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ISO 9342-1

Second edition
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Optics and optical instruments — Test lenses for calibration of focimeters —

Part 1: Reference lenses for focimeters used for measuring spectacle lenses

Optique et instruments d'optique — Verres étalons pour l'étalonnage des frontofocomètres —

Partie 1: Verres de référence pour frontofocomètres pour le mesurage des verres de lunettes

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 7, *Ophthalmic optics and instruments*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 170, *Ophthalmic optics*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 9342-1:2005), which has been technically revised.

The main changes are as follows:

— use of the term "reference lens" to denote these high precision test lenses;

— use of the term "verified power" instead of "conventional power";

— the addition of the spherocylindrical-power reference lens and, with some modification to tolerances, reference filters that were added to ISO 8598-1 during its last revision;

— the optional addition of low power spherical reference lenses;

— editorial revision and clarification of Annex A on the design of reference spherical lenses

— the addition of annexes on the design and validation of prismatic reference lenses and the validation of the cylindrical reference lens.

A list of all parts in the ISO 9342 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Optics and optical instruments — Test lenses for calibration of focimeters —

Part 1: Reference lenses for focimeters used for measuring spectacle lenses

1 Scope

This document specifies requirements for reference lenses for the calibration and verification of focimeters that are used for the measurement of spectacle form lenses, e.g. those complying with ISO 8598-1. It also gives a method for the determination of the back vertex power of the reference lenses.

NOTE It is accepted that other reference lenses can also be used with powers within the given range, manufactured to the same standard of accuracy and form, but different back vertex powers. However, only lenses with integer nominal powers, as described in 4.1, can be used for the calibration of digitally-rounding focimeters.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7944, *Optics and optical instruments — Reference wavelengths*

ISO 13666, *Ophthalmic optics — Spectacle lenses — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 13666 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
back vertex power
reciprocal of the paraxial vertex focal length

Note 1 to entry: According to ophthalmic convention, the “power” of a lens is specified as the back vertex power.

Note 2 to entry: The unit for expressing focal length is the metre and for vertex power is the reciprocal metre (m^{-1}). The name for this unit is “dioptre”, and the symbol is “D”.

[SOURCE: ISO 13666:2019, 3.10.8, modified — A Note 2 to entry was added.]

3.2
reference lens
lens complying with the requirements of this document used for the calibration and verification of focimeters

3.3
spherical reference lens
lens with spherical front and back surfaces used for the calibration and verification of dioptric power measurements by focimeters

Note 1 to entry: A plane surface is a special case of a spherical surface having an infinite radius of curvature and hence of zero power.

3.4
prismatic reference lens
prismatic lens constructed with two non-parallel plane surfaces used for the calibration and verification of prismatic power measurements by focimeters

Note 1 to entry: The unit for expressing prismatic power is centimetres deviation per metre distance (cm/m). The name for this unit is “prism dioptre” and the symbol is “Δ”.

Note 2 to entry: The prism shall be constructed to give the correct deviation with light incident perpendicular to one surface.

3.5
cylindrical reference lens
lens with one plane surface and one cylindrical surface used to calibrate and verify the axis indicator and axis marker with reference to the orientation of the adjusting rail

3.6
spherocylindrical-power reference lens
lens with one spherical surface and one toroidal surface used to check the non-symmetric cylindrical power and non-symmetric cylinder axis error given by an automated focimeter after calibration

3.7
reference filter
neutral density filter of plano power used to check the capability of an automated focimeter to measure tinted lenses

3.8
surface power
local ability of a finished surface to change the vergence of a bundle of rays incident at the surface

Note 1 to entry: The surface power is determined from the radius or radii of the surface and the refractive index of the optical material, and is calculated for light incident or emergent in air. The refractive index may be the actual refractive index of the material or a nominal value.

Note 2 to entry: Back surface power is given by the following formula:

$$F_{BS} = (1 - n)/r_2$$

where

F_{BS} is the back surface power in D (m^{-1});

n is the refractive index of the material of the lens;

r_2 is the radius of curvature of the back surface in metres, regarded as being positive if the centre of curvature is behind the surface according to the direction of travel of light through the surface.

