
**Optics and photonics — Test method
for refractive index of optical
glasses —**

**Part 1:
Minimum deviation method**

*Optique et photonique — Méthode d'essai pour déterminer l'indice de
réfraction des verres optiques —*

Partie 1: Méthode de la déviation minimale



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Contents

	Page
Foreword	iv
Introduction	v
1 Scope	1
2 Normative references	1
3 Terms and definitions	1
4 Principle	1
5 Measuring apparatus	2
5.1 General construction	2
5.2 Goniometer	3
5.3 Light source	3
5.4 Detector	4
6 Specimen prism	4
6.1 General	4
6.2 Dimensions	5
6.3 Apex angle	5
6.4 Flatness	5
7 Environmental condition of measurement	5
7.1 Temperature	5
7.2 Humidity	5
7.3 Atmospheric pressure	5
8 Measurement	6
8.1 Adjustment of the measurement specimen prism	6
8.2 Measurement of the apex angle, α	6
8.3 Measurement of the angle of minimum deviation, $\delta_{\min}$	7
9 Indication	8
10 Test report	8
Annex A (informative) Calculation of principal dispersion, Abbe number, partial dispersion and relative partial dispersion	9
Annex B (informative) Dispersion formulae for calculation of refractive index at arbitrary wavelength	12
Annex C (informative) Correction of refractive index for temperature, humidity and atmospheric pressure	14
Annex D (informative) Other measurement methods of the apex angle	16
Annex E (informative) Other measurement methods of the angle of minimum deviation	18
Bibliography	21

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 documents 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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 3, *Optical materials and components*.

A list of all parts in the ISO 21395 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.

Introduction

The refractive index of optical glasses has been measured by various methods, but up to now, an International Standard for the measurement has not been available. The refractive index of optical glasses is the most important characteristic for the optical elements to be manufactured from them. This document defines a suitable method for measuring the refractive index of optical glasses accurately and also helps to improve communication between raw optical glass suppliers and optical element manufacturers.

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Optics and photonics — Test method for refractive index of optical glasses —

Part 1: Minimum deviation method

1 Scope

This document specifies the measuring method for the refractive index of optical glasses with the accuracy within 1×10^{-5} used in the spectral range from 365 nm to 2 400 nm.

Additional information on how to apply the refractive index in the dispersion and the various dispersion formulae of optical glasses is given in [Annex A](#) and [Annex B](#).

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.

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminological databases for use in standardization at the following addresses.

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

4 Principle

As shown in [Figure 1](#), when the monochromatic light beam is refracted by the specimen prism at the angle of minimum deviation, the relative refractive index of the specimen prism to the air at the wavelength of the monochromatic light beam is described by the following [Formula \(1\)](#):

$$n_{\text{rel}} = \frac{\sin \frac{\alpha + \delta_{\text{min}}}{2}}{\sin \frac{\alpha}{2}} \quad (1)$$

where

- n_{rel} is the relative refractive index ($n_{rel} = n_{abs}/n_{air}$);
- n_{abs} is the absolute refractive index of the specimen prism;
- n_{air} is the refractive index of air;
- α is the apex angle;
- δ_{min} is the angle of minimum deviation.

As shown in [Figure 1](#), light enters the plane AB of the specimen prism at an angle of incidence (θ) and exits from the plane AC at an exit angle (θ'). The incident and the exiting light ray form the deviation angle (δ). With the deviation angle minimized, the incident and the exiting angles are equal. The smallest angle of deviation is called the angle of minimum deviation. The angle of minimum deviation (δ_{min}) and the apex angle (α) of the specimen prism are measured, and the refractive index is calculated using those angles. Formulae for the calculation of principal dispersion, Abbe number, partial dispersion and relative partial dispersion are given in [Annex A](#). The dispersion formulae that calculate the refractive index at the wavelength different from the measured wavelengths are given in [Annex B](#). The correction of the refractive index of optical glasses for temperature, humidity and atmospheric pressure of optical glasses are given in [Annex C](#).

NOTE When measuring the refractive index with this method, it is necessary to consider temperature, pressure, humidity and measurement errors. Expressions for the relations of these errors are described in ISO 17328. The dependence of the refractive index of air on temperature and pressure can be found in ISO 12123:2018, A.3.

