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

**Part 2:
V-block refractometer method**

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

Partie 2: Méthode du réfractomètre à blocs en V





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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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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.

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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

This document specifies the method to determine the refractive index of optical glasses with the V-block refractometer. Some explanation of the V-block refractometer can be found in Reference [3]. The refractive index of optical glasses is the most important characteristic for the optical elements manufactured from them.

Regarding the standardization of the method of refractive index measuring method of optical glasses, the minimum deviation method is defined as ISO 21395-1.

The minimum deviation method is most accurate in refractive index measurement but requires an advanced technical skill to prepare a specimen with a precise shape and to measure the refractive index.

In contrast the V-block refractometer method is easier and faster when preparing a specimen and requires less technical skill for measurement. Therefore, this method is commonly used by people checking the quality of the optical glass products on a daily basis.

This document is intended to aid in measuring the refractive index of optical glasses accurately and improving the communications between raw optical glass suppliers and optical element manufacturers as well.

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

Part 2: V-block refractometer method

1 Scope

This document specifies a method to determine the refractive index of optical glass with the accuracy within 3×10^{-5} at the wavelength range from 365 nm to 2 400 nm by using the V-block refractometer method.

While this document can be used for non-glass materials, the user is informed that only optical glass has been considered in the development of this document, and other materials can have issues, which have not been taken into consideration.

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 280, *Essential oils — Determination of refractive index*

ISO 9802, *Raw optical glass — Vocabulary*

ISO 21395-1, *Optics and photonics — Test method for refractive index of optical glasses — Part 1: Minimum deviation method*

ISO 80000-1, *Quantities and units — Part 1: General*

ISO 80000-3, *Quantities and units — Part 3: Space and time*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 9802, ISO 80000-1, ISO 80000-3 and the following apply.

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 <https://www.electropedia.org/>

3.1

V-block prism

prism manufactured from optical glass material with a known refractive index

3.2

refractive index matching liquid

transparent liquid having the refractive index close to that of the specimen

4 Principles

As shown in [Figure 1 a](#)), when a beam aligned perpendicular to the entrance face transmits through the V-block prism, it is refracted at the interface between the V-block prism and the specimen and exits from the exit face nominally parallel to the entrance face. The relationship among the deviation angle of the emergent beam to the incident beam, γ , the relative refractive index of the V-block prism to the measurement atmosphere, N , and the relative refractive index of the specimen to the measurement atmosphere, n , is expressed by the following [Formula \(1\)](#):

$$\gamma = \arcsin \frac{\sqrt{2 \times n^2 - N^2} - \sqrt{3 \times N^2 - 2 \times n^2}}{2} \quad (1)$$

where

- n is the relative refractive index of the specimen to the measurement atmosphere;
- N is the relative refractive index of the V-block prism to the measurement atmosphere;
- γ is the deviation angle.

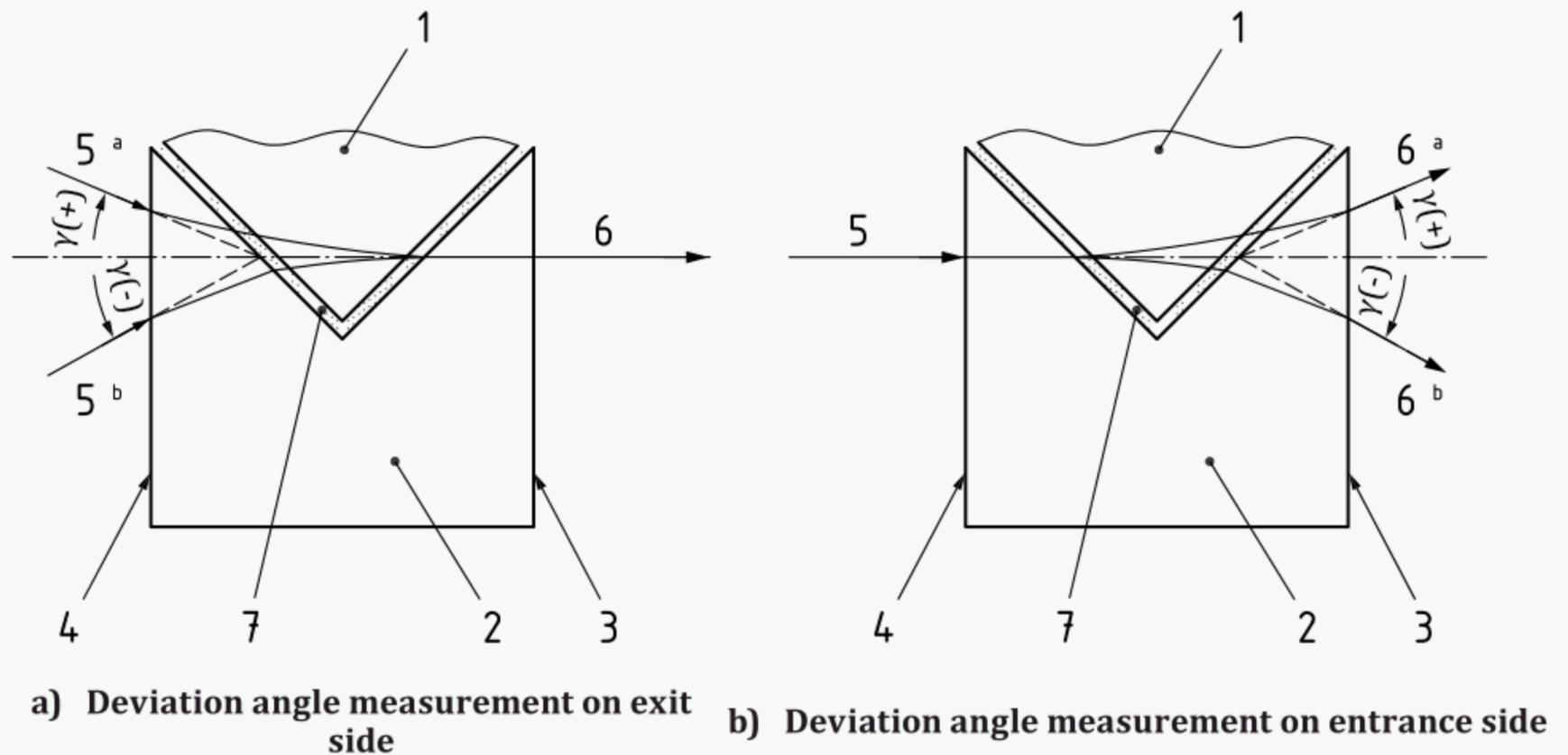
NOTE In general, the symbol of the refractive index is the lowercase n . However, this document intentionally uses the capital letter N for the relative refractive index of the V-block prism to make it more distinct from that of the specimen.

The sign of the deviation angle of the emergent beam shall be positive (+) for upward deviation (that is, $n > N$) and negative (-) for downward deviation ($n < N$) respectively, relative to the incident beam.

Therefore, by measuring γ , n can be obtained by calculation.

This principle is also applicable when the incident beam angle is controlled so that the emergent beam is perpendicular to the exit face of the V-block prism. Therefore, as shown in [Figure 1b](#)), it is also possible to calculate the refractive index based on the measurement result of the deviation angle of the incident beam to the emergent beam.

[7.2.6](#) provides the formula for the calculation of n .

**Key**

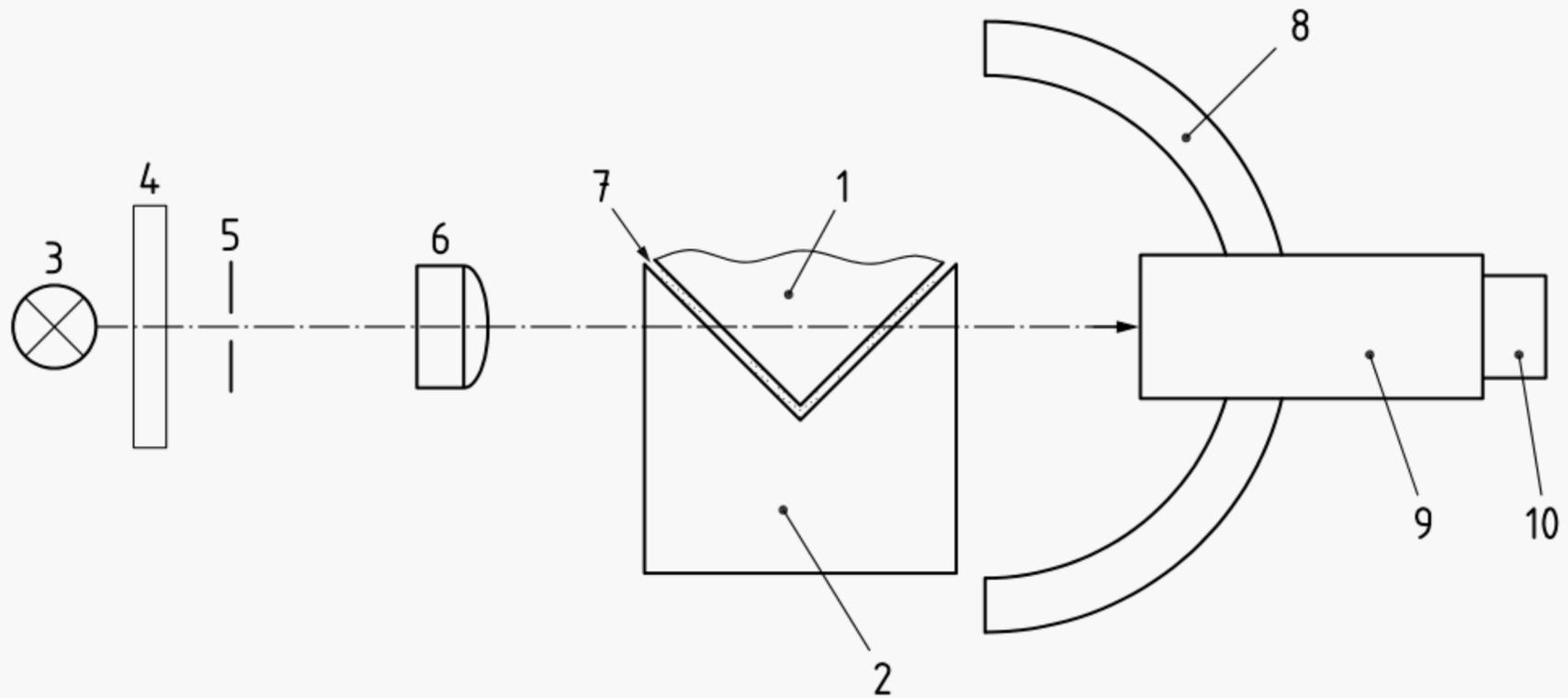
1	specimen (with relative refractive index, n)	6	emergent beam
2	V-block prism (with relative refractive index, N)	7	refractive index matching liquid
3	exit face	γ	deviation angle
4	entrance face	a	$n > N$.
5	incident beam	b	$n < N$.

