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**Eye and face protection — Test  
methods —**

**Part 2:  
Physical optical properties**

*Protection des yeux et du visage — Méthodes d'essai —  
Partie 2: Propriétés optiques physiques*

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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.

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](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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](http://www.iso.org/iso/foreword.html).

This document was prepared by Technical Committee ISO/TC 94, *Personal safety — Protective protective equipment*, Subcommittee SC 6, *Eye and face protection*.

This first edition of ISO 18526-2, together with ISO 18526-1, cancels and replaces ISO 4854:1981.

A list of all parts in the ISO 18526 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](http://www.iso.org/members.html).

## Introduction

This family of documents comprised of the ISO 16321 series, the ISO 18526 series and the ISO 18527 series was developed in response to the worldwide stakeholders' demand for minimum requirements and test methods for eye and face protectors traded internationally. ISO 4007 gives the terms and definitions for all the various product types. The test methods are given in the ISO 18526 series, while the requirements for occupational eye and face protectors are given in the ISO 16321 series. Eye protectors for specific sports are mostly dealt with by the ISO 18527 series. A guidance document, ISO 19734, for the selection, use and maintenance of eye and face protectors is under preparation.

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# Eye and face protection — Test methods —

## Part 2: Physical optical properties

### 1 Scope

This document specifies the reference test methods for determining the physical optical properties of personal eye and face protectors.

This document does not apply to any eye and face protection products for which the requirements standard(s) specifies other test methods.

Other test methods can be used provided they have been shown to be equivalent and include uncertainties of measurement no greater than those required of the reference method.

### 2 Normative references

The following documents are referred to 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 4007, *Personal protective equipment — Eye and face protection — Vocabulary*

ISO/CIE 11664-1, *Colorimetry — Part 1: CIE standard colorimetric observers*

ISO 11664-2, *Colorimetry — Part 2: CIE standard illuminants*

CIE 15:2019, *Colorimetry*

CIE S 017, *International lighting vocabulary*

### 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4007 and CIE S 017 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 <http://www.electropedia.org/>

### 4 Preparatory information

Before testing, refer to the appropriate product's requirements standard for the information needed to apply the tests in this document, for example:

- the number of test samples<sup>1)</sup>;
- preparation of test samples;

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1) For the purpose of this document, “test sample” is taken to be the object under test, e.g. “ocular”, “lens”, “filter”, or “complete protector” as specified in the requirements standard.

- the selection of test samples (if included in this document);
- any prior conditioning or testing;
- test method (if more than one is included in this document);
- any deviations from the method(s);
- characteristics to be assessed subjectively (if appropriate);
- pass/ fail criteria.

## 5 General test requirements

Unless otherwise specified, the values stated in this document are expressed as nominal values. Except for temperature limits, values that are not stated as maxima or minima should be subject to a tolerance of  $\pm 5$  %.

Unless otherwise specified, the ambient temperature for testing should be between 16 °C and 32 °C but if any temperature limits are specified, these should be subject to an accuracy of  $\pm 2$  °C. Relative humidity should be maintained at  $(50 \pm 20)$  %.

Unless otherwise specified, the test samples shall be tested at the reference points (for testing) as defined in ISO 4007.

The tests shall be done by trained observers.

For each of the required measurements performed in accordance with this document, a corresponding estimate of the uncertainty of measurement shall be evaluated according to [Annex A](#).

## 6 Test methods for measuring transmittance — General

### 6.1 Uncertainty of measurement

Unless otherwise indicated, the measures calculated from spectral transmittance or optical density and the broadband measures of transmittance or optical density shall have uncertainties less than or equal to those given in [Table 1](#).

**Table 1 — Uncertainty of measured spectral transmittance and optical density**

| Spectral transmittance value |             | Relative uncertainty<br>% | Spectral optical density |                     | Absolute uncertainty |
|------------------------------|-------------|---------------------------|--------------------------|---------------------|----------------------|
| less than %                  | to %        |                           | from                     | $T$<br>to less than |                      |
| 100                          | 17,8        | $\pm 5$                   | 0,0                      | 0,7                 | $\pm 0,02$           |
| 17,8                         | 0,44        | $\pm 10$                  | 0,7                      | 2,4                 | $\pm 0,05$           |
| 0,44                         | 0,023       | $\pm 15$                  | 2,4                      | 3,6                 | $\pm 0,07$           |
| 0,023                        | 0,001 2     | $\pm 20$                  | 3,6                      | 4,9                 | $\pm 0,10$           |
| 0,001 2                      | 0,000 023   | $\pm 30$                  | 4,9                      | 6,6                 | $\pm 0,15$           |
| 0,000 023                    | 0,000 001 2 | $\pm 40$                  | 6,6                      | 7,9                 | $\pm 0,22$           |
| 0,000 001 2                  |             | $\pm 50$                  | 7,9                      |                     | $\pm 0,30$           |

The application of uncertainty to compliance is set out in [Annex A](#).