[SOURCE: ISO 13666:2019, 3.10.4, modified — Note 2 to entry was added.]

3.9
verified power
<reference lens> power derived from measurements of a set of parameters of the *reference lens* (3.2)

Note 1 to entry: Each verified power comes with an uncertainty. This uncertainty is derived from the uncertainties of the individual measurements used to establish the verified power and should be within the values specified in this document.

Note 2 to entry: An example for the set of parameters to be measured for a spherical reference lens are the refractive index, radii of curvature of the two surfaces and thickness (see Annex A). For a prismatic reference lens, an example for a set of parameters to be measured are the refractive index and its apical angle (i.e. the angle between its two surfaces); (see Annex B).

Note 3 to entry: These parameters are measured using procedures and/or equipment traceable to certificates issued by an appropriate metrology laboratory.

4 Design requirements and recommendations for reference lenses

4.1 General

All reference lenses shall be made of homogeneous white crown glass selected to be free of bubbles and striae in an area of 8 mm radius surrounding the centre of the aperture.

Other materials may also be used provided their use results in lenses with a durability and optical reproducibility within the given tolerance over time and that can be manufactured to the same standard of uncertainty and form as the glass lenses specified in this document.

The reference wavelength for the reference lenses used to calibrate and calculate the verified power value of the back vertex power shall be stated. The reference wavelengths shall be either the green mercury e-line (λ_e = 546,07 nm) or the yellow helium d-line (λ_d = 587,56 nm), in accordance with ISO 7944.

The actual powers of the reference lenses should be close to, but need not be not exactly, the nominal power. The verified power (see 3.9) is that used to calibrate instruments. The closer the verified powers are to integral values, the easier it will be to calibrate or verify the calibration of some types of focimeter, e.g. manual focusing instruments or automated instruments that have display steps of 0,25 D.

The verified power of a reference lens is defined as a calculated value, which is based on actual measurements of the individual design parameters of the reference lens, such as refractive index, radius of curvature of lens surface, etc. These are measured using procedures and/or equipment traceable to certificates issued by an appropriate metrology laboratory. An appropriate metrology laboratory may be one accredited to ISO/IEC 17025 for these measurements or one specified in national or regional regulations.

The reference lenses are recommended to have protective mounts designed so that, when a lens is correctly placed on the lens support, the focimeter is not obstructed. It is also recommended that the verified power of the lens and the reference wavelength be marked on the mount.

4.2 Spherical reference lenses

4.2.1 Standard spherical reference lenses

For a complete set of spherical reference lenses, the following set of nominal back vertex powers is recommended:

−25 D, −20 D, −15 D, −10 D, −5 D, +5 D, +10 D, +15 D, +20 D, +25 D

The spherical reference lenses should have an aperture of at least 15 mm.

In order to minimize the influence of spherical aberration, the curvature of the back surface and the centre thickness shall approximately correspond to those of normal spectacle lenses. Table 1 gives nominal back surface powers and ranges for centre thickness, which will ensure that the reference lenses are of this form.

The highest permissible uncertainties on the verified spherical power for the standard spherical reference lenses are also specified in Table 1.

Table 1 — Design range for the standard spherical reference lenses

Nominal back vertex power D	Range for back surface power D	Range for centre thickness[a] mm	Highest permissible uncertainty on the verified spherical power D
−25	−26 to −24	2 to 6	±0,03
−20	−21 to −19	2 to 6	±0,02
−15	−16 to −14	2 to 6	±0,02
−10	−13 to −11	2 to 8	±0,01
−5	−10 to −8	2 to 8	±0,01
+5	−6 to −4	3 to 7	±0,01
+10	−4 to −2	3 to 7	±0,02
+15	−2 to 0[b]	5 to 7	±0,02
+20	−1 to 0[b]	7 to 9	±0,03
+25	−1 to 0[b]	9 to 11	±0,04

[a] These centre thicknesses are required to guarantee stability in the negative power range.

[b] The back surface shall not be convex.

NOTE 1 In Annex A, an example is given for the design of reference lenses that meet the requirements of Tables 1 for apertures of up to 15 mm diameter.