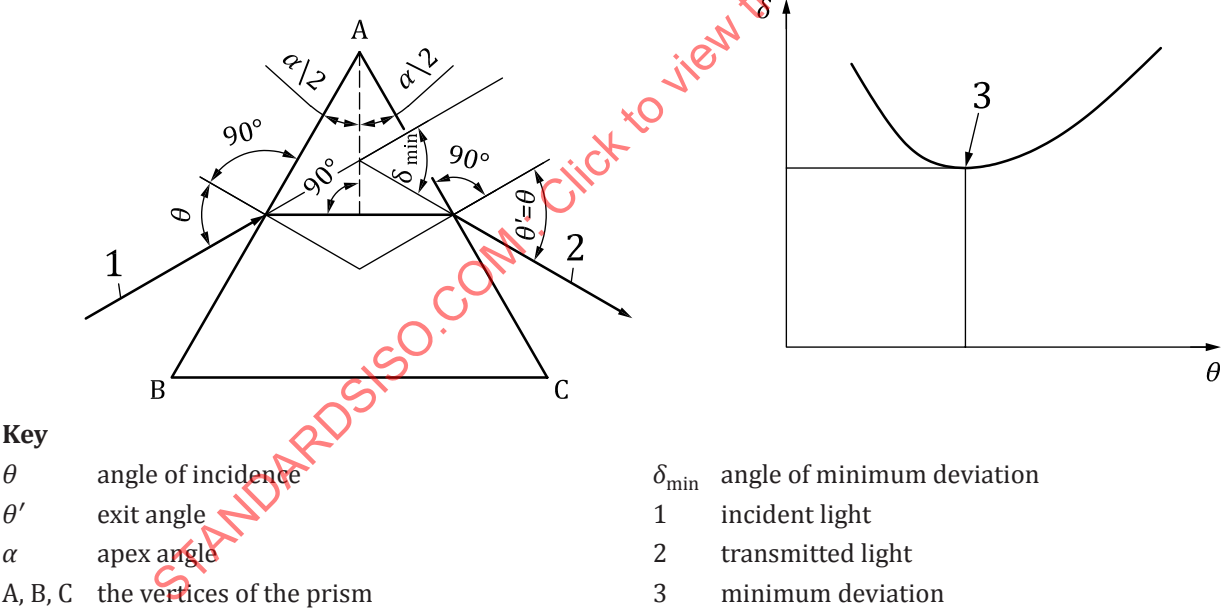
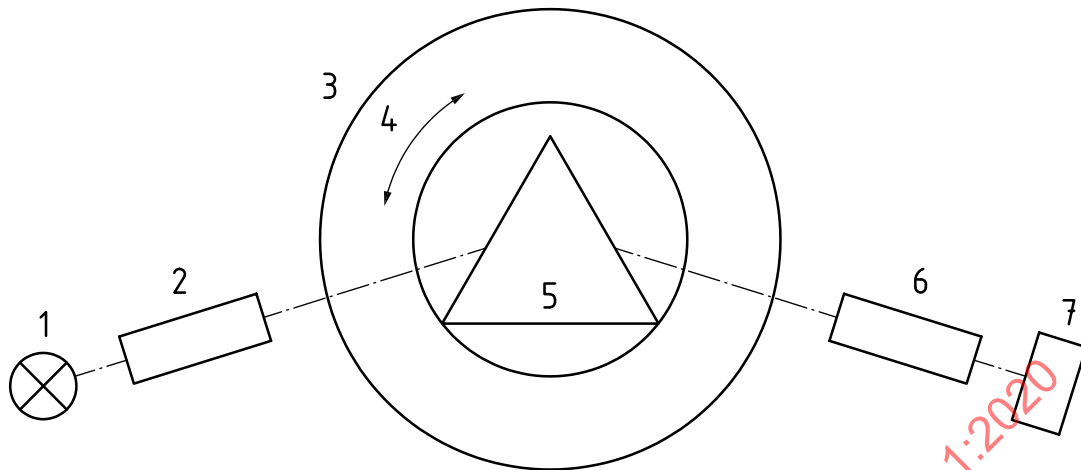


Figure 1 — Principle of minimum deviation method

5 Measuring apparatus

5.1 General construction

The measuring apparatus is shown in [Figure 2](#).



Key

- | | | | |
|---|--|---|---------------------------------------|
| 1 | light source | 4 | rotating stage coupled with prism (5) |
| 2 | collimator | 5 | specimen prism |
| 3 | goniometer coupled with telescope (6) and detector (7) | 6 | telescope |
| | | 7 | detector |

Figure 2 — Schematic of minimum deviation method

5.2 Goniometer

The goniometer shall provide the capability of reading the angle within ± 1 arc sec.

5.3 Light source

The light source should be a mercury, hydrogen, helium, rubidium, cesium or cadmium lamp, also He-Ne laser or Nd:YAG laser defined in ISO 7944. The spectral lines and their associated wavelengths are shown in [Table 1](#).