The general methods of evaluating the components of uncertainty are set out in ISO/IEC Guide 98-3. [Annex B](#) is a guidance to the sources of uncertainty in spectrophotometry, their evaluation and minimization.

## 6.2 Reporting compliance

Any compliance statement based on values reported from these test methods shall take into account the uncertainty of measurement as set out in [Annex A](#).

## 6.3 Applicability

The spectrophotometric method applies to measurement of transmittance regardless of the test sample tested, e.g. filters and frames. Assessment of the uncertainty of measurement shall, if necessary, include the consequences of non-parallel surfaced test samples. [Annex C](#) gives the various formulae for calculating UV, luminous and IR transmittances from spectral values in summation form; otherwise, these are the same formulae as in ISO 4007.

## 6.4 Position and direction of measurement

The location and direction of measurement of transmittance shall be as specified in the relevant product requirement standard. If the measurements are not made normal to the surface of the test sample, then particular attention should be paid to the effects of beam displacement, see [Annex B](#). If the direction of measurement is not specified, then it shall be measured normal to the surface of the test sample at the geometrical centre.

Unless otherwise stated, transmittance is measured as direct transmittance (diffuse component excluded).

The test beam shall be incident normally on the surface and any divergence or convergence of the beam shall not result in an uncertainty of measurement exceeding those in [Table 1](#).

## 6.5 Wavelength intervals

Spectral measurements and calculations shall be carried out at not more than 5 nm intervals ( $\Delta\lambda = 5 \text{ nm}$ ) in the ultraviolet and visible region (180 nm to 780 nm) and not more than 10 nm intervals in the infrared region (780 nm to 3 000 nm). The necessary data for calculations at these intervals are provided in [Annex D](#). If smaller intervals are used then linear interpolation of the [Annex D](#) data is appropriate.

## 6.6 Test report

The spectral transmittances and the associated uncertainties of measurement shall be reported as required in the standard referencing this test method.

# 7 Luminous transmittance

## 7.1 Calculations of luminous transmittance from spectral values

Luminous transmittance is calculated as a percentage from the spectral transmittances determined hereafter and with reference to a standard observer and a source or illuminant. For the purposes of this document, all calculations use the CIE 2° standard observer (ISO/CIE 11664-1) and CIE standard illuminant A and/or CIE standard illuminant D65 (ISO 11664-2) and/or a Planckian radiator of distribution temperature 1 900 K. See ISO 4007:2018, 3.10.1.32 and, in this document, [C.3.1](#) and [Tables D.2](#) to [D.4](#).

## 7.2 Test report

The luminous transmittance(s), the applicable illuminant(s) and/or source(s) and the associated uncertainty of measurement shall be reported as required in the standard(s) referencing these methods.

## 7.3 Broadband method of measurement of luminous transmittance

### 7.3.1 Apparatus

The luminous transmittance is measured by using a test apparatus consisting of a light source and a photodetector. The light source shall be a broadband collimated light source with approximately the spectral distribution of a CIE standard illuminant in accordance with ISO 11664-2 in the spectral range 380 nm to 780 nm or other source as specified in the standard referencing this test method. The photodetector shall have a spectral response corresponding to CIE 2° standard observer in accordance with ISO/CIE 11664-1. The photodetector shall be mounted normal to the beam of illumination.

### 7.3.2 Calibration

The broadband method shall be calibrated by comparison with filters for which the luminous transmittances are known with uncertainties of measurement sufficiently small as to enable the applicable requirement of [Table 1](#) to be met by the test method. The maximum difference in shade number between the test sample and the nearest reference filter shall ensure compliance with [Table 1](#).

### 7.3.3 Procedure

The luminous transmittance is measured as the ratio of the luminous flux transmitted by the test sample to the incident luminous flux measured with no test sample in the light beam.