Figure 1 — Principle of V-block method

In order for [Formula \(1\)](#) to satisfy the required tolerance indicated in [Clause 1](#) (i.e., within 3×10^{-5}), the shape of the V-block prism and the specimen shall be manufactured following to [5.6](#) and [6.1](#), respectively.

5 Measuring equipment**5.1 General**

The measuring equipment is composed of the elements and instruments shown in [Figure 2](#).



- Key**
- 1 specimen or origin point reference block
 - 2 V-block prism
 - 3 light source
 - 4 bandpass filter
 - 5 slit
 - 6 collimator lens
 - 7 refractive index matching liquid
 - 8 deviation-angle measurement device (scale plate)
 - 9 telescope
 - 10 detector (or human eye)

Figure 2 — Outline of V-block measurement equipment

Figure 2 illustrates the configuration in which the direction of the incident beam is fixed as shown in Figure 1 a). When measuring the deviation angle in the case of Figure 1 b), the deviation-angle measurement device (Key 8) shall be attached not to the telescope but to the light source.

The details of the components are described in 5.2 to 5.10.

5.2 Light source

The sources of the spectral/optical radiation should be discharge lamps of mercury, hydrogen, helium, rubidium, caesium or cadmium, or the He-Ne or Nd:YAG laser specified in ISO 7944[1]. The spectral lines shown in Table 1 as the measurement wavelength are used with the bandpass filter of respective wavelength(s). It is necessary to select the light source considering the light transmittance of the V-block prism and the specimen.

It is permissible to use a light source having a wavelength different from those specified in Table 1, or a light source combining a continuous spectral light source and a monochromator/bandpass filter. However, the wavelength deviation due to the finite bandwidth shall be considered when using alternative light sources.

Table 1 — Wavelength and spectral light source

Wavelength nm	Spectral line	Light source
365,01	i	Mercury discharge tube
404,66	h	Mercury discharge tube
435,83	g	Mercury discharge tube
479,99	F'	Cadmium discharge tube

Table 1 (continued)

Wavelength nm	Spectral line	Light source
486,13	F	Hydrogen discharge tube
543,5	-	He-Ne laser
546,07	e	Mercury discharge tube
587,56	d	Helium discharge tube
632,8	-	He-Ne laser
643,85	C'	Cadmium discharge tube
656,27	C	Hydrogen discharge tube
706,52	r	Helium discharge tube
780,00	-	Rubidium discharge tube
852,11	s	Caesium discharge tube
1 013,98	t	Mercury discharge tube
1 064,1	-	Nd:YAG laser
1 128,66	-	Mercury discharge tube
1 395,1	-	Mercury discharge tube
1 529,6	-	Mercury discharge tube
1 813,1	-	Mercury discharge tube

5.3 Bandpass filter

The bandpass filter transmits only the desired wavelength of light by blocking the light of unnecessary wavelengths.

5.4 Slit

The slit adjusts the width of the incident beam.

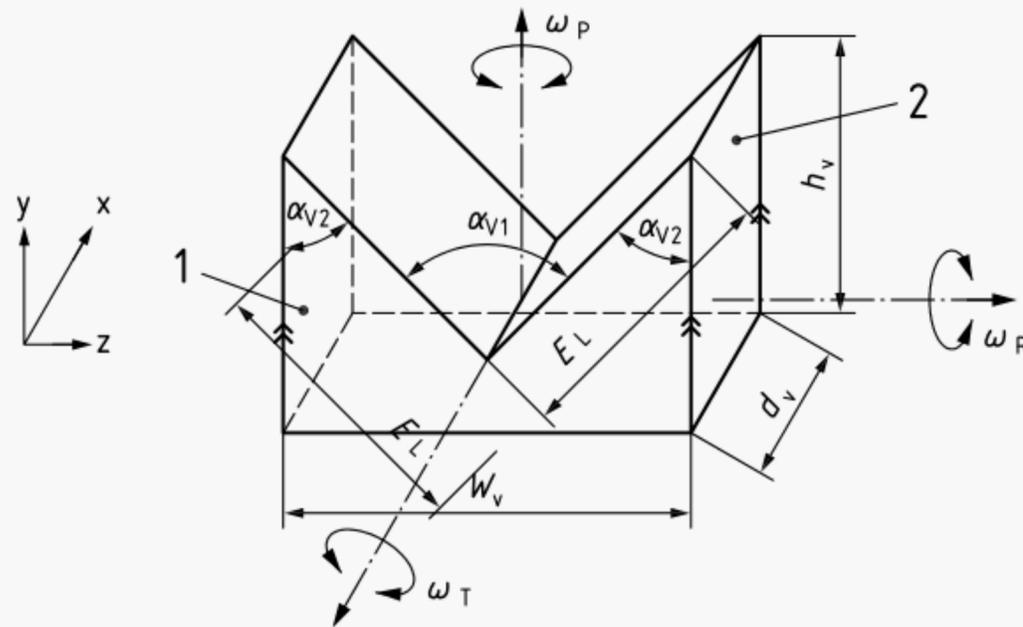
5.5 Collimator lens

The collimator lens changes the divergent beam into a parallel beam.

5.6 V-block prism

The function of the V-block prism on which the specimen is placed is to keep the deviation angle, γ , of the emergent beam relative to the incident beam within a measurable range. The V-block prism shall be manufactured from a glass where the refractive index is known with an accuracy of at least $1,0 \times 10^{-5}$ according to the measurement method of ISO 21395-1. The refractive index of the V-block prism shall be selected so that the deviation angle due to the refractive index difference between the V-block prism and a specimen falls within the range of $\pm 45^\circ$. The shape of the V-block prism is shown in [Figure 3](#).

NOTE In order to guarantee a refractive index value with $1,0 \times 10^{-5}$ units, the measured refractive index requires a value of 6 digits or more after the decimal point.



Key

1	entrance face	h_V	height
2	exit face	W_V	width
α_{V1}	angle of V-shaped faces	ω_R	roll angle
α_{V2}	angle between V-shaped face and entrance or exit face	ω_T	tilt angle
E_L	lateral edge	ω_P	pan angle
d_V	thickness		

Figure 3 — V-block prism

The required accuracies of the V-block prism are as follows:

- a) The angle α_{V1} of V-shaped faces shall be within $90^\circ \pm 5''$. The angles α_{V2} between V-shaped face and entrance or exit face shall be $45^\circ \pm 5''$;
- b) The degree of parallelism between the entrance face and the exit face shall be within $\pm 5''$;
- c) The entrance face, exit face and V-shaped surface shall be polished with the flatness approximately $\lambda/2$ at the measurement wavelength λ ;
- d) The roll angle ω_R concerning the incident beam optical axis on the V-shaped surface shall be within $\pm 20''$.

If it is difficult to obtain such a fine-shaped V-block prism, a method shown in [Annex C](#) can be used, but in that case the calculation of the refractive index of the specimen is more complicated.

5.7 Origin-point reference block

The origin-point reference block is used for setting the deviation-angle reference point (0°) by placing it on the V-shaped face of the V-block prism. The origin-point reference block and the V-block prism shall be manufactured from the same glass lump, and the difference in refractive index between the two shall be within 5×10^{-6} . The shape of the origin point reference block is specified in [6](#).

5.8 Telescope

The telescope captures the emergent beam from the exit surface of the V-block prism and forms an image of the light at the measurement wavelength on the detector. It can be rotated around a rotation axis close to the V-block prism.

It can include an auto-collimation function. [Annex B](#) explains the composition of a telescope with an auto-collimation function.

5.9 Detector

The detector detects the light of the measurement wavelength as an image or a strength signal. Instead of using a detector, the light may be detected by looking into the telescope with the human eye.