Light sources and their corresponding wavelengths not defined in [Table 1](#) are also applicable for measurement, but the spectral bandwidth of the light source and the accuracy/certainty of emission line (for example D line (589,3 nm)) should be checked before use.

Table 1 — Wavelength and spectral line of light source

Wavelength/nm	Spectral line	Light source
365,01	i	Mercury lamp
404,66	h	Mercury lamp
435,83	g	Mercury lamp
479,99	F'	Cadmium lamp
486,13	F	Hydrogen lamp
543,5	—	He-Ne laser
546,07	e	Mercury lamp
587,56	d	Helium lamp
632,8	—	He-Ne laser
643,85	C'	Cadmium lamp
656,27	C	Hydrogen lamp
706,52	r	Helium lamp

Table 1 (continued)

Wavelength/nm	Spectral line	Light source
780,00	—	Rubidium lamp
852,11	s	Cesium lamp
1 013,98	t	Mercury lamp
1 064,1	—	Nd:YAG laser
1 128,7	—	Mercury lamp
1 395,1	—	Mercury lamp
1 529,6	—	Mercury lamp
1 813,1	—	Mercury lamp
1 970,1	—	Mercury lamp
2 325,4	—	Mercury lamp

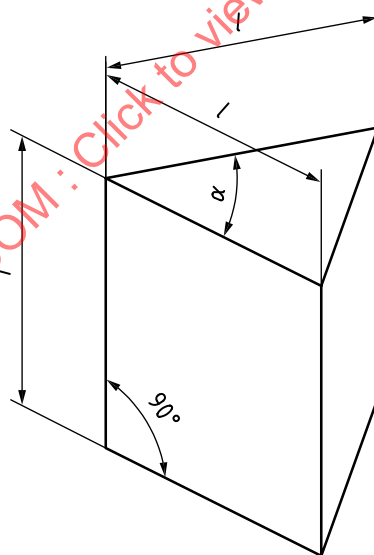
5.4 Detector

A general-type detector that is capable of detecting each wavelength or easily exchangeable for different spectral ranges should be used.

6 Specimen prism

6.1 General

An example of the shape of specimen prism is shown in [Figure 3](#).



Key

- l length
- t thickness
- α apex angle

Figure 3 — Shape of the specimen prism

6.2 Dimensions

The length of the edges making the apex angle should be between 15 mm and 40 mm and the thickness should be between 10 mm and 30 mm.

6.3 Apex angle

A reasonable choice of apex angle, α , for a test prism can be calculated from the expected refractive index of the prism, n_{rel} , and the angle of incidence, θ .

$$\alpha = 2 \arcsin \left[\frac{\sin \theta}{n_{\text{rel}}} \right]$$

α is typically between 35° and 80°.

6.4 Flatness

The plane polished sides should have a peak to valley flatness better than $\frac{1}{4}\lambda$ over 80 % of the aperture at the measurement wavelength of 546 nm or 632,8 nm.

7 Environmental condition of measurement

7.1 Temperature

The temperature shall be between 20 °C and 25 °C. Environmental temperature stability and uniformity shall be controlled according to the required measurement accuracy. This requirement shall be calculated so that the temperature variation of the glass contributes no more than 50 % to the desired total measurement error. Sufficient time should be allowed for the prism to acclimatise to the test conditions prior to commencing (typically 24 h). Care should be taken in handling the prism to minimise heat transfer from the person to the prism prior to measurements.

The temperature fluctuation is less than 1/2 of required accuracy for the refractive index variation value obtained from the refractive index temperature coefficient.

NOTE In the most cases, the measurements are made at 22 °C.

EXAMPLE The refractive index change with temperature of SF57 is about $3 \cdot 10^{-5}/\text{K}$. To achieve a refractive

index accuracy of $1 \cdot 10^{-5}$, the temperature fluctuation should be less than $0,5 \cdot \left(\frac{1 \cdot 10^{-5}}{3 \cdot 10^{-5} \cdot \frac{1}{\text{K}}} \right) = 0,167 \text{ K}$.

7.2 Humidity

The relative humidity should be between 30 % and 70 %. The fluctuation of the relative humidity during the measurement should be within ± 10 %.