If the direction of measurement is not specified, measurement shall be with incident radiation normal to the surface of the test sample. If the position of measurement is not specified, the boxed or geometric centre of the test sample shall be used.

### 7.3.4 Test reports for luminous transmittance values

The luminous transmittance(s), the applicable source (CIE standard illuminant A or D65 or other source) and the associated uncertainty of measurement shall be reported as required in the standard referencing this test method.

## 7.4 Measurement of uniformity of luminous transmittance

### 7.4.1 Unmounted filter covering one eye

#### 7.4.1.1 Test method

Locate the reference point defined in ISO 4007:2018, 3.8.8. Determine a circular area centred on the reference point with diameter  $d$  calculated as follows, (see [Figure 1](#)):

- for test samples equal to or greater than 50 mm in the vertical dimension at the reference point,  $d = (40,0 \pm 0,5)$  mm;
- for test samples less than 50 mm in the vertical dimension at the reference point,  $d = [(h - 10) \pm 0,5]$  mm where  $h$  is the vertical depth of test sample.

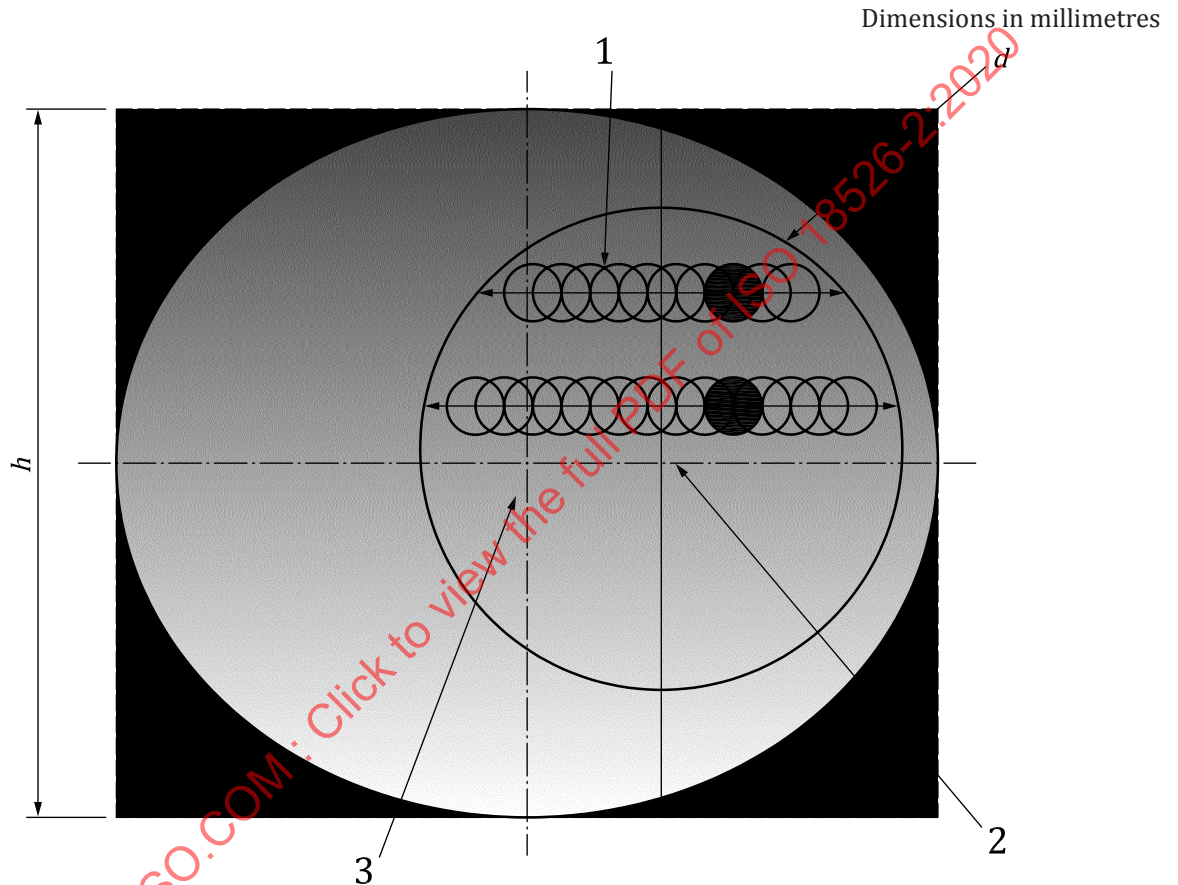
If a 5 mm wide portion around the edge of the test sample intrudes into this circular area, then this intrusion shall be excluded from testing.