NOTE 2 The astigmatic power can be assessed the same way as uncertainties in spherical power by measuring surface geometries. See Annex A.

4.2.2 Low power spherical reference lenses (optional)

When validating automated instruments, it is recommended to add extra low powers into the range. Suggested values can be found in Table 2. The highest permissible uncertainties on the verified spherical power for these reference lenses are also specified in Table 2.

Table 2 — Design range for the low power spherical reference lenses

Nominal back vertex power D	Range for back surface power D	Range for centre thickness[a] mm	Highest permissible uncertainty on the verified spherical power D
−2,5	−8 to −6	2 to 8	±0,01
−0,25 [b]	−7 to −5		
−0,12 [b]	−7 to −5		
+0,12 [b]	−7 to -5		
+0,25 [b]	−7 to −5		
+2,5	−7 to −5		

[a] These centre thicknesses are required to guarantee stability.

[b] Choose either +0,25 and −0,25 or +0,12 and −0,12.

NOTE 1 In Annex A, an example is given for the design of reference lenses that meet the requirements of Tables 1 for apertures of up to 15 mm diameter.

NOTE 2 The astigmatic power can be assessed the same way as uncertainties in spherical power by measuring surface geometries. See Annex A.

4.3 Prismatic reference lenses

The optical surfaces of prismatic reference lenses shall be plane and their aperture shall be at least 15 mm.

The number of prismatic reference lenses that should be used to adjust or to check a focimeter depends on the measuring range of the instrument. The prismatic power marked on the mount shall be the power for light incident normal to the surface resting on the lens support.

For a complete set, the following set of prismatic powers is recommended:

2 Δ, 5 Δ, 10 Δ, 15 Δ, 20 Δ

NOTE The prismatic value may depend on the design of the focimeter (IOA or FOA – see ISO 13666) due to the implications of incident angle. This is explained in ISO/TR 28980.

The highest permissible uncertainties on the verified prismatic power for prismatic reference lenses are specified in Table 3. See Annex B for a discussion on the uncertainties for prismatic power lenses.

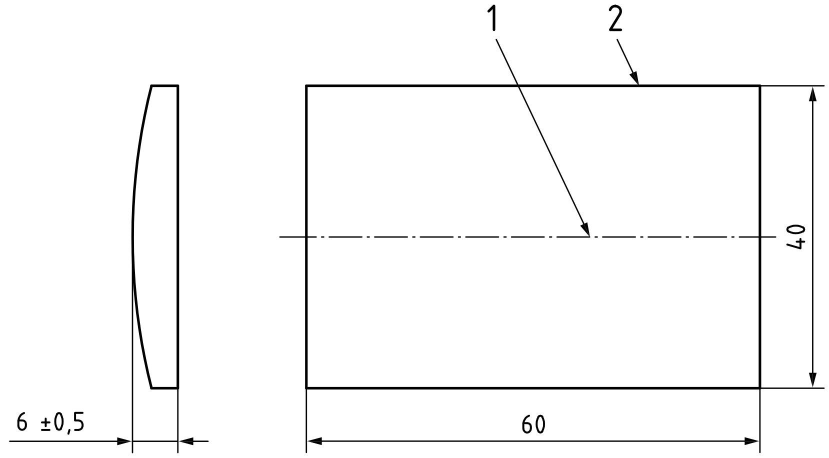
Table 3 — Uncertainties for prismatic reference lenses

Nominal prismatic power Δ	Highest permissible uncertainty on the verified prismatic value Δ
2	±0,02
5	±0,03
10	±0,05
15	±0,10
20	±0,15

4.4 Cylindrical reference lens

This reference lens shall be a positive plano-cylindrical lens of at least 5 D edged to a rectangular shape and shall have the dimensions, nominal unless otherwise stated, shown in Figure 1. The cylinder axis shall be parallel to the longer, reference, side of the rectangle and shall be marked by a centre line. The reference side shall also be marked.

Dimensions in millimetres



Key

1 centre line

2 reference side/edge

Figure 1 — Cylindrical reference lens

The angular deviation between the cylinder axis and the longer side of the rectangle (see Figure 1) shall not exceed 20 min of arc. See Annex C for a discussion on uncertainty for the cylindrical reference lens.