7.3 Atmospheric pressure

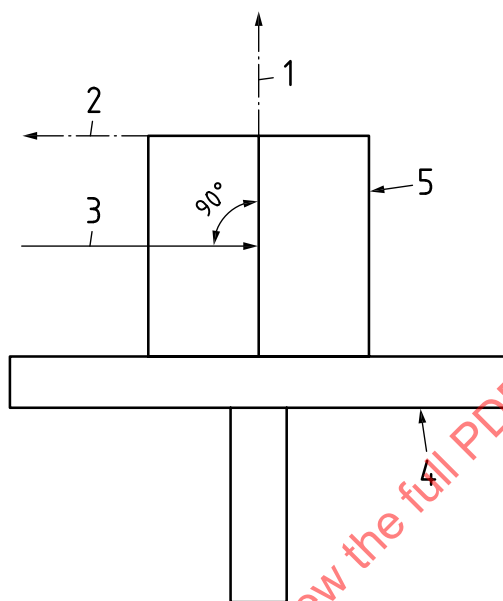
The atmospheric pressure shall be between 86 kPa and 106 kPa. The fluctuation of the pressure during the measurement should be within $\pm 0,5$ kPa.

8 Measurement

8.1 Adjustment of the measurement specimen prism

The measurement prism shall be oriented so that the vectors of the normals to both the incident and exit surfaces of the prism are perpendicular to the rotation axis. The incident light should also be oriented perpendicular to the rotation axis of the prism as shown in [Figure 4](#).

It is common to use an accuracy of ± 3 arcsec for the adjustment measured by an autocollimator.



Key

- | | | | |
|---|----------------|---|----------------|
| 1 | rotation axis | 4 | rotating stage |
| 2 | normal vector | 5 | specimen prism |
| 3 | incident light | | |

Figure 4 — Adjustment of specimen prism

8.2 Measurement of the apex angle, α

A collimated beam of light is used to determine the angle of the specimen prism. The apex angle, α , shall be calculated. A schematic diagram is shown in [Figure 5](#). The detailed measurement of the apex angle is given in [Annex D](#).

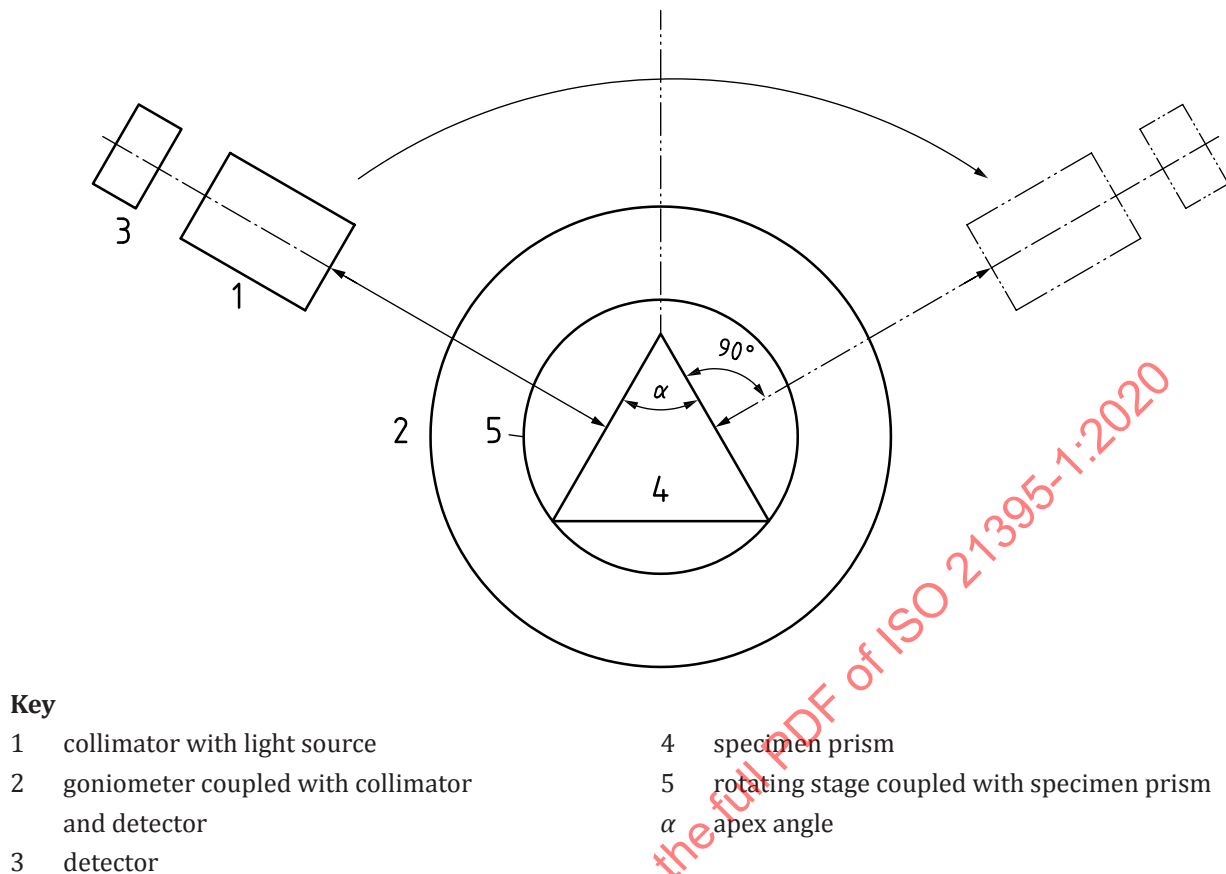
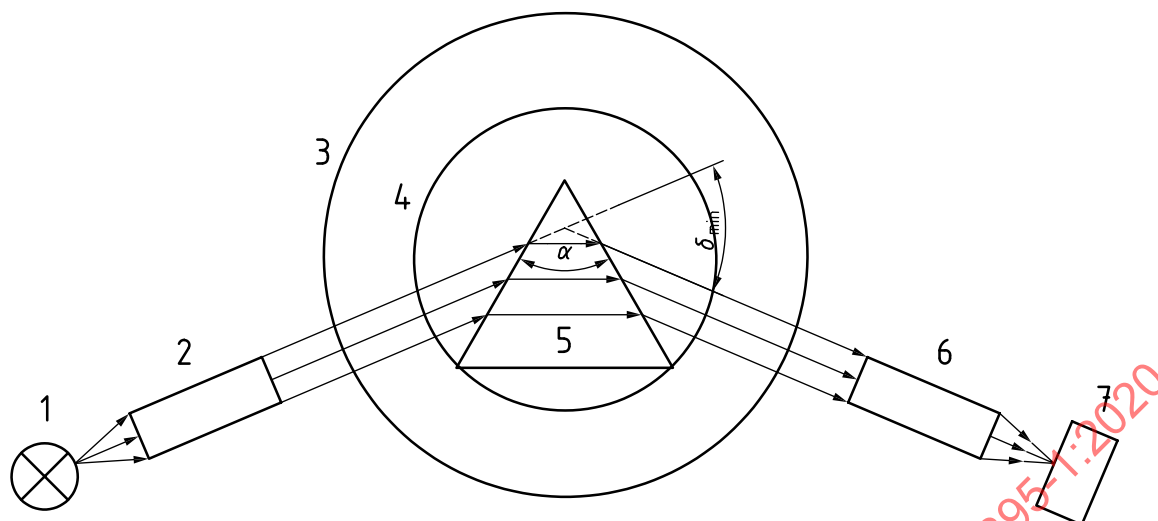