Scan this circular area with beam of light of 5 mm nominal diameter incident normally on the surface of the test sample. Use either white light and a photodetector whose spectral responsivity approximates that of the CIE 2° standard colorimetric observer (ISO/CIE 11664-1) or use a narrow spectral band of light with a maximum spectral energy at  $(555 \pm 25)$  nm (the spectral sensitivity of the photodetector does not influence the relative measurement). Compensate for any effects of displacement of the light beam by any prismatic effect of the test sample (see [B.3.4.1](#)). If necessary to demonstrate compliance, the effects of variation of thickness of the test sample shall be compensated for as in [7.4.1.4](#).

For test samples with bands or gradients of different luminous transmittance, the requirement for variations in luminous transmittance applies in this circular area but perpendicular to the gradient (see [Figure 1](#)). Two example scans perpendicular to the gradient are shown in [Figure 1](#).

Position the test sample and the light beam so that the incident light falls normally on the surface of the test sample at the reference point and parallel to that direction when testing at other locations on the test sample.

Measure and record the maximum value of luminous transmittance  $\tau_{v,\max}$  and the minimum value of luminous transmittance  $\tau_{v,\min}$ .



#### Key

- 1 light beam, nominal 5 mm diameter
- 2 reference point
- 3 nominated interpupillary distance/2

- $h$  vertical depth of the test sample
- $d$  diameter of the area under test as specified in [7.4.1.1](#)

**Figure 1 — Luminous transmittance uniformity measurement for test samples with bands or gradients of different luminous transmittance**

#### 7.4.1.2 Calculations

Calculate the value of  $\Delta F$ , as a percentage, from the following [Formula \(1\)](#);

$$\Delta F = 100 \times \frac{(\tau_{v,\max} - \tau_{v,\min})}{\tau_{v,\max}} \quad (1)$$

where

$\tau_{v,max}$  is the maximum value of luminous transmittance;

$\tau_{v,min}$  is the minimum value of luminous transmittance.

#### 7.4.1.3 Test report

The value of  $\Delta F$  as a percentage, the applicable illuminant(s) or source(s) and the associated uncertainty of measurement shall be reported as required in the standard referencing this test method.

#### 7.4.1.4 Method to correct transmittance for variations in thickness of the test sample

The following relation holds between the transmittance and the thickness,  $t$ , if multiple reflections within the test sample are neglected:

$$\tau = (1 - \rho_1) \cdot (1 - \rho_2) \cdot e^{-k \cdot t} \quad (2)$$

where

$\rho_1$  is the reflectance at the front surface;

$\rho_2$  is the reflectance of the back surface;

$t$  is the thickness;

$k$  is the absorption coefficient.

The absorption coefficient  $k$  can be calculated from the transmittance,  $\tau$ , for the reference thickness,  $t$ , as follows:

$$k = \frac{-\log_e \left[ \frac{\tau}{(1 - \rho_1) \cdot (1 - \rho_2)} \right]}{t} \quad (3)$$

The expected transmittance for a different thickness can then be calculated using [Formula \(2\)](#). Where the refractive index,  $n$ , of the medium is known and there is no surface treatment, the reflectance at the interface between the medium and air is given by the following [Formula \(4\)](#):

$$\rho = \left( \frac{n-1}{n+1} \right)^2 \quad (4)$$

### 7.4.2 Filter covering both eyes

#### 7.4.2.1 Test method

Locate the reference points defined in ISO 4007:2018, 3.8.9 for the nominated interpupillary distance. Determine the two circular areas centred on the reference points with diameter,  $d$ , calculated as follows, (see [Figure 2](#)):

- for test samples equal to or greater than 50 mm in vertical depth at the reference point,  $d = (40,0 \pm 0,5)$  mm;
- for test samples less than 50 mm in vertical depth at the reference point,  $d = [(h - 10) \pm 0,5]$  mm, where  $h$  is the vertical depth of test sample.

If a 5 mm wide portion around the edge of the test sample intrudes into this circular area, then this intrusion shall be excluded from testing.