5.10 Deviation-angle measuring device

The deviation-angle measuring device measures the deviation angle between the incident and the emergent beam. The resolution of the angle reading on the scale plate shall be smaller than 2".

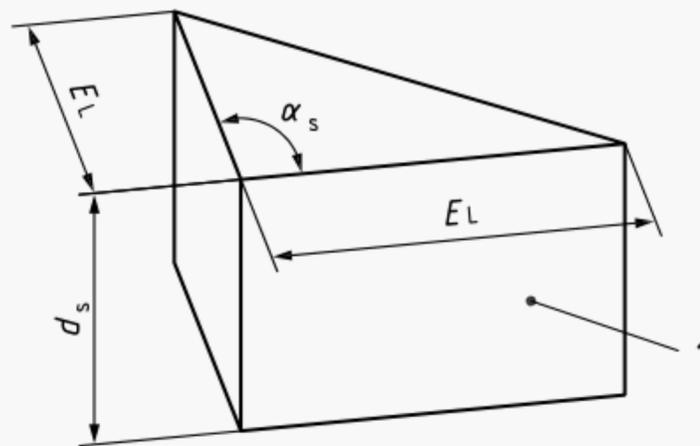
5.11 Refractive index matching liquid

The refractive index matching liquid shall be used to fill the air gaps between the specimen (or origin-point reference block) and the V-block prism. The refractive index value of the matching liquid should be close to that of the specimen. [Annex A](#) provides the information about the selection of appropriate refractive index matching liquid.

6 Shapes of origin-point reference block and specimen

6.1 General

The shape of the origin-point reference block and the specimen are shown in [Figure 4](#).



Key

- 1 contact face with V-block prism
- α_s apex angle
- E_L lateral edge
- d_s thickness

Figure 4 — Origin-point reference and specimen

6.2 Apex angle

The apex angle shall be within $90^\circ \pm 2'$.

6.3 Contact face with V-block prism

The contact face through which the beam is transmitted shall be fine ground and flattened sufficiently.

7 Measurement method

7.1 Measurement environment

7.1.1 Temperature

The ambient air, the V-block prism, the refractive index matching liquid and the specimen shall have a temperature between 20 °C and 25 °C with a fluctuation within $\pm 1,0$ °C. When the refractive index temperature coefficient of the specimen is estimated to be more than $1,0 \times 10^{-5}/\text{K}$ or less than $-1,0 \times 10^{-5}/\text{K}$, the temperature fluctuation should be within $\pm 0,5$ °C in order to measure with high accuracy.

7.1.2 Atmospheric pressure

The atmospheric pressure should be maintained between 86 kPa and 106 kPa and the fluctuation range during the measurement should be within ± 1 kPa.

7.2 Measurement

7.2.1 General

In the following subclauses, the measurement procedure is described when the direction of the incident beam is fixed as shown in [Figure 1 a\)](#) and [Figure 2](#).

Even if the angle of the incident beam is variable as shown in [Figure 1 b\)](#), the procedure is almost the same except that the position of the light source is adjusted instead of the telescope indicated in [Figure 2](#).

7.2.2 Preparation for measurement

Select a V-block with the specification shown in [5.6](#) and install it.

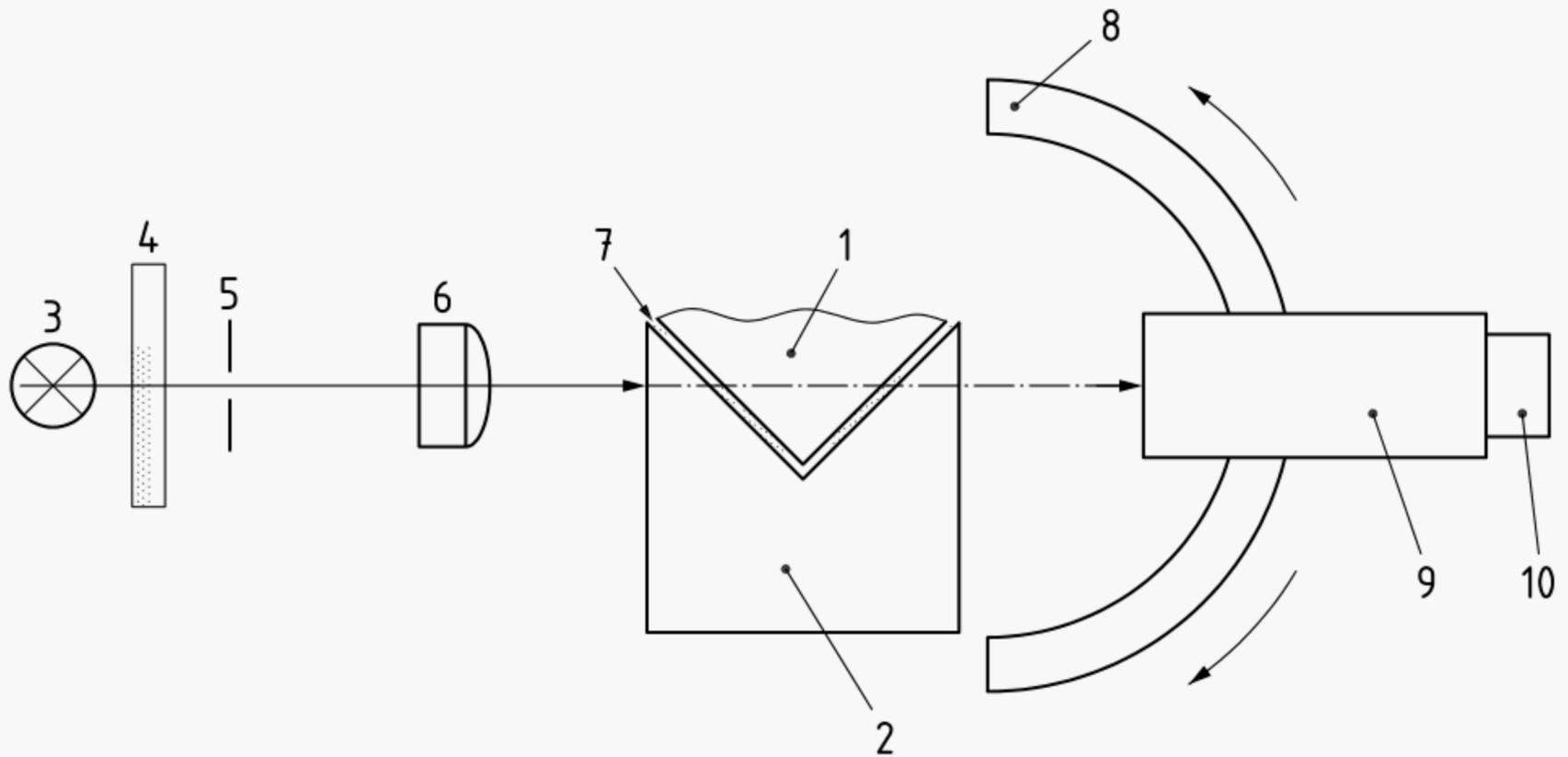
In addition, the material of V-block prism should be selected according to the refractive index of the specimen at the d line (587,56 nm).

7.2.3 Setting of deviation-angle origin point (0°)

Place the origin-point reference block on the V-block prism, filling the air gaps between the specimen and the V-block prism with the appropriate refractive index matching liquid.

Inject the incident beam into the entrance face of the V-block prism, and detect the emergent beam from the exit face of the prism by rotating a telescope with a light detector. Set the angular position when detecting maximum light output as the deviation-angle origin point (0°) for future measurements.

[Figure 5](#) shows an arrangement for setting the deviation-angle origin point.

**Key**

- | | | | |
|---|------------------------------|----|--|
| 1 | origin-point reference block | 6 | collimator lens |
| 2 | V-block prism | 7 | refractive index matching liquid |
| 3 | light source | 8 | deviation-angle measurement device (scale plate) |
| 4 | bandpass filter | 9 | telescope |
| 5 | slit | 10 | detector (or human eye) |

Figure 5 — Schematic diagram of setting the deviation-angle origin point

7.2.4 Adjustment of V-block prism

The V-block shall be adjusted by using an autocollimation method so that the emergent beam is aligned perpendicular to the exit face of the V-block prism. Specifically, the positioning tolerance of pan angle and tilt angle of V-block prism, which are shown in [Figure 3](#) as ω_p and ω_T , shall be within 1' and 4", respectively.