The displacement of the centre line from the afocal principal meridian shall not exceed ±0,1 mm.

These tolerances shall not be additive and allow the angular deviation between the cylinder axis and the centre line to be greater than 20 min of arc.

For systems with alignment based on optical features of the lens (e.g. permanent markings) instead of adjusting rails, appropriate means to secure the orientation shall be applied (e.g., optical markings) with the same uncertainty instead of the orthogonal shape.

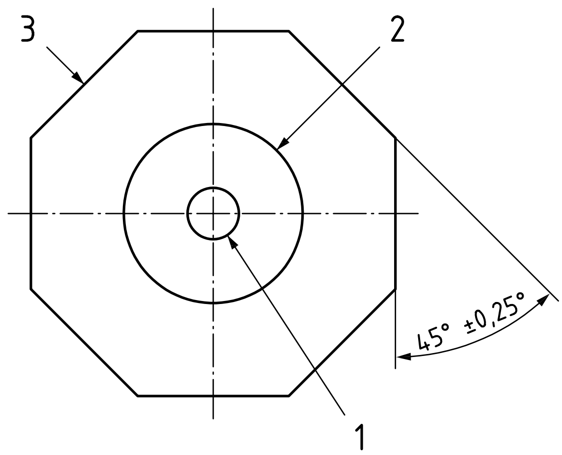
4.5 Spherocylindrical-power reference lens

The spherocylindrical-power reference lens is a specially mounted spherocylindrical-power lens with a power of −2,00 D sph/−1,50 D cyl, of spectacle form and quality conforming to ISO 8980-1, and shall have a diameter of not less than 25 mm.

The spherocylindrical-power reference lens is centred and firmly affixed on to an octagonal disk so that the optical centre of the lens is coincident with the geometrical centre of the disk. The length of the sides of the disk shall be between 25 mm and 30 mm. The axis of the cylinder should be aligned as close as practicable to one of the faces of the disk. The disk shall have a clear central aperture of at least 10 mm diameter centred on the geometrical centre of the disk. The disk is constructed of metal or rigid plastic at least 3 mm in thickness.

An illustration of the specially mounted spherocylindrical-power reference lens with the disk is shown in Figure 2.

As an alternative to using a lens mounted on an octagonal disc, a lens may be edged to the same octagonal shape. The length of the sides of the edged lens shall be between 20 mm and 25 mm in order to have stable and accurate measurements. The optical centre of the edged lens shall be coincident with its geometrical centre.



Key

1 10 mm clear central aperture within octagonal disc or edged lens

2 spherocylindrical lens, 25 mm to 40 mm in diameter, cemented to an octagonal disc (3), or edged to these dimensions

3 octagonal disk, with length of sides between 25 mm and 30 mm, or octagonal-shaped lens with length of sides between 20 mm and 25 mm

Figure 2 — Spherocylindrical-power lens, with disk or edged to shape

4.6 Reference filter

The reference filter shall be a solid tinted glass neutral density filter with plane surfaces with a luminous transmittance, τ_v, or a spectral transmittance, $\tau(\lambda)$, at around 555 nm of $\left(18_0^{+3}\right)\%$.

To define the neutrality of transmittance, the spectral transmittance, $\tau(\lambda)$, of the reference filter in the range of 450 nm to 650 nm shall be $\left(18_0^{+3}\right)\%$.

Conformity with a darker filter according to 4.7 shall be taken as conformity with this subclause.

4.7 Darker reference filters (optional)

Where claims are made about the performance of focimeters with lower transmittance filters, additional, darker, reference filters with τ_v or $\tau(\lambda)$ at around 555 nm <15 % are necessary to validate the claim.

A darker reference filter shall be a solid tinted glass neutral density filter with plane surfaces. The luminous transmittance, τ_v, and/or the spectral transmittance, $\tau(\lambda)$, at around 555 nm shall be nominated and the value of transmittance for which the claim is made shall be that value.

The spectral transmittances, $\tau(\lambda)$, of the reference filter in the range of 450 nm to 650 nm shall be within the limits in Table 4.