Figure 5 — Measurement of apex angle

8.3 Measurement of the angle of minimum deviation, $\delta_{\min}$

According to the size of the specimen prism, the diameter of the measuring spectral beam from the collimator should be adjusted or shaped by an aperture so that it enters the plane surface of incidence of the specimen prism. And then, the position of the prism should be adjusted so that the intersection between the extended incident light and transmitting light is at the rotation centre of the rotation stage. After setting the specimen prism, use the telescope to detect the light beam transmitted through the prism and emitted from the exit surface while rotating the stage so that the light beam of the spectral line to be measured enters the incident surface of the prism. The prism table and telescope are then slowly rotated together to find the position where the deviation is at a minimum. The angle indicated by the goniometer at that time shall be treated as the minimum deviation. A schematic diagram is shown in [Figure 6](#). Other measurements methods of the angle of minimum deviation are given in [Annex E](#).



Key

- | | | | |
|---|--|----------|----------------|
| 1 | light source | 5 | specimen prism |
| 2 | collimator | 6 | telescope |
| 3 | goniometer coupled with telescope and detector | 7 | detector |
| 4 | rotating stage coupled with specimen prism | α | apex angle |

Figure 6 — Measurement of the angle of minimum deviation

9 Indication

The refractive index shall be indicated at least to the fifth decimal place.

10 Test report

For the measurement result, the following items shall be reported:

- method used (for apex angle and angle of minimum deviation);
- a reference to this document, e.g. ISO 21395-1:2020;
- melt number, lot number or alternative means of indicating the specific test sample;
- atmosphere (if an atmosphere other than air is used);
- atmospheric pressure;
- humidity;
- temperature;
- error in temperature;
- any deviation from the procedure;
- any unusual features observed;
- date of the test.