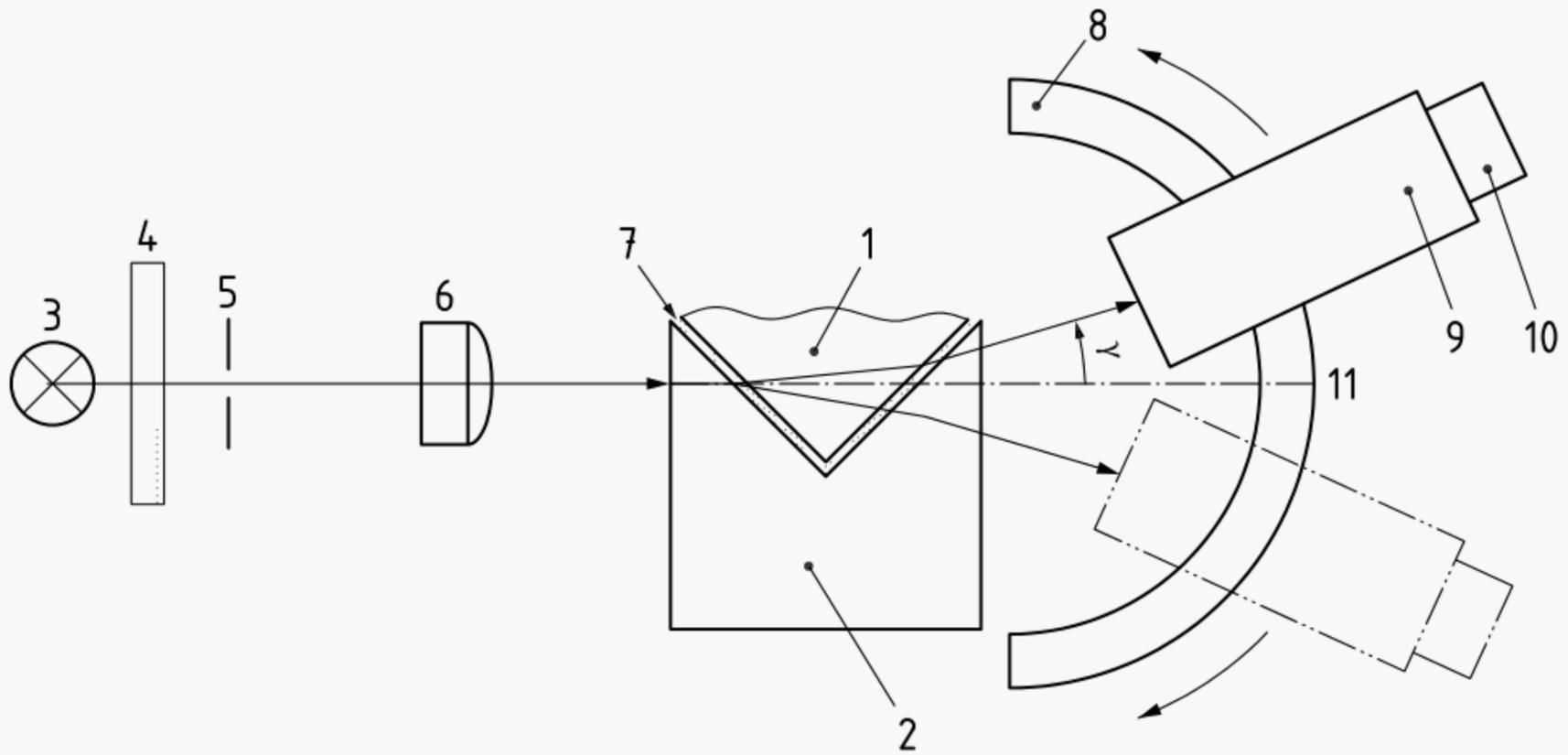
[Annex B](#) provides further details of the telescope with an autocollimation function.

7.2.5 Measurement of deviation angle

[Figure 6](#) shows a schematic diagram for the deviation angle measurement.

Place the specimen on the V-block prism, filling the air gaps between the specimen and the V-block prism with the appropriate refractive index matching liquid.

Inject the incident beam perpendicular to the incident face of the V-block prism and detect the emergent beam from the exit face of the V-block prism by rotating a telescope with a light detector. The difference between the angular position of maximum light output and the previously obtained origin point is the deviation angle for this specimen.



Key	
1	specimen
2	V-block prism
3	light source
4	bandpass filter
5	slit
6	collimator lens
7	refractive index matching liquid
8	deviation-angle measurement device (scale plate)
9	telescope
10	detector (or human eye)
11	deviation-angle origin point
γ	deviation angle

Figure 6 — Schematic diagram of the deviation angle measurement

7.2.6 Calculation of refractive index

Calculate the refractive index by the following [Formula \(2\)](#):

$$n = \sqrt{N^2 + \sin \gamma} \times \sqrt{N^2 - \sin^2 \gamma} \tag{2}$$

where

- n is the relative refractive index of specimen to the measurement atmosphere;
- N is the relative refractive index of V-block prism to the measurement atmosphere;
- γ is the deviation angle.

8 Indication

Indicate the calculated refractive index with five digits or more after the decimal point.

9 Test report

The report shall specify the following:

- a) a reference to this document, i.e. ISO 21395-2:2022;

- b) the method used ([Clause 7](#) or [Annex C](#) or [Annex D](#));
- c) details to identify the specimen;
- d) temperature and atmospheric pressure for which the refractive index value is valid;
- e) measurement wavelength;
- f) refractive index value of the specimen;
- g) deviations from the procedure;
- h) unusual features observed;
- i) date of the test.

Annex A (normative)

Refractive index matching liquid

A.1 General

[Annex A](#) provides the information about the selection of the refractive index matching liquid. A refractive index matching liquid is a transparent liquid having the same, or sufficiently close, refractive index as the specimen. The reference refractive index shall be the refractive index at the Fraunhofer d line. Since the refractive index is measured at multiple wavelengths, it is preferable that the refractive indices are known at multiple wavelengths.

A.2 Refractive index matching liquid

The refractive index matching liquid used shall be a liquid whose refractive index is known in advance, or shall be determined by using the method shown in ISO 280.

[Table A.1](#) provides the examples of general refractive index matching liquids and their refractive index value. The listed liquid may be blended to obtain the desired refractive index.

Table A.1 — General refractive index matching liquids

Name	n_d or n_D at 20 °C
Liquid paraffin	1,47
Cedar oil	1,51
1,1,2,2-tetrabromoethane	1,63
1-bromonaphthalene	1,66
Diiodomethane	1,74
Saturated sulfur solution in diiodomethane	1,78

NOTE n_d of commercially available refractive index matching liquids are commonly in the range of 1,40 to 1,78.

A.3 Selection method of refractive index matching liquid

The apical-angle deviation of the specimen and the difference in refractive index between the specimen and the refractive index matching liquid affect the measurement accuracy of the refractive index determined by the V-block method. In general, the coefficient that shows the effect of these two factors on the measurement accuracy is expressed by the following [Formula \(A.1\)](#):

$$K = \Delta\alpha_s \times \Delta n_{oil} \quad (\text{A.1})$$

where

K is the coefficient which expresses the effect on the measurement accuracy (in arc min);

$\Delta\alpha_s$ is the apex-angle deviation (in arc min) of the specimen;

Δn_{oil} is the absolute value of the difference in refractive index between specimen and refractive index matching liquid.

The relationship between the measurement accuracy ε of the refractive index and the coefficient K is expressed by the following [Formula \(A.2\)](#):

$$\varepsilon = \frac{K}{2000'} \quad (\text{A.2})$$

To measure the refractive index with an accuracy ε of 3×10^{-5} or less, $K \leq 0,06'$ is required. The relationship between $\Delta\alpha_s$ and Δn_{oil} which satisfies $K \leq 0,06'$ is shown in [Table A.2](#).

Table A.2 — Relationship between $\Delta\alpha_s$ and Δn_{oil} to satisfy $K \leq 0,06'$

$\Delta\alpha_s$	Δn_{oil}
2'	0,03 or less
1'	0,06 or less
0,5'	0,12 or less
0,2'	0,3 or less

Therefore, the refractive index matching liquid shall be selected in consideration of the allowable difference in refractive index calculated from the apex angle deviation of the specimen. Specifically, the following two points shall be noted;

- a) When an appropriate refractive index matching liquid cannot be obtained and Δn_{oil} exceeds 0,03, the apex angle deviation of the specimen $\Delta\alpha_s$ shall be smaller than 2', which is specified in [6.2](#), in order to measure the refractive index of the specimen with the accuracy within 3×10^{-5} .
- b) To measure the refractive indices at multiple wavelengths, the selection of an appropriate refractive index matching liquid for each measurement wavelength should be selected because there is a difference between the dispersion characteristics of the specimen and that of the refractive index matching liquid.

However, as an exception, the method shown in [Annex D](#) may be used without considering above two cautions if there is a reference material whose refractive index is known and whose value is close to the specimen.

Since the refractive index of the refractive index matching liquid varies significantly with temperature, the temperature shall be closely monitored.