NOTE 1 Useful values of the nominated luminous transmittance or spectral transmittance at around 555 nm would be at the boundaries of the luminous transmittance categories used for spectacle lenses and eye protection, being 8 % and 3 %.

NOTE 2 The values for nominated transmittances less than 3 % can be calculated accounting for the surface reflections and assuming that the filter has been made thicker by the required amount given that the internal spectral optical density is proportional to the thickness.

Table 4 — Permitted limits of spectral transmittance for the luminous transmittance, τ_v, and/or the spectral transmittance, $\tau(\lambda)$, at around 555 nm of the darker filter

τ_v or $\tau(\lambda)$ % in the region of 555 nm	Limits of τ_v or $\tau(\lambda)$ % 450 nm to 650 nm	
	upper	lower
15	+2,8	−3,7
14	+2,7	−3,5
13	+2,6	−3,4
12	+2,5	−3,2
11	+2,4	−3,1
10	+2,3	−2,9
9	+2,2	−2,7
8	+2,1	−2,5
7	+1,9	−2,3
6	+1,8	−2,1
5	+1,6	−1,8
4	+1,5	−1,5
3	+1,1	−1,2

Annex A
(informative)

Design of spherical reference lenses

A.1 General

Spherical reference lenses that meet the requirements given in 4.2 can be manufactured by observing the following specifications and procedure.

To manufacture reference lenses according to this annex, the manufacturer will need a selection of master reference surfaces against which the reference lens surfaces can be checked using standard precision optical techniques.

A.2 Selection of glass

To manufacture spherical reference lenses using this method, precision grade homogeneous optical glass should be used.

The refractive index should be known to an accuracy of at least $\pm 2 \times 10^{-4}$. Glass[1)] should be selected with a refractive index around $n_e = 1{,}525 \pm 0{,}001$; $n_d = 1{,}523 \pm 0{,}001$ – see ISO 7944. The Abbe number should be 59 ± 4.

A.3 Design and selection of parameters

The nominal radius of the back surface (i.e. the surface that is put onto the lens support of the focimeter) is found by using Table 1.

For each nominal back vertex power, a nominal back surface power is given. The nominal radius of the back surface is found by using the formula given in the Note to entry to 3.8.

Formula (A.1) for back vertex power, F_{bv}, as a function of the four variables, front surface radius of curvature, back surface radius of curvature, refractive index of the lens material, and centre lens thickness, is as follows:

$$F_{bv} = (n-1)\left[\frac{1}{r_f - t\left(\frac{n-1}{n}\right)} - \left(\frac{1}{r_b}\right)\right] \quad \text{(A.1)}$$

where

F_{bv} is the back vertex power (in D or m^{-1});

r_f is the radius of curvature of the front surface (in m);

r_b is the radius of curvature of the back surface (in m);

t is the centre thickness of the lens (in m);

n is the refractive index of the lens material at a reference wavelength.

1) Barberini glass N-K5 is an example of a suitable, commercially available, product. This information is given for the convenience of users of this part of ISO 9342 and does not constitute an endorsement by ISO of this product.

and the Cartesian sign convention is adopted, i.e. radii are regarded as positive, if their centres of curvature lie in the direction of travel of the light from the respective surfaces.

Formula A.1 is re-arranged to give Formula A.2 for finding the front surface radius of curvature when the back vertex power, back surface radius of curvature, refractive index and centre thickness are known.

$$r_\mathrm{f} = \frac{n-1}{F_\mathrm{bv} + \left(\dfrac{n-1}{r_\mathrm{b}}\right)} + t\left(\frac{n-1}{n}\right) \tag{A.2}$$

Formula A.2 is re-arranged to give Formula A.3 for finding the centre thickness when the back vertex power, back surface radius of curvature, refractive index and front surface radius of curvature are known.

$$t = n\left[\left(\frac{r_\mathrm{f}}{n-1}\right) - \frac{1}{F_\mathrm{bv} + \left(\dfrac{n-1}{r_\mathrm{b}}\right)}\right] \tag{A.3}$$

To design a reference lens of the desired back vertex power, the value of the back surface radius is calculated from the surface power given in Tables 1 or 2. This radius value is then compared to the available master test surfaces and the master surface radius closest to the desired value is chosen as the back surface radius.