Annex A (informative)

Calculation of principal dispersion, Abbe number, partial dispersion and relative partial dispersion

A.1 General

The definition of principal dispersions, Abbe number, partial dispersion and relative partial dispersion are listed in ISO 7944 and ISO 9802. The formulae for calculation are described in ISO 9802. The standards are applicable also when calculating respective values from the refractive index measured according to this standard.

A.2 Reference wavelength

The reference wavelength is the d-line (587,56 nm) and/or the e-line (546,07 nm).

A.3 Calculation of principal dispersion

The principal dispersion is calculated with the [Formula \(A.1\)](#) when the reference wavelength is the d-line.

$$n_F - n_C \quad (A.1)$$

where

n_F is the refractive index of the F-line (486,13 nm);

n_C is the refractive index of the C-line (656,27 nm).

The principal dispersion is calculated with the [Formula \(A.2\)](#) when the reference wavelength is the e-line.

$$n_{F'} - n_{C'} \quad (A.2)$$

where

$n_{F'}$ is the refractive index of the F'-line (479,99 nm);

$n_{C'}$ is the refractive index of the C'-line (643,85 nm).

The principal dispersion is indicated to at least five decimal place.

A.4 Calculation of Abbe number

The Abbe number is calculated with the [Formula \(A.3\)](#) when the reference wavelength is the d-line.

$$v_d = \frac{n_d - 1}{n_F - n_C} \quad (A.3)$$

where

- ν_d is the Abbe number of the d-line (587,56 nm);
- n_d is the refractive index of the d-line (587,56 nm);
- n_F is the refractive index of the F-line (486,13 nm);
- n_C is the refractive index of the C-line (656,27 nm).

The Abbe number is calculated with the [Formula \(A.4\)](#) when the reference wavelength is the e-line.

$$\nu_e = \frac{n_e - 1}{n_{F'} - n_{C'}} \quad (\text{A.4})$$

where

- ν_e is the Abbe number of the e-line (546,07 nm);
- n_e is the refractive index of the e-line (546,07 nm);
- $n_{F'}$ is the refractive index of the F'-line (479,99 nm);
- $n_{C'}$ is the refractive index of the C'-line (643,85 nm).

The Abbe number is indicated to at least one decimal place.

A.5 Calculation of partial dispersion

The partial dispersion is calculated by [Formula \(A.5\)](#).

$$n_x - n_y \quad (\text{A.5})$$

where

- n_x is the refractive index of wavelength x ;
- n_y is the refractive index of wavelength y .

The partial dispersion is indicated to at least five decimal place.

A.6 Calculation of relative partial dispersion

The relative partial dispersion is calculated with the [Formula \(A.6\)](#) when the reference wavelength is the d-line.

$$\frac{n_x - n_y}{n_F - n_C} \quad (\text{A.6})$$

where

- n_x is the refractive index of wavelength x ;
- n_y is the refractive index of wavelength y ;
- n_F is the refractive index of the F-line (486,13 nm);
- n_C is the refractive index of the C-line (656,27 nm).

The relative partial dispersion is calculated with the [Formula \(A.7\)](#) when the reference wavelength is the e-line.

$$\frac{n_x - n_y}{n_{F'} - n_{C'}} \quad (\text{A.7})$$

where

n_x is the refractive index of wavelength x ;

n_y is the refractive index of wavelength y ;

$n_{F'}$ is the refractive index of the F'-line (479,99 nm);

$n_{C'}$ is the refractive index of the C'-line (643,85 nm).

The relative partial dispersion is indicated to at least four decimal place.

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Annex B (informative)

Dispersion formulae for calculation of refractive index at arbitrary wavelength

B.1 General

The refractive index at an arbitrary wavelength can be calculated with the wavelength dispersion formula. The constants of the dispersion formula are obtained by fitting the dispersion curve to the measured refractive index values.

NOTE The unit of the wavelength in dispersion formulae is μm .

B.2 Wavelength dispersion formulae

The Cauchy's dispersion formula is given by (B.1).

$$n = A + \sum_{i=1}^j \frac{B_i}{\lambda^{2i}} \quad (\text{B.1})$$

where

n is the refractive index;

j is an integer number;

λ is the wavelength;

A, B are constants.

The Hartmann's dispersion formula is given by (B.2).

$$n = A + \frac{B}{(\lambda - C)^D} \quad (\text{B.2})$$

where

n is the refractive index;

λ is the wavelength;

A, B, C, D are constants.

Special cases are $D = 1$ and $D = 2$.

