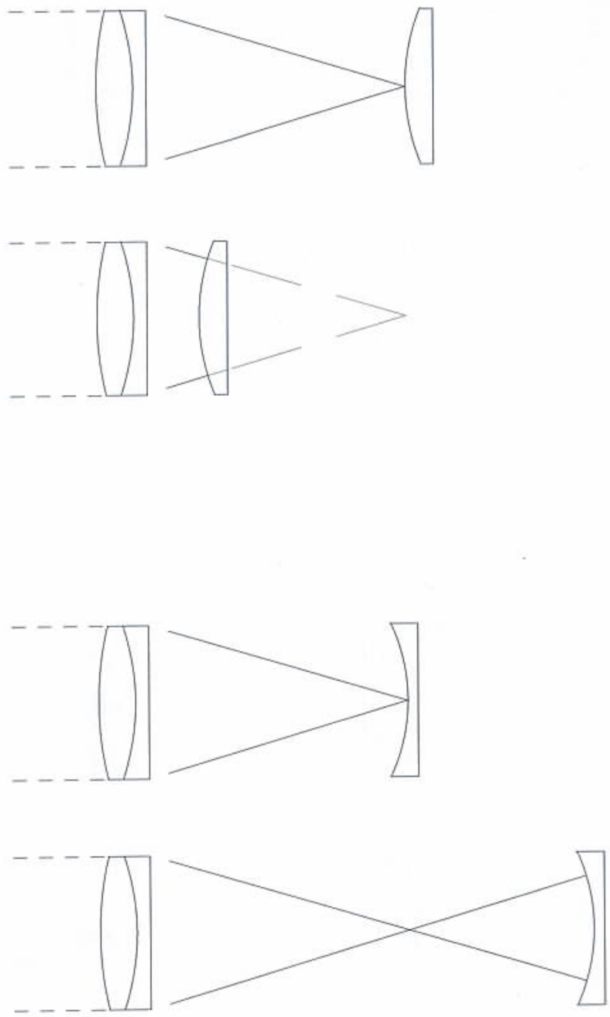

Figure 2: *Determination of the radius of curvature of a surface by means of a translation equal to the radius. The lens on the left (doublet) is the one pertaining to the reference sphere; the lens on the right is the one whose surface is being measured. Top pair of figures: case of convex surface. Bottom pair: case of concave surface.*

Appendix 2

The measurements are performed at the wave length of the line e. Knowing the glass type (K5), it is shown how the prism power at the wave length of the line d is computed.

To indicate the glass refractive indices at the lines e, d, the symbols n_e, n_d, respectively, are used; D_e, D_d are the corresponding deflections.

Equation (10) is intended for $n = n_e$, $D = D_e$; also considering $I = 0$ (normal incidence), it is written

$$D_e = -A + \arcsin(n_e \sin A) \tag{10}$$

hence obtaining

$$A = \arctan \frac{\sin D_e}{n_e - \cos D_e} \tag{11}$$

Equation (12) is then written for the line d:

$$D_d = -A + \arcsin(n_d \sin A) \tag{12}$$

The deviation D_e is the quantity measured; n_e, n_d are known from the glass specifications. The above equations let D_d be computed. At last, the prism power at the line d is given as in equation (11).

The values at the line d presented in the table of the results have been verified in the laboratory with test measurements.