Using this and a centre thickness that is in the range specified in Table 1, the front surface radius is calculated using Formula A.2 above. This radius value is then compared to the available master test surfaces and the master surface radius closest to the desired value is chosen as the front surface radius.

Finally, Formula A.3 is used with the selected values of the front and back radius and the known refractive index to calculate the centre thickness to be manufactured.

A.4 Determination of lens back vertex power and uncertainty

While a lens produced using the method given in A.2 and A.3 will have a back vertex power very close to the calculated value, a more precise value is needed for a reference lens. To find the precise value for the back vertex power of a reference lens, it is necessary to measure the lens's actual parameters with the uncertainties given in A.5.

The uncertainty in back vertex power of the reference lens due to an uncertainty in one of the variables with the other three held constant is given by multiplying the uncertainty in that variable by the partial derivative of F_bv with respect to that variable. The expressions for the four partial derivatives are given by Formulae (A.4) to (A.7) as follows:

$$\frac{\partial F_\mathrm{bv}}{\partial r_\mathrm{f}} = \frac{-(n-1)}{\left[r_\mathrm{f} - t\left(\dfrac{n-1}{n}\right)\right]^2} \tag{A.4}$$

$$\frac{\partial F_\mathrm{bv}}{\partial r_\mathrm{b}} = \frac{n-1}{{r_\mathrm{b}}^2} \tag{A.5}$$

$$\frac{\partial F_\mathrm{bv}}{\partial t} = \frac{(n-1)^2}{n\left[r_\mathrm{f} - t\left(\dfrac{n-1}{n}\right)\right]^2} \tag{A.6}$$

$$\frac{\partial F_{bv}}{\partial n} = \left[\frac{1}{r_f - t\left(\frac{n-1}{n}\right)} - \frac{1}{r_b} \right] + \frac{(n-1)t}{n^2\left[r_f - t\left(\frac{n-1}{n}\right)\right]^2} = \frac{F_{bv}}{n-1} + \frac{(n-1)t}{n^2\left[r_f - t\left(\frac{n-1}{n}\right)\right]^2} \quad \text{(A.7)}$$

These formulae can be simplified by defining

$$P_f' = \frac{n-1}{r_f - t\left(\frac{n-1}{n}\right)} \quad \text{(A.8)}$$

as the thickness corrected front surface power and

$$P_b = \frac{-(n-1)}{r_b} \quad \text{(A.9)}$$

as the back surface power.

The back vertex power is then from Formulae A.8 and A.9:

$$F_{bv} = P_f' + P_b \quad \text{(A.10)}$$

The uncertainty in F_{bv} due to an uncertainty in r_f is given by ΔF_{bvr_f} as follows:

$$\Delta F_{bvr_f} = \frac{-P_f'^2}{n-1} \Delta r_f \quad \text{(A.11)}$$

where Δr_f is the uncertainty in r_f.

The uncertainty in F_{bv} due to an uncertainty in r_b is given by ΔF_{bvr_b} as follows:

$$\Delta F_{bvr_b} = \frac{P_b{}^2}{n-1} \Delta r_b \quad \text{(A.12)}$$

where Δr_b is the uncertainty in r_b.

The uncertainty in F_{bv} due to an uncertainty in n is given by ΔF_{bvn} as follows:

$$\Delta F_{bvn} = \left[\frac{F_{bv}}{n-1} + \frac{tP_f'^2}{n^2(n-1)} \right] \Delta n \quad \text{(A.13)}$$

where Δn is the expected uncertainty in n.

The uncertainty in F_{bv} due to an uncertainty in t is given by ΔF_{bvt} as follows:

$$\Delta F_{bvt} = \frac{P_f'^2}{n} \Delta t \quad \text{(A.14)}$$

where Δt is the uncertainty in t.

The total uncertainty, ΔF_{bv}, associated with a reference lens that results from all four parameter uncertainties acting simultaneously is given by their geometrical sum following Formula (A.15):

$$\Delta F_{bv} = \sqrt{\Delta F_{bvr_f}{}^2 + \Delta F_{bvr_b}{}^2 + \Delta F_{bvt}{}^2 + \Delta F_{bvn}{}^2} \quad \text{(A.15)}$$

A.5 Example of a calculation for uncertainty

The following case illustrates the method for calculating the uncertainty using the method given in A.4.