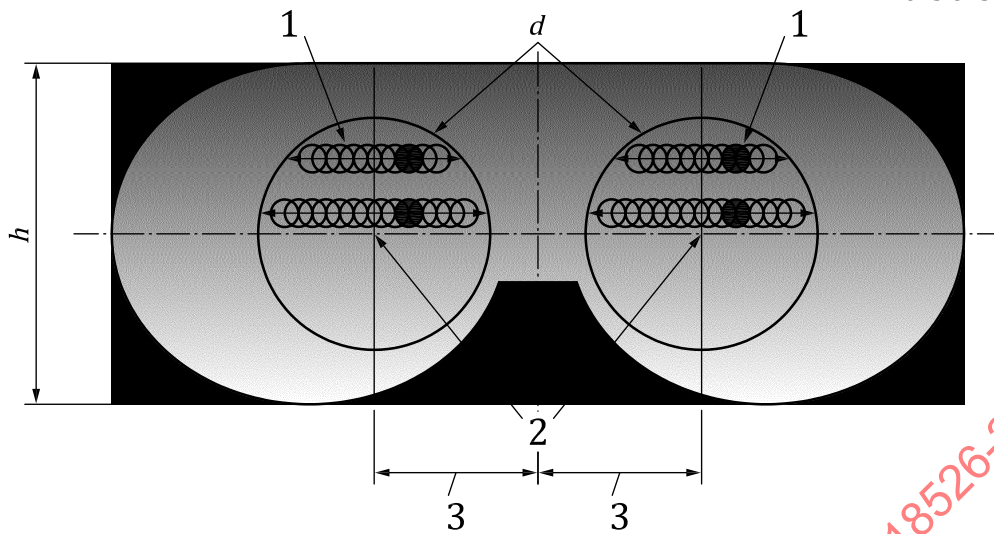
Scan this circular area with beam of light of 5 mm nominal diameter incident normally on the surface of the test sample. Use either white light and a photodetector whose spectral responsivity approximates that of the CIE 2° standard colometric observer (ISO/CIE 11664-1) or use a narrow spectral band of light with a maximum spectral energy at  $(555 \pm 25)$  nm (the spectral sensitivity of the photodetector does not influence the relative measurement). Compensate for any effects of displacement of the light beam by any prismatic effect of the test sample (see [B.3.4.1](#)). If necessary to demonstrate compliance, the effects of variation of thickness of the test sample shall be compensated for as in [7.4.1.4](#).

For a test sample with bands or gradients of different luminous transmittance, the requirement for variations in luminous transmittance applies in this circular area but perpendicular to the gradient. Two example scans perpendicular to the gradient for each of the reference points are shown in [Figure 2](#).

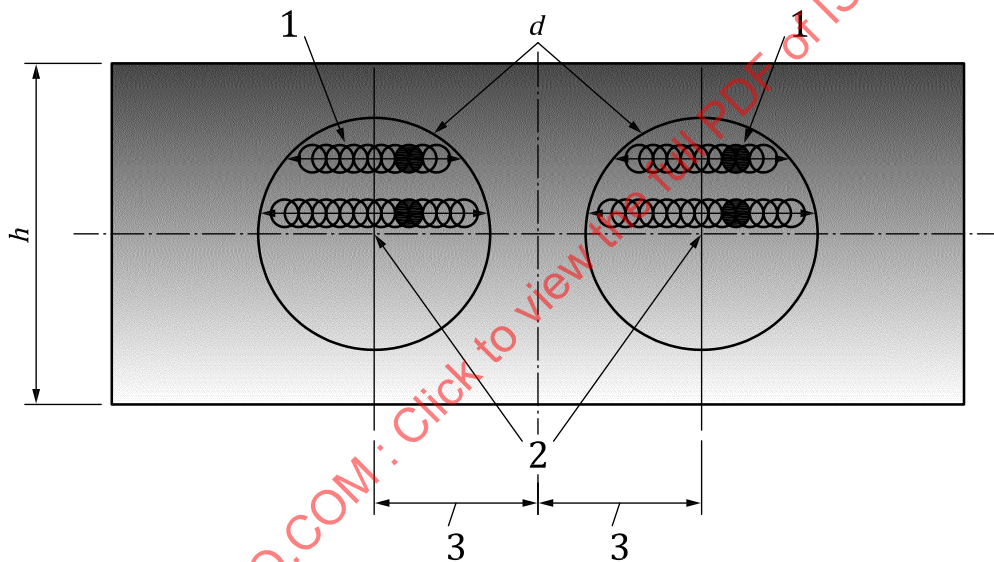
Measure and record the maximum value of luminous transmittance  $\tau_{v,max}$  and the minimum value of luminous transmittance  $\tau_{v,min}$ .