Annex B (informative)

Telescope with autocollimation function

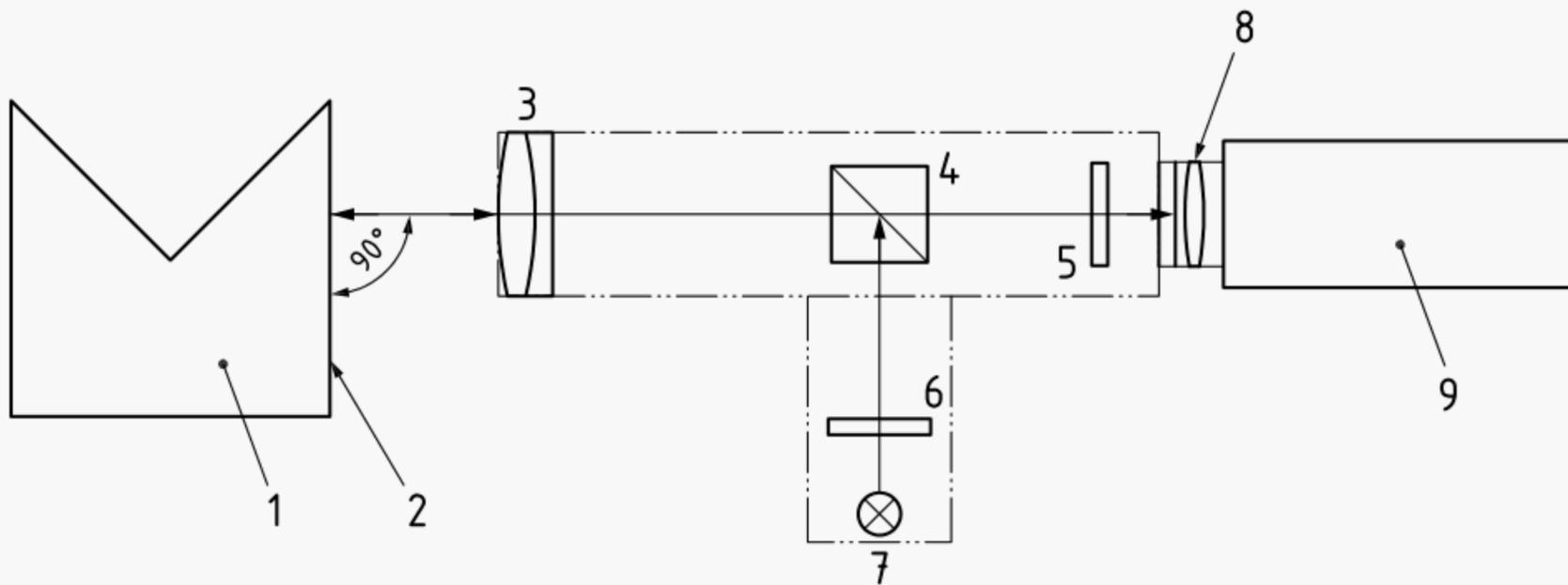
B.1 General

This annex describes a telescope with an autocollimation function. In general, such instrument is used to determine angles for reflecting surfaces. In this standard, it is used to determine the tilt angle ω_{TA} and the pan angle ω_{PA} as described in [Figure 3](#).

B.2 Configuration

[Figure B.1](#) provides an example of a telescope with the autocollimation function in the relationship with the V-block prism.

The telescope deflects the light from the reticle (item 6) to form an image in infinite distance. The beam is reflected by the exit face (item 2) of the V block prism (item 1). The reflected beam is captured by the telescope lens (item 3) to form an image on the detector (item 9). The whole telescope can be rotated around a rotation axis close to the V block prism (item 1).



Key

- | | | | |
|---|--------------------------------|---|----------------------------------|
| 1 | V-block prism | 6 | reticle (or slit) |
| 2 | exit face | 7 | light source for autocollimation |
| 3 | telescope lens | 8 | focusing lens (or eyepiece) |
| 4 | beam splitter (or half mirror) | 9 | detector (or human eye) |
| 5 | reticle | | |

Figure B.1 — Telescope with autocollimation function and the relationship with V-block prism

Annex C (normative)

Alternative measurement

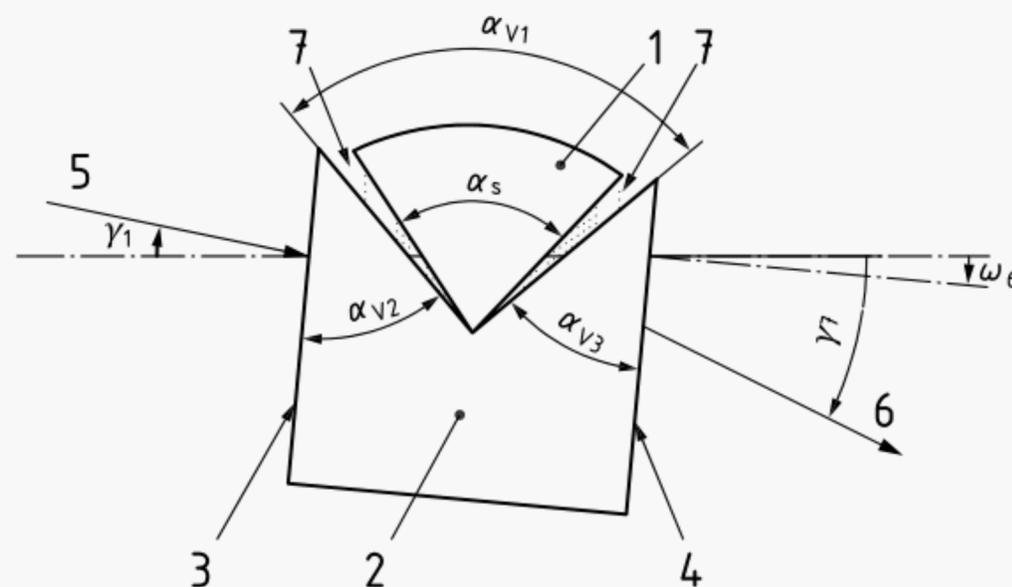
C.1 General

This annex describes a measurement and refractive index calculation method allowing the use of a V-block prism manufactured to lower tolerances, less adjustment effort and avoids the necessity of an origin-point reference block. It requires a more complicated calculation for the resulting refractive index.

This method takes into account the difference of the refractive index matching liquid and inaccuracies in the fabrication of the V-block prism and the specimen. This means that the same refractive index matching liquid can be used through the whole spectrum range 365,01 nm to 2 325,4 nm, removing the restrictions of [A.3](#).

[C.7](#) describes the evaluation procedure considering non-ideal V-block-, specimen- and adjustment angles in detail. The calculation is based on adding/subtracting angles and calculations according to Snell's law of refraction.

C.2 Principle



Key

1	specimen	γ_1	incident beam angle
2	V-block prism	γ_7	emergent beam angle
3	incident face	ω_6	normal angle of the exit face
4	exit face	α_{V1}	angle of V-shaped faces
5	incident beam	α_{V2}	V-block angle, entrance face
6	emergent beam	α_{V3}	V-block angle, exit face
7	refractive index matching liquid	α_s	apex angle of the specimen

Figure C.1 — Measurement principle

Measuring the

— incident angle, γ_1 ,

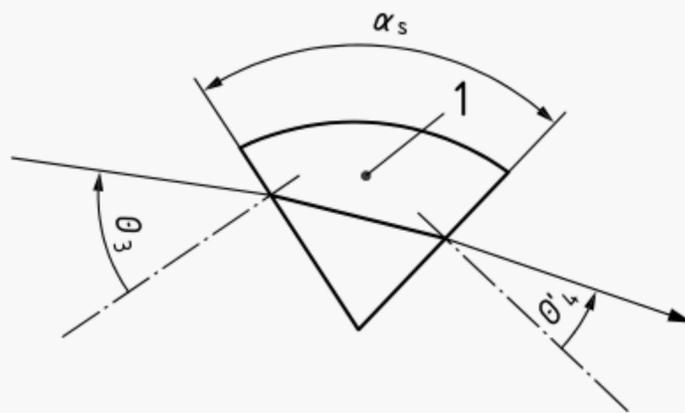
- exit angle, γ_7 ,
 - normal angle of the exit face, ω_6 ,
- and knowing the
- absolute refractive index, N_{abs} , of the V-block prism,
 - absolute refractive index, $n_{\text{abs,oil}}$, of the refractive index matching liquid,
 - refractive index, n_{air} , of the ambient air,
 - angle, α_{V1} , of the V-shaped faces,
 - angle, α_{V2} , of the opposite V-block faces at the incident side,
 - angle, α_{V3} , of the opposite V-block faces at the exit side,
 - apex angle, α_s , of the specimen,

from the prior separated measurement or datasheet, the beam path can be calculated

- forwards from the incident beam to the entrance face of the specimen,
- backwards from the emergent beam to the exit face of the specimen,

thus achieving finally the incident angle θ_3 at the entrance face of the specimen and the emergent beam angle θ'_4 at the exit face of the specimen, shown in [Figure C.2](#).

From the values θ_3 , θ'_4 , α_s and $n_{\text{abs,oil}}$ the refractive index n_{abs} of the specimen can be calculated as described in [C.7](#).