The nominal back vertex power of the reference lens is +15 D. It is constructed of spectacle crown glass, n_d = 1,522 49, and has a centre thickness of 5,40 mm. The radii of curvature of the lens surfaces are r_f = 34,47 mm and r_b = 510,53 mm.

This combination of parameters produces a lens with surface powers (from Formulae A.8 and A.9):

$$P_f' = \frac{1{,}522\,49 - 1}{0{,}034\,47 - 0{,}005\,4\dfrac{(1{,}522\,49-1)}{1{,}522\,49}} \text{ D} = 16{,}02 \text{ D}$$

$$P_b = \frac{-(1{,}522\,49-1)}{0{,}510\,53} \text{ D} = -1{,}02 \text{ D}$$

and a back vertex power of:

$$F_{bv} = 16{,}02 \text{ D} - 1{,}02 \text{ D} = 15{,}00 \text{ D}$$

Hence the uncertainties in the measurement of the parameters found using their values given above and the uncertainty given in A.4:

The radii of curvature of the surfaces can be measured using an interferometer with an uncertainty of no more than ±1 × 10^{-5} m (10 μm). Hence:

$$\Delta r_f = 1 \times 10^{-5} \text{ m}$$

$$\Delta r_b = 1 \times 10^{-5} \text{ m}$$

The refractive index of the material will typically be supplied by the glass manufacturer and shall be known to ±0,000 2. Hence:

$$\Delta n = 2 \times 10^{-4}$$

The centre thickness can be measured with an uncertainty of ±3 × 10^{-6} m (3 μm). Hence:

$$\Delta t = 3 \times 10^{-6} \text{ m}$$

From Formulae A.11 to A.14

$$\Delta F_{bvr_f} = \frac{-16{,}02^2}{1{,}522\,49-1} \cdot 10^{-5} \text{ D} = 4{,}9 \times 10^{-3} \text{ D}$$

$$\Delta F_{bvr_b} = \frac{1{,}02^2}{1{,}522\,49-1} \cdot 10^{-5} \text{ D} = 2{,}0 \times 10^{-5} \text{ D}$$

$$\Delta F_{bvn} = \left(\frac{15{,}00}{1{,}522\,49-1} + \frac{(0{,}005\,4)16{,}02^2}{(1{,}522\,49)^2(1{,}522\,49-1)} \right) \cdot 2{,}0 \times 10^{-4} \text{ D} = 6{,}0 \times 10^{-3} \text{ D}$$

$$\Delta F_{\mathrm{bv}t} = \frac{16{,}02^2}{1{,}522\,49} \cdot 3 \times 10^{-6}\ \mathrm{D} = 5{,}1 \times 10^{-4}\ \mathrm{D}$$

The total uncertainty, ΔF_{bv}, associated with a reference lens that results from all four parameter uncertainties acting simultaneously is given by their geometrical sum following Formula (A.15):

$$\Delta F_{\mathrm{bv}} = \sqrt{\left(4{,}9 \times 10^{-3}\right)^2 + \left(2{,}0 \times 10^{-5}\right)^2 + \left(6{,}0 \times 10^{-3}\right)^2 + \left(5{,}1 \times 10^{-4}\right)^2}\ \mathrm{D} = 0{,}008\ \mathrm{D}$$

This reference lens therefore has a power of +15,00 D ± 0,008 D which meets the requirements of Table 1, which allows an uncertainty of 0,02 D.

Annex B
(informative)

Design and/or validation of prismatic reference lenses

B.1 Using the apical angle

B.1.1 General

Prismatic reference lenses that meet the requirements given in 4.3 can be manufactured by observing the following specifications and procedure.