The test sample and the light beam are positioned so that the incident light falls normally on the surface of the test sample at the reference point and parallel to that direction when testing at other locations on the test sample.

Dimensions in millimetres



a) One piece lens



b) Rectangular filter covering both eyes

**Key**

- 1 light beam, nominal 5 mm diameter  
 2 reference point  
 3 nominated interpupillary distance/2

- $h$  vertical depth of the test sample  
 $d$  diameter of the area under test as specified in 7.4.2.1

**Figure 2 — Luminous transmittance uniformity measurement for test samples covering both eyes with bands or gradients of different luminous transmittance**

**7.4.2.2 Calculations**

Calculate the values of  $\Delta F_R$  and  $\Delta F_L$  as a percentage, for the right (R) and left (L) scanned areas from the following [Formula \(5\)](#);

$$\Delta F_R = 100 \times \frac{(\tau_{v,\max,R} - \tau_{v,\min,R})}{\tau_{v,\max,R}} \quad \Delta F_L = 100 \times \frac{(\tau_{v,\max,L} - \tau_{v,\min,L})}{\tau_{v,\max,L}} \quad (5)$$

where

$\tau_{v,\max}$  is the maximum value of luminous transmittance for the applicable lens;

$\tau_{v,\min}$  is the minimum value of luminous transmittance for the applicable lens.

### 7.4.2.3 Test report

The values of  $\Delta F_R$  and  $\Delta F_L$  for the right and left scanned areas as percentages, the applicable illuminant(s) or source(s) and the associated uncertainty of measurement shall be reported as required in the standard referencing this test method.

## 7.5 Transmittance matching at right and left reference points

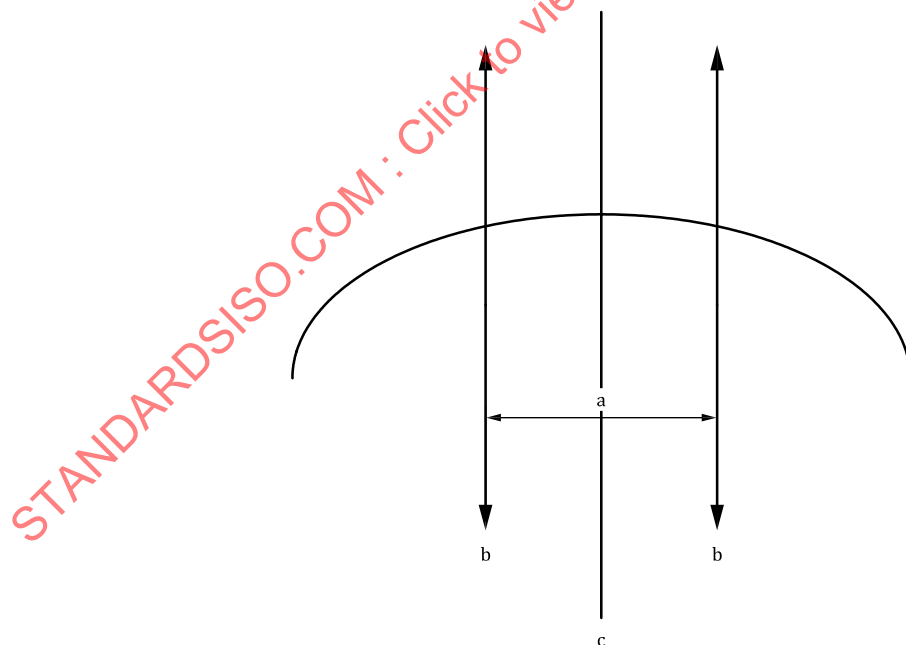
### 7.5.1 Test method

For mounted lenses, locate the reference points as defined in ISO 4007:2018, 3.8.7 and measure along the lines of sight in the as-worn position. Measurement may be made in either direction.

For unmounted pairs of lenses, locate the reference points as defined in ISO 4007:2018, 3.8.8. In the absence of specific instructions from the manufacturer, test at the boxed centres and normal to the surface.