Key

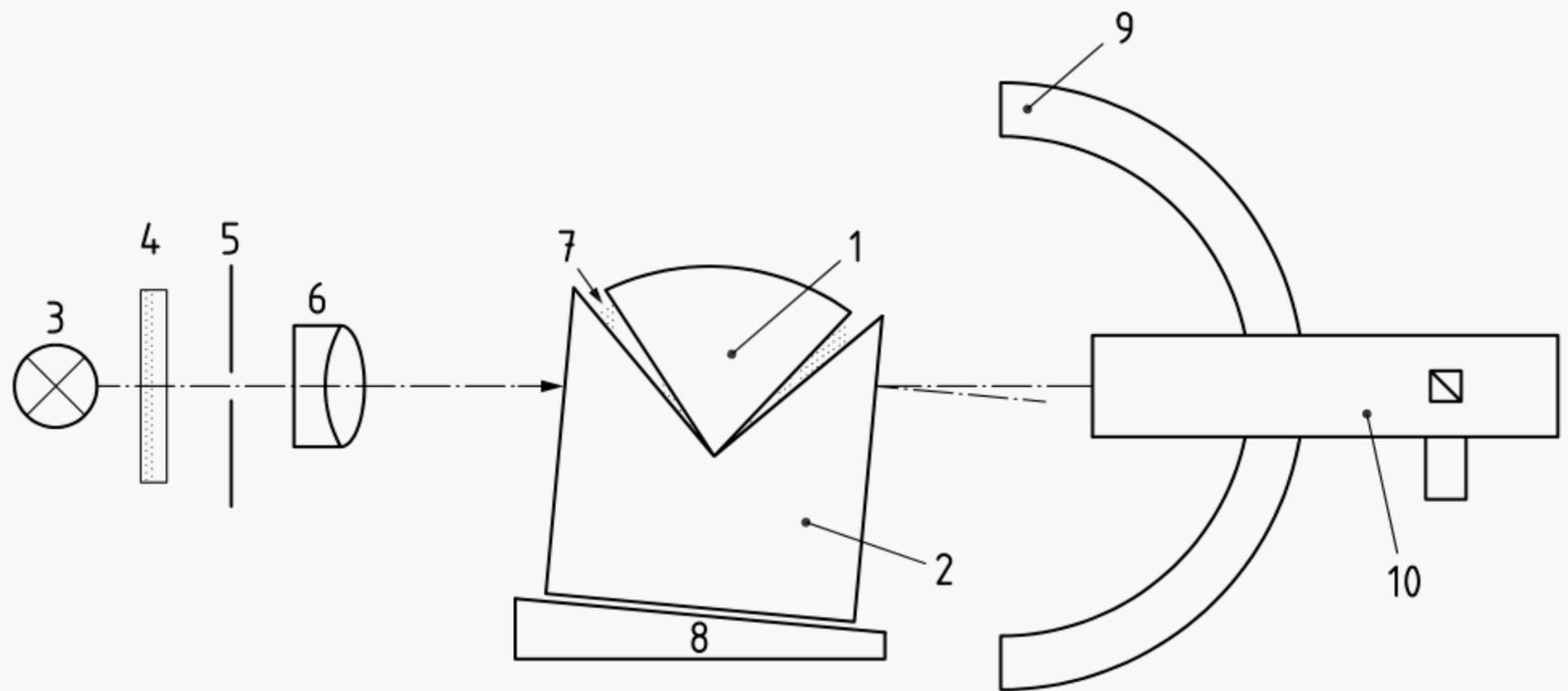
- 1 specimen
- α_s apex angle of the specimen
- θ_3 incident beam angle to the specimen
- θ'_4 emergent beam angle to the specimen

Figure C.2 — Incident and emergent beam angles to the specimen

C.3 Measuring equipment

C.3.1 General

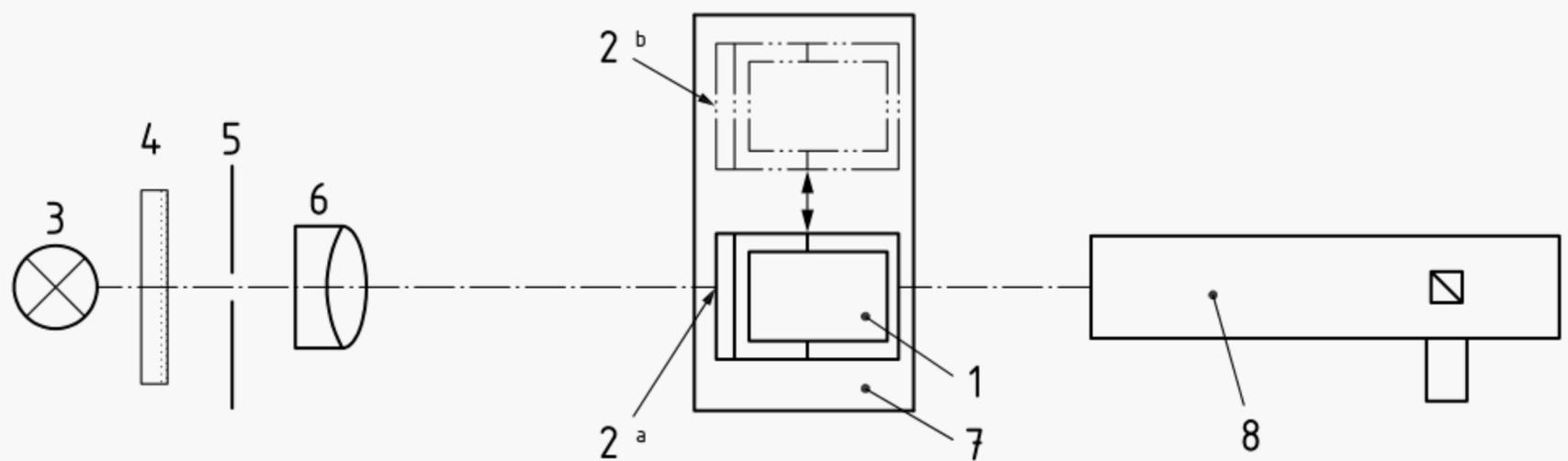
The measurement equipment is very similar to the equipment described in [Clause 5](#), but a translation stage to move the V-block prism in precisely controlled manner is also required. Furthermore, the telescope needs to be equipped with an autocollimation function as described in [Annex B](#).



Key

- | | |
|-------------------|--|
| 1 specimen | 6 collimator lens |
| 2 V-block prism | 7 refractive index matching liquid |
| 3 light source | 8 translation stage |
| 4 bandpass filter | 9 deviation angle measurement device |
| 5 slit | 10 telescope with autocollimation function |

Figure C.3 — Outline of V-block alternative measurement equipment, side view



Key

- | | |
|-------------------|---|
| 1 specimen | 6 collimator lens |
| 2 V-block prism | 7 translation stage |
| 3 light source | 8 telescope with autocollimation function |
| 4 bandpass filter | a In measurement position. |
| 5 slit | b In reference position. |

Figure C.4 — Outline of V-block alternative equipment, top view

C.3.2 Angles between faces

The angles, α_{V1} , α_{V2} and α_{V3} , shown in [Figure C.1](#) shall be known with an accuracy of better than $\pm 1''$.

The angle, α_{V1} , shall be manufactured within $90^\circ \pm 5''$, as described in [5.6](#).

The values of the angles, α_{V2} and α_{V3} , are of low importance as they are considered in the refractive index calculation procedure. It is recommended to manufacture these angles to $45^\circ \pm 5'$.

The degree of parallelism between the entrance face and the exit face is of low importance as the angles, α_{V1} , α_{V2} and α_{V3} , determining this degree of parallelism is considered in the refractive index calculation procedure. It is recommended to manufacture this degree of parallelism to $0^\circ \pm 5'$.

C.3.3 Precision of the translation stage

C.3.3.1 Positioning precision in direction of travel,

The positioning error in direction of travel shall be smaller than 1/10 of the specimen thickness, d_s , as shown in [Figure 4](#). In case a specimen selection slit (see [Figure D.2](#), item 7) is used, the positioning error shall be smaller than 1/10 of the width of the slit.

C.3.3.2 Pan and roll angle

The movement of the translation stage shall not cause a pan angle, ω_p , or roll angle, ω_R , larger than the specifications stated in [5.6](#). The guidance accuracy of the translation stage shall be sufficient to ensure this.

C.3.3.3 Tilt angle

The tilt angle, ω_T , is measured and considered in the evaluation calculation, hence, its absolute value is of lower interest. It is recommended to keep it within $\pm 1^\circ$.

C.4 Shapes of the specimen

The apex angle, α_s , of the specimen and the contact faces to the V-block prism through which the light is transmitted shall be prepared as described in [6.3](#).

C.5 Refractive index matching liquid

The refractive index matching liquid shall be selected according to [Annex A](#).

C.6 Measurement procedure

The measurement procedure is close to the method description in [Clause 7](#). Differences are the insertion of the following steps before the measurement of the deviation angle:

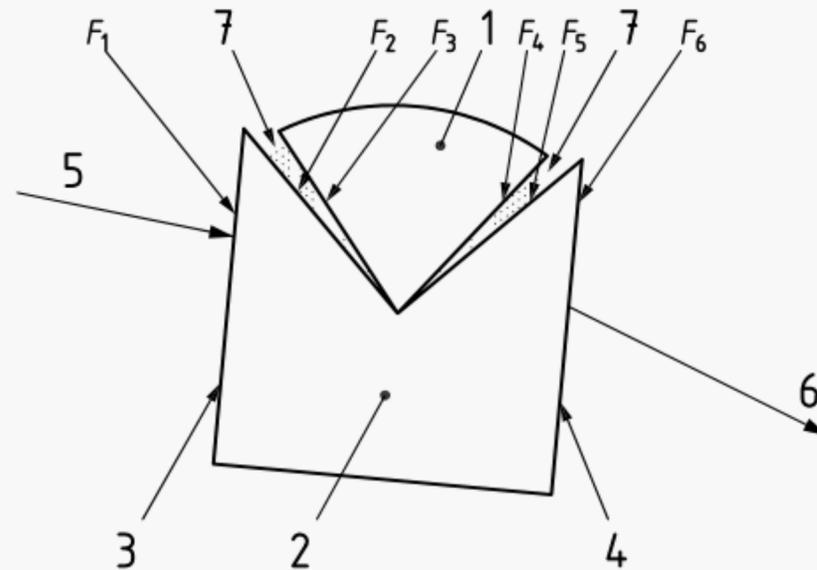
- Move the V-block prism out of the beam path as illustrated in [Figure C.4](#), position 2^b and measure the angle, γ_1 , of the incident beam. Ideally, this angle, γ_1 , is zero. Different from the description in [7.2.2](#), there is no need to adjust the position readout at this point and there is no need to use an origin-point reference.
- After having set the deviation-angle origin point, move the V-block prism back into the beam path as illustrated in [Figure C.4](#), position 2^a.
- Then measure the normal angle ω_6 of the exit face using the autocollimation function of the telescope. Ideally, this angle ω_6 is zero. Different to the description in [7.2.3](#) there is no need to adjust the prism.