The Sellmeier's dispersion formula is given by (B.3).

$$n^2 - 1 = \frac{B_1 \lambda^2}{\lambda^2 - C_1} + \frac{B_2 \lambda^2}{\lambda^2 - C_2} + \frac{B_3 \lambda^2}{\lambda^2 - C_3} \quad (\text{B.3})$$

where

n is the refractive index;

λ is the wavelength;

$B_1, B_2, B_3,$
 C_1, C_2, C_3 are constants.

The Laurent dispersion formula is given by (B.4).

$$n^2 = a_0 + a_1 \lambda^2 + a_2 \lambda^{-2} + a_3 \lambda^{-4} + a_4 \lambda^{-6} + a_5 \lambda^{-8} \quad (\text{B.4})$$

where

n is the refractive index;

λ is the wavelength;

$a_0, a_1, a_2,$
 a_3, a_4, a_5 are constants.

The Hertzberger's dispersion formula is given by (B.5).

$$n = A + \frac{B}{\lambda^2 - 0,028} + \frac{C}{(\lambda^2 - 0,028)^2} + D \lambda^2 + E \lambda^4 + F \lambda^6 \quad (\text{B.5})$$

where

n is the refractive index;

λ is the wavelength;

A, B, C, D, E, F are constants.

Annex C (informative)

Correction of refractive index for temperature, humidity and atmospheric pressure

C.1 General

The relative refractive index of optical glass is dependent on temperature, humidity and atmospheric pressure. The relative refractive index for a setting temperature can be calculated from two measurements at different temperatures T_1 and T_2 as described in [C.2](#). Likewise, calculation of the relative refractive index for a setting temperature and a setting pressure can be done using the formulae given in ISO 12123:2018, A.3.

C.2 Correction of the refractive index

C.2.1 Calculation of the absolute refractive index

The absolute refractive index of glass is calculated, based on the refractive indices measured under various conditions, by using the [Formula \(C.1\)](#). The refractive index of air under various conditions is given in References [\[7\]](#), [\[8\]](#) and ISO 17328:2014, A.3.

$$n_{\text{abs}} = n_{\text{rel}} \times n_{\text{air}} = \frac{\sin \frac{\alpha + \delta_{\text{min}}}{2}}{\frac{\sin \alpha}{2}} \times n_{\text{air}} \quad (\text{C.1})$$

where

- n_{abs} is the absolute refractive index;
- n_{rel} is the measured refractive index;
- n_{air} is the refractive index of air under conditions at measurement location;
- α is the apex angle;
- δ_{min} is the angle of minimum deviation.

C.2.2 Calculation of the temperature coefficient of the absolute refractive indices

The temperature coefficient of the absolute refractive index is calculated using [Formula \(C.2\)](#).

$$\left[\frac{dn}{dT} \right]_{\text{abs}} = \frac{n_{\text{abs}}(T_2) - n_{\text{abs}}(T_1)}{T_2 - T_1} \quad (\text{C.2})$$

where

- $\left[\frac{dn}{dT} \right]_{\text{abs}}$ is the temperature coefficient of the absolute refractive index (K^{-1});
- $n_{\text{abs}}(T_1), n_{\text{abs}}(T_2)$ are the absolute refractive indices of the specimen at temperatures T_1 and at T_2 respectively;
- T_1, T_2 are temperatures of the specimen ($^{\circ}\text{C}$).

C.2.3 Calculation of the temperature coefficient of the relative refractive index

The temperature coefficient of the refractive index is calculated using [Formula \(C.3\)](#).

NOTE For more information see ISO 12123.

$$\left[\frac{dn}{dT} \right]_{\text{rel}} = \left[\frac{dn}{dT} \right]_{\text{abs}} - n_{\text{abs}}(T) \times \left[\frac{dn}{dT} \right]_{\text{air}} \quad (\text{C.3})$$

where

- $\left[\frac{dn}{dT} \right]_{\text{rel}}$ is the temperature coefficient of the relative refractive index (K^{-1});
- $\left[\frac{dn}{dT} \right]_{\text{abs}}$ is the temperature coefficient of the absolute refractive index (K^{-1});
- $n_{\text{abs}}(T)$ is the absolute refractive index at the temperature, T , at the location of the specimen;
- $\left[\frac{dn}{dT} \right]_{\text{air}}$ is the temperature coefficient of refractive index of the air (K^{-1}), when the temperature of the measurement location is from 20°C to 40°C .