For unmounted lenses covering both eyes, locate the reference points as defined in ISO 4007:2018, 3.8.9. In the absence of specific instructions from the manufacturer, measure at two points horizontally symmetrical either side of the midline of the filter separated by the intended interpupillary distance and in a direction parallel to the normal to the filter at the centre. See [Figure 3](#).

Measure and record the value of luminous transmittance,  $\tau_{v,L}$ , at the left reference point and the value of luminous transmittance,  $\tau_{v,R}$ , at the right reference point.



#### Key

a Interpupillary distance (PD).

b Direction of measurement.

c Normal to centre of filter.

**Figure 3 — Luminous transmittance matching measurement for unmounted test samples covering both eyes**

### 7.5.2 Calculations

Divide the absolute difference between the values of the luminous transmittance at the two reference points  $\tau_{v,L}$  and  $\tau_{v,R}$  by the higher value of the two luminous transmittances and express this ratio  $\Delta P$  as a percentage as given in [Formula \(6\)](#):

$$\Delta P = 100 \times \frac{|\tau_{v,R} - \tau_{v,L}|}{\max(\tau_{v,R}, \tau_{v,L})} \quad (6)$$

where

$\tau_{v,L}$  is the value of luminous transmittance at the left reference point of the test sample;

$\tau_{v,R}$  is the value of luminous transmittance at the right reference point of the test sample.

**EXAMPLE** If a test sample (covering both eyes) transmits 40,0 % for the left eye and 42,0 % for the right eye (see [Figure 3](#)), then the result is  $100 \times (2,0/42,0) = 4,8$  %.

### 7.5.3 Test report

The value of  $\Delta P$  as a percentage, the applicable illuminant(s) or source(s) and the associated uncertainty of measurement shall be reported as required in the standard referencing this test method.

## 8 Ultraviolet transmittance

### 8.1 General

Ultraviolet transmittance shall be calculated from the spectral transmittances measured in [Clause 7](#). There is no broadband method specified.

### 8.2 Spectral transmittance and mean spectral transmittance

#### 8.3 Solar UV transmittance

See ISO 4007:2018, 3.10.1.28. See also [C.3.2.1](#).

The values of  $E_s(\lambda)$ ,  $S(\lambda)$  and  $W(\lambda)$  are given in [Table D.1](#).

#### 8.4 Solar UV-A transmittance

See ISO 4007:2018, 3.10.1.29. See also [C.3.2.2](#).

The values of  $E_s(\lambda)$ ,  $S(\lambda)$  and  $W(\lambda)$  are given in [Table D.1](#).

#### 8.5 Solar UV-B transmittance

See ISO 4007:2018, 3.10.1.30. See also [C.3.2.3](#).

The values of  $E_s(\lambda)$ ,  $S(\lambda)$  and  $W(\lambda)$  are given in [Table D.1](#).

#### 8.6 Mean UV-A transmittance

See ISO 4007:2018, 3.10.1.26. See also [C.3.2.4](#).

## 8.7 Mean UV-B transmittance

See ISO 4007:2018, 3.10.1.27. See also [C.3.2.5](#).

## 8.8 Mean 380 nm to 400 nm transmittance

See ISO 4007:2018, 3.10.1.31. See also [C.3.2.6](#).

## 8.9 Test report

The values of spectral, mean unweighted and weighted transmittances and the associated uncertainties of measurement shall be reported as required in the standard referencing this test method.

## 9 Blue-light transmittance

### 9.1 Solar blue-light transmittance

#### 9.1.1 Calculation of solar blue-light transmittance from spectral values

See ISO 4007:2018, 3.10.1.35. See also [C.3.3.1](#).

The values of  $E_s(\lambda)$  and  $B(\lambda)$  are given in [Table D.1](#).

#### 9.1.2 Broadband method of measurement of solar blue-light transmittance

##### 9.1.2.1 Apparatus

**9.1.2.1.1 Light source**, with a broadband high intensity collimated light source with a spectral distribution in the wavelength range from 380 nm to 500 nm, i.e. approximately that of the solar spectral irradiance in [Table D.1](#).

**9.1.2.1.2 Photodetector**, with a spectral response approximately corresponding to the blue-light hazard weighting function  $B(\lambda)$  in the wavelength range from 380 nm to 500 nm. The photodetector shall be mounted normal to the beam of illumination.

The values of  $B(\lambda)$  are given in [Table D.1](#).