Then the measurement continues with determination of the deviation angle γ as described in [7.2.5](#).

C.7 Evaluation

C.7.1 Face numeration

To write down the necessary formulae in a useful manner, the optically relevant faces are numbered starting with F_1 at the entrance face of the V-block prism to F_6 at the exit face of the V-block prism as shown in [Figure C.5](#).



Key

1	specimen	5	incident beam
2	V-block prism	6	emergent beam
3	entrance face	7	refractive index matching liquid
4	exit face	F_1 to F_6	optically relevant faces

Figure C.5 — Face numbers

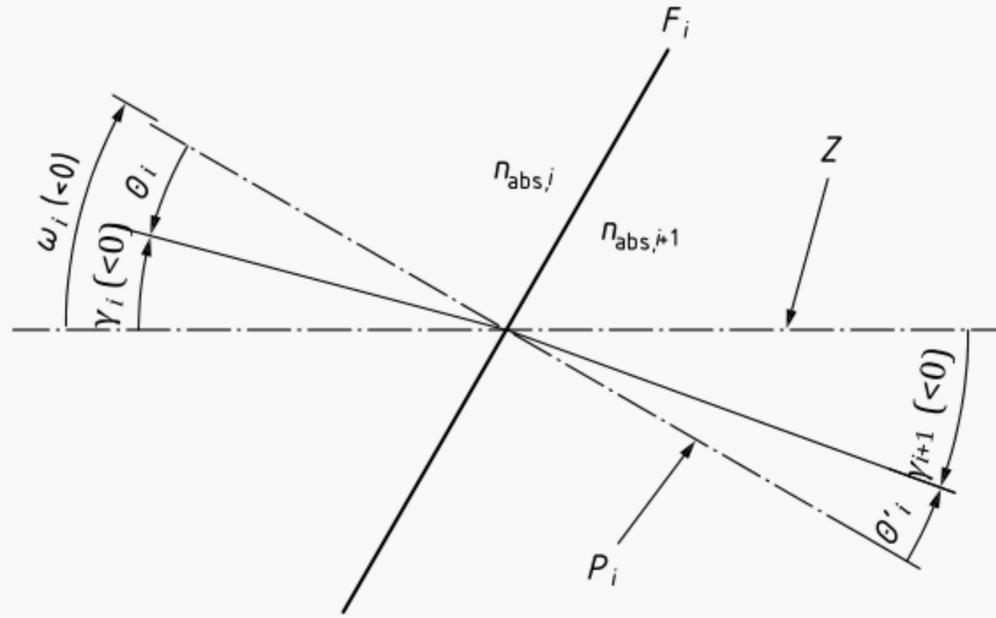
C.7.2 Angle and refractive index definitions

Related to each face F_i ($i = 1$ to 6), there is

- a tilt angle, ω_i , from the system axis to the line normal to F_i ,
- a deviation angle, γ_i , from the system axis to the incident beam,
- an incident angle, θ_i , from the face normal to the incident beam,
- a refractive index, n_i , at the incident side of the face,
- an exit angle, θ'_i , from the face normal to the emergent beam.

All angles are positive if counter clockwise and negative if clockwise, as illustrated in [Figure C.6](#).

The refractive index and the deviation angle at the exit side are related to the next face, hence bearing the index " $i + 1$ " in [Figure C.6](#).



Key

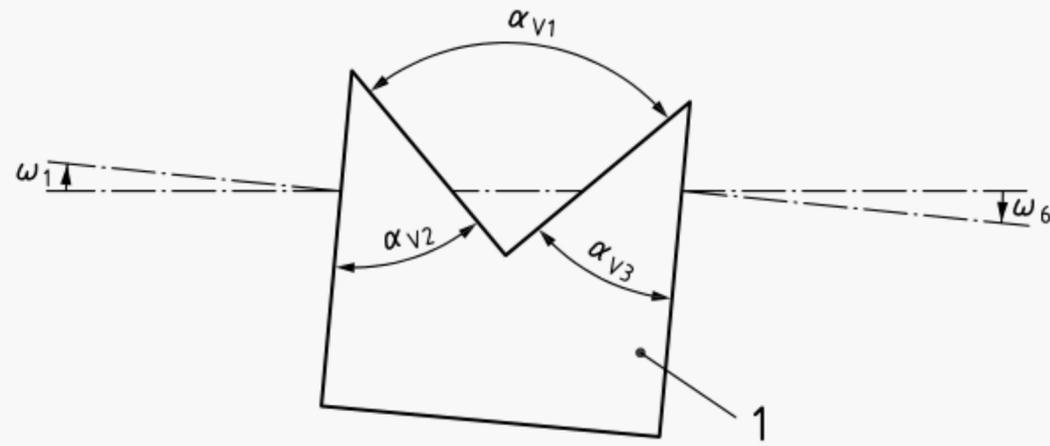
- | | | | |
|-------------|--|----------------|--|
| Z | system axis | F_i | i -th optically relevant face |
| P_i | line normal to F_i | ω_i | tilt angle of F_i |
| $n_{abs,i}$ | absolute refractive index at incident side of the face | $n_{abs,i+1}$ | absolute refractive index at exit side of the face |
| γ_i | beam deviation at incident side of the face F_i | γ_{i+1} | beam deviation at exit side of the face F_i |
| θ_i | incident angle as to Snell's law | θ'_i | exit angle as to Snell's law |

Figure C.6 — Angle and refractive index definitions

Table C.1 — Default, ideal values

i	medium at incident side	$n_{abs,i}$	ω_i (ideal)	γ_i (ideal)
1	atmosphere (air)	n_{air}	0°	0°
2	V-block prism	N_{abs} (V-block prism)	$+45^\circ$	0°
3	refractive index matching liquid	$n_{abs,oil}$	$+45^\circ$	-
4	specimen	n_{abs} (specimen)	-45°	-
5	refractive index matching liquid	$n_{abs,oil}$	-45°	-
6	V-block prism	N_{abs} (V-block prism)	0°	-
7	atmosphere (air) (no face defined)	n_{air}	-	-

C.7.3 Calculation of V-block prism face tilt angles $\omega_1, \omega_2, \omega_5, \omega_6$

**Key**

- 1 V-block prism
- ω_1 tilt angle of F_1 (entrance face of V-block prism)
- ω_6 tilt angle of F_6 (exit face of V-block prism)
- α_{V1} angle of V-shaped faces
- α_{V2} angle between V-shaped face and entrance face
- α_{V3} angle between V-shaped face and exit face

Figure C.7 — Angles at V-block prism

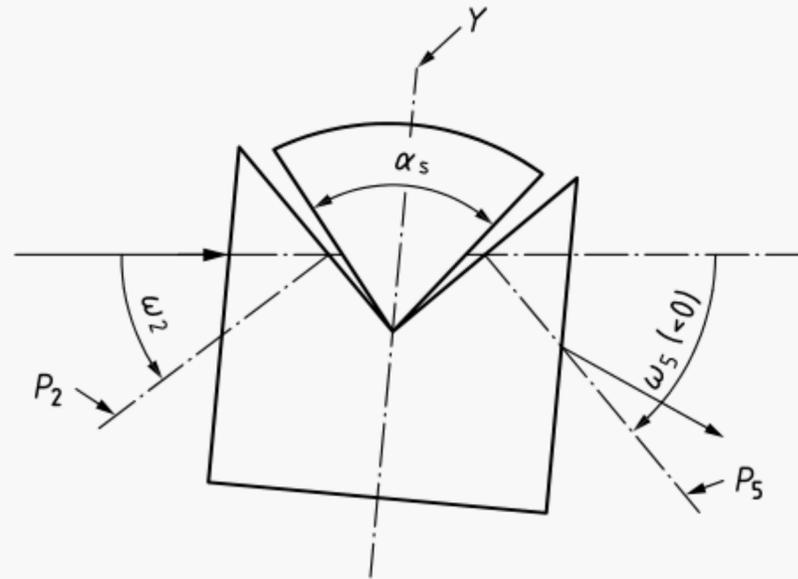
From the measured tilt angle ε_6 the tilt angles of the V-block faces can be calculated using [Formulae \(C.1\) to \(C.3\)](#). The angles α_{V1} , α_{V2} , and α_{V3} are always positive, ideal $\alpha_{V1} = 90^\circ$, $\alpha_{V2} = \alpha_{V3} = 45^\circ$.

$$\omega_5 = \omega_6 - \alpha_{V3} \quad (\text{C.1})$$

$$\omega_2 = \omega_5 - \alpha_{V1} \quad (\text{C.2})$$

$$\omega_1 = \omega_2 - \alpha_{V2} \quad (\text{C.3})$$

C.7.4 Calculation of specimen face tilt angles, ω_3 and ω_4



Key

- Y angle bisecting line of α_s , equal to angle bisecting line of α_{v1}
- P_2 line normal to face F_2 ("inner" face of V-block prism, entrance face side)
- P_5 line normal to face F_5 ("inner" face of V-block prism, exit face side)
- ω_2 tilt angle of face F_2 ("inner" face of V-block prism, entrance face side)
- ω_5 tilt angle of face F_5 ("inner" face of V-block prism, exit face side)
- α_s apex angle of the specimen