C.2.4 Correction of the refractive index by using the temperature coefficient

The correction of the refractive index by using the temperature coefficient is calculated using [Formula \(C.4\)](#).

$$n_c = \frac{\sin \frac{\alpha + \delta_{\min}}{2}}{\sin \frac{\alpha}{2}} + \left[\frac{dn}{dT} \right]_{\text{rel}} \times \Delta T \quad (\text{C.4})$$

where

- n_c is the refractive index after correction;
- $\left[\frac{dn}{dT} \right]_{\text{rel}}$ is the temperature coefficient of the relative refractive index (K^{-1});
- ΔT is the difference between setting temperature and the temperature at the measurement location ($^{\circ}\text{C}$);
- α is the apex angle;
- $\delta_{\min}$ is the angle of minimum deviation.

Annex D (informative)

Other measurement methods of the apex angle

D.1 General

The apex angle, α , is obtained as follows.

D.2 Measurement of the apex angle, α , by Auto collimation

A collimated beam of light is used to determine the angle of the specimen prism.

D.2.1 Refraction method

The schematic diagram of the refraction method of measurement is shown in [Figure D.1](#).

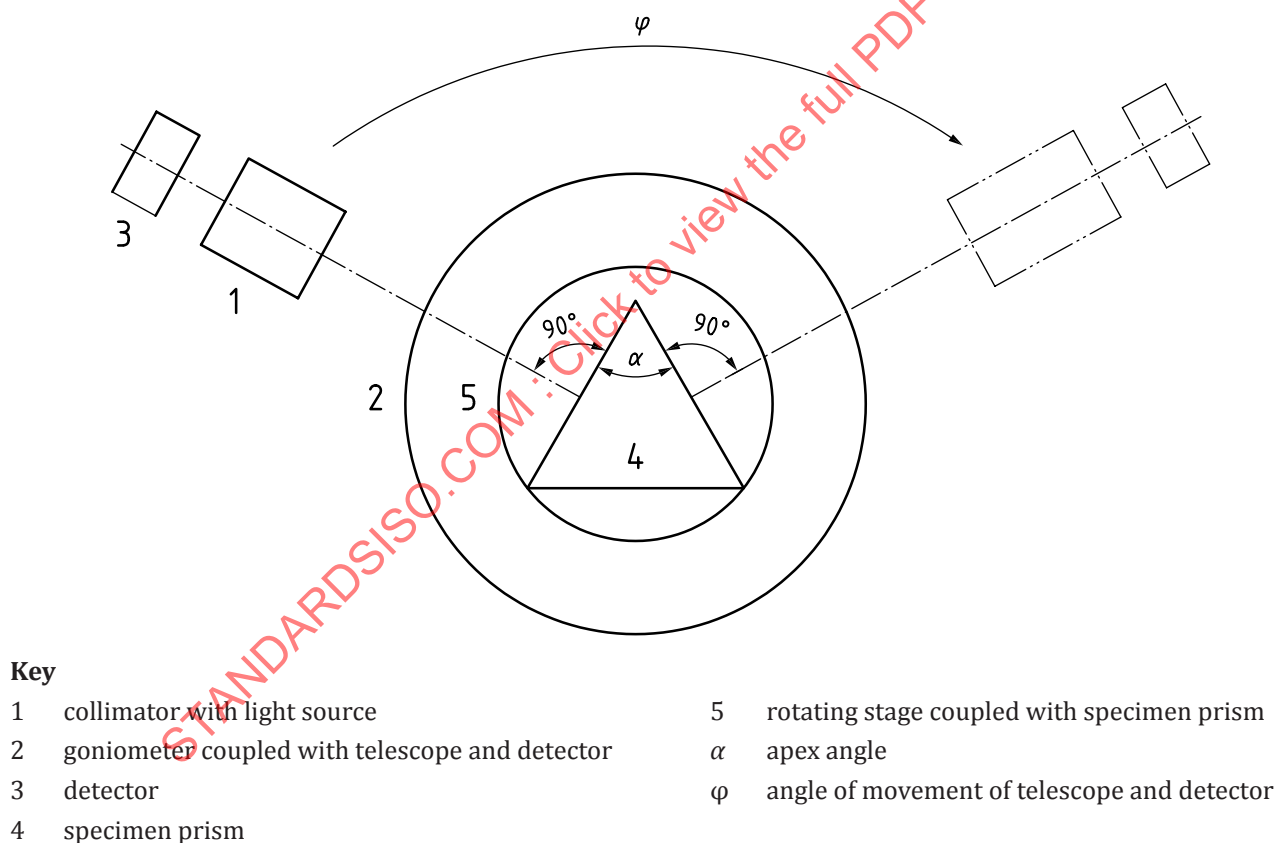


Figure D.1 — Measurement of apex angle by refraction method

The apex angle is calculated using [Formula \(D.1\)](#)

$$\alpha = 180^\circ - \varphi \quad (\text{D.1})$$