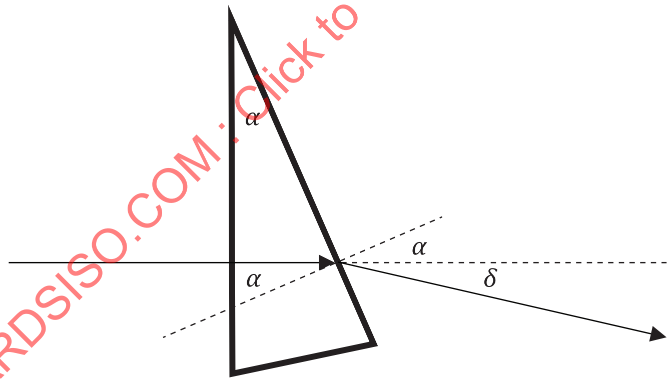
To manufacture prismatic reference lenses complying with 4.3, the manufacturer will need to manufacture or measure the apical angle and know the refractive index (e line and d line – see ISO 7944) with sufficient accuracy and precision to comply with the prismatic deviations and tolerances.

B.1.2 Selection of glass

See A.2.

B.1.3 Steps in the design

The two surfaces should be flat and inclined at the apical angle, α, to give a deviation, δ, with a refractive index, n.



Key

α apical angle

δ angle of deviation of light

Figure B.1 — Deviation of light by a thin prism

By Snell's Law, $\sin(\alpha + \delta) = n \sin \alpha$

which when rearranged gives:

$$\tan\alpha = \frac{\sin\delta}{n - \cos\delta}$$

The highest permissible uncertainty on refractive index in A.2 of $\pm 2 \times 10^{-4}$ represents less than 0,04 % change in deviation. The permitted tolerance varies from 1 % at 2^{Δ} to 0,75 % at 20^{Δ}, so the contribution of uncertainty in the value of n to the value of d may be considered negligible and only the uncertainty in the value of a need be accounted for.

By comparing the apical angles required for prismatic powers of δ and $(\delta + \Delta\delta)$, the uncertainty required in α is given by

$\Delta\alpha =$ apical angle for deviation δ – apical angle for deviation $(\delta + \Delta\delta)$

$= |\arctan(\sin\delta/(n - \cos\delta) - \arctan(\sin(\delta + \Delta\delta)/[n - \cos(\delta + \Delta\delta)]|$

The calculated values for the nominal powers in Table 3 are shown in Table B.1.

Table B.1 — Uncertainties in apical angle for prismatic reference lenses

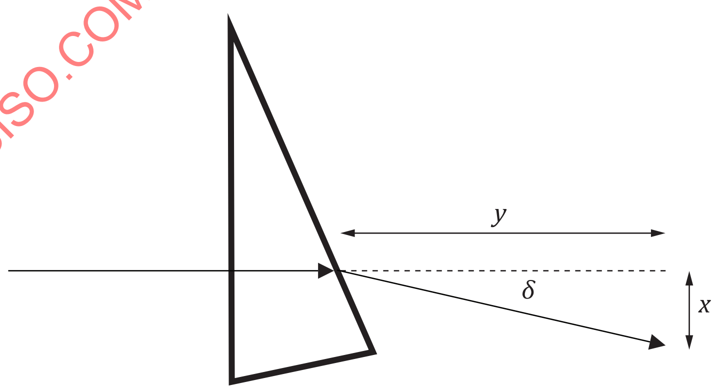
Prismatic power and uncertainty	Apical angle ± uncertainty	
Δ	Δ	degrees
2 ± 0,02	3,82 ± 0,04	2,19 ± 0,02
5 ± 0,03	9,52 ± 0,06	5,44 ± 0,03
10 ± 0,05	18,84 ± 0,09	10,67 ± 0,05
15 ± 0,10	27,28 ± 0,17	15,52 ± 0,09
20 ± 0,15	36,16 ± 0,24	19,88 ± 0,12

B.2 Direct measurement of deviation

B.2.1 General

Assessment of the actual value of deviation of prismatic reference lenses can be carried out quite simply. To verify prismatic reference lenses as complying with 4.3, a direct measurement of the angle of deviation as a lateral displacement, x, in cm at a known distance, y, in m is made.

δ (cm/m or Δ) = x (cm)/y (m)



Key

x displacement, in cm

y longitudinal measurement distance, in m

δ angle of deviation of light

Figure B.2 — Deviation of light by a thin prism expressed as a lateral displacement