Figure C.8 — For clarification of angle calculation at specimen

For calculation of the specimen face tilt angles, it is assumed that the specimen is symmetrically inserted into the V-block prism, i.e. the angle bisecting line of the apex angle α_s of the specimen is equal to the angle bisecting line of the angle α_{v1} of the V-shaped faces of the V-block prism as illustrated in [Figure C.7](#). With this assumption, the tilt angles ε_3 and ε_4 of the specimen faces can be calculated using the [Formulae \(C.4\)](#) and [\(C.5\)](#). The apical angle α_s of the specimen is always positive, ideal 90°.

$$\omega_3 = \frac{\omega_2 + \omega_5}{2} + \frac{\alpha_s}{2} \tag{C.4}$$

$$\omega_4 = \frac{\omega_2 + \omega_5}{2} - \frac{\alpha_s}{2} \tag{C.5}$$

C.7.5 Calculation of θ_1 to θ_3 and θ'_6 to θ'_4

Using the tilt angles gained as to [C.7.3](#) and [C.7.4](#), and the measured deviation angles, γ_1 and γ_7 , the angles along the beam path can be calculated using [Formulae \(C.6\)](#) to [\(C.19\)](#). The figures of interest in this clause are the incident angle, θ_3 , and the exit angle, θ'_4 , at the specimen.

$$\theta_1 = \gamma_1 - \omega_1 \tag{C.6}$$

$$\theta'_1 = \arcsin\left(\frac{n_{abs,1}}{n_{abs,2}} \times \sin\theta_1\right) \tag{C.7}$$

$$\gamma_2 = \theta'_1 + \omega_1 \tag{C.8}$$

$$\theta_2 = \gamma_2 - \omega_2 \tag{C.9}$$

$$\theta'_2 = \arcsin\left(\frac{n_{\text{abs},2}}{n_{\text{abs},3}} \times \sin\theta_2\right) \quad (\text{C.10})$$

$$\gamma_3 = \theta'_2 + \omega_2 \quad (\text{C.11})$$

$$\theta_3 = \gamma_3 - \omega_3 \quad (\text{C.12})$$

$$\theta'_6 = \gamma_7 - \omega_6 \quad (\text{C.13})$$

$$\theta_6 = \arcsin\left(\frac{n_{\text{abs},7}}{n_{\text{abs},6}} \times \sin\theta'_6\right) \quad (\text{C.14})$$

$$\gamma_6 = \theta_6 + \omega_6 \quad (\text{C.15})$$

$$\theta'_5 = \gamma_6 - \omega_5 \quad (\text{C.16})$$

$$\theta_5 = \arcsin\left(\frac{n_{\text{abs},6}}{n_{\text{abs},5}} \times \sin\theta'_5\right) \quad (\text{C.17})$$

$$\gamma_5 = \theta_5 + \omega_5 \quad (\text{C.18})$$

$$\theta'_4 = \gamma_5 - \omega_4 \quad (\text{C.19})$$

C.7.6 Calculation of the refractive index n of the specimen

With the results for θ_3 and θ'_4 from [C.7.5](#), the refractive index, n , of the specimen can be calculated using [Formulae \(C.20\)](#), [\(C.21\)](#) and [\(C.22\)](#).

$$\theta_4 = \arctan\left(\frac{-n_{\text{abs},5} \times \sin\theta'_4 \times \sin\alpha_s}{n_{\text{abs},3} \times \sin\theta_3 - n_{\text{abs},5} \times \sin\theta'_4 \times \cos\alpha_s}\right) \quad (\text{C.20})$$

$$n_{\text{abs}} = n_{\text{abs},4} = \frac{n_{\text{abs},5} \times \sin\theta'_4}{\sin\theta_4} \quad (\text{C.21})$$

$$n = \frac{n_{\text{abs}}}{n_{\text{air}}} \quad (\text{C.22})$$

Annex D (normative)

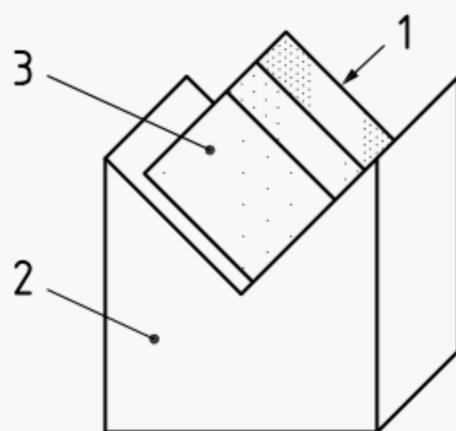
Measurement with reference specimen

D.1 General

This annex describes a measurement method especially for high refractive index glass types where adapted refractive index matching liquids are not available and/or toxic and/or not durable.

D.2 Principle

A reference specimen of well-known refractive index is glued together with the specimen to be measured thus forming a specimen-stack. This stack is cut and ground to form a specimen as described in [Clause 6](#). Different to the description in [Clause 6](#) is that the contact faces (see [Figure 4](#), item 1) are polished.



Key

- 1 specimen to be measured
- 2 V-block prism
- 3 reference specimen

Figure D.1 — V-block prism with specimen and reference specimen

When the refractive index value of the reference specimen is close to the specimen to be measured, the measurement errors of two specimens can be regarded as the same.

Hence, the refractive index, n , of the specimen to be measured can be calculated using [Formula \(D.1\)](#).

$$n = n_M + (n_R - n_{R,M}) \quad (D.1)$$

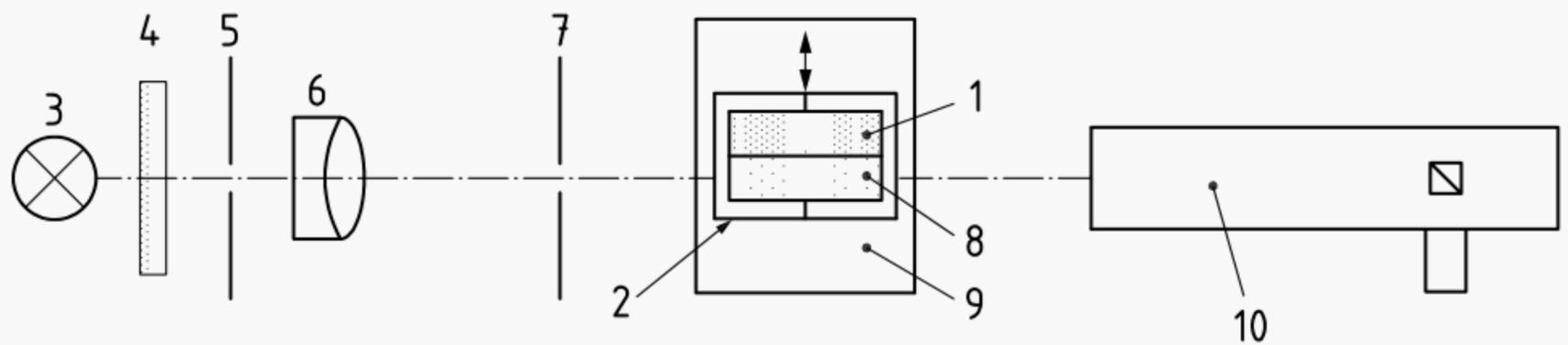
where

- n refractive index of the specimen
- n_M measured refractive index of the specimen
- n_R refractive index of the reference specimen
- $n_{R,M}$ measured refractive index of the reference specimen

D.3 Measuring equipment

D.3.1 General

The measurement equipment is very similar to the equipment described in [Clause 5](#). A translation stage to move the V-block prism in precisely controlled manner as described in [C.3.1](#) should be used. Additionally, a specimen selection slit in the incident beam is necessary to make sure that the incident beam hits only one of the specimens, either the reference specimen or the specimen to be measured. [Figure D.2](#) shows the principal outline of such measurement equipment.



Key

1	specimen to be measured	6	collimator lens
2	V-block prism in reference position	7	specimen selection slit
3	light source	8	reference specimen
4	bandpass filter	9	translation stage
5	slit	10	telescope with autocollimation function

Figure D.2 — Outline of V-block equipment, V-block prism in position to measure the reference specimen

D.3.2 Reference specimen

The refractive index, $n_{R,M}$, of the reference specimen must be known with substantially higher accuracy than the desired accuracy for the refractive index, n , of the specimen to be measured. Furthermore, the refractive index, n_R , of the reference specimen shall be close to the refractive index n of the specimen S to measure. The difference, $|n - n_R|$, shall not exceed 1×10^{-3} .

D.4 Measurement procedure

The measurement procedure is close to the method description in [Clause 7](#) respectively in [Annex C](#). Important is to measure the two specimens (reference specimen and specimen to measure) sequentially without removing the specimen stack from the V-block prism or to adjust or realign anything after measurement of the first and before measurement of the second specimen.

Bibliography

- [1] ISO 7944, *Optics and optical instruments — Reference wavelengths*
- [2] ISO 8486-2, *Bonded abrasives — Determination and designation of grain size distribution — Part 2: Microgrits F230 to F2000*
- [3] SIMMONS J., POTTER K. *Optical Materials*, Academic Press, 2000, pp. 136-137