##### 9.1.2.2 Test procedure

The solar blue-light transmittance is measured as the ratio of the luminous flux transmitted by the test sample to the incident light measured with no test sample in the light path.

##### 9.1.2.3 Test report

The values of solar blue-light transmittance and the associated uncertainty of measurement shall be reported as required in the standard referencing this test method.

### 9.2 Blue-light transmittance from artificial sources

#### 9.2.1 Calculation of blue-light transmittance from artificial sources from spectral values

See ISO 4007:2018, 3.10.1.36. See also [C.3.3.2](#).

The values of  $B(\lambda)$  are given in [Table D.1](#).

## 9.2.2 Broadband method of measurement of blue-light transmittance from artificial sources

### 9.2.2.1 Apparatus

**9.2.2.1.1 Light source**, with a broadband high intensity collimated light source with an approximately flat spectral distribution in the wavelength range from 380 nm to 500 nm.

**9.2.2.1.2 Photodetector**, with a spectral response approximately corresponding to the blue-light hazard weighting function  $B(\lambda)$  in the wavelength range from 380 nm to 500 nm as defined in ISO 4007:2018, Table A.1. The photodetector shall be mounted normal to the beam of illumination.

### 9.2.2.2 Procedure

The blue-light transmittance from artificial sources is measured as the ratio of the light transmitted by the test sample to the incident light measured with no test sample in the light ray.

### 9.2.3 Test report

The values of each blue-light transmittance from artificial sources and the associated uncertainty of measurement shall be reported as required in the standard referencing this test method.

## 10 IR transmittance

### 10.1 Near IR transmittance

#### 10.1.1 Calculation

See ISO 4007:2018, 3.10.1.39. See also [C.3.4.1](#).

### 10.2 IR-A transmittance

#### 10.2.1 Calculation

See ISO 4007:2018, 3.10.1.40. See also [C.3.4.2](#).

### 10.3 IR-B transmittance

#### 10.3.1 Calculation

See ISO 4007:2018, 3.10.1.41. See also [C.3.4.3](#).

### 10.4 Solar IR transmittance

#### 10.4.1 Calculation

See ISO 4007:2018, 3.10.1.42. See also [C.3.4.4](#).

The values of  $E_s(\lambda)$  are given in [Table D.4](#).

### 10.5 Test report

The values of each IR transmittance measure and the associated uncertainty of measurement shall be reported as required in the standard referencing the this test method.

## 11 Relative visual attenuation coefficient for traffic signal light detection, $Q_{\text{signal}}$

### 11.1 Calculation

See ISO 4007:2018, 3.10.1.34. See also [C.3.5](#).

The values of  $S_{D65}(\lambda) \cdot V(\lambda)$  and  $E_{\text{signal}} \cdot V(\lambda)$  for traffic signals with quartz halogen tungsten filament lamps and for traffic signals with LED signals are given in [Table D.5](#). The  $Q_{\text{signal}}$  values are currently calculated using the  $E_{\text{signal}}$  values for traffic signals with quartz halogen tungsten filament lamps.

### 11.2 Test report

Report the values of  $Q_{\text{red}}$ ,  $Q_{\text{yellow}}$ ,  $Q_{\text{green}}$  and  $Q_{\text{blue}}$  and the associated uncertainties of measurement in the standard referencing this test method.

## 12 Spectral reflectance

### 12.1 Uncertainty of measurement

Unless otherwise indicated, test methods used in the measurement of spectral reflectance, the measures calculated from spectral reflectance and the broadband measures of reflectance shall have relative uncertainties less than or equal to those given in [Table 2](#).

**Table 2 — Relative uncertainty of measured spectral reflectance**

| Spectral reflectance value |         | Uncertainty<br>% |
|----------------------------|---------|------------------|
| Less than<br>%             | To<br>% |                  |
| 100                        | 17,8    | ±5 % relative    |
| 17,8                       |         | ±1 % absolute    |

### 12.2 Position and direction of measurement

Specular or regular reflection is a mirror-like reflection obeying the laws of geometrical optics (see also CIE S 017:2011, 17-1240 specular, 17-1241 specular angle, 17-1242 specular reflection and 17-1076 regular reflectance). Diffuse reflectance is the light reflected other than regularly (see also CIE S 017:2011, 17-304 diffuse reflectance). There are several measures of reflectance that deal with these two factors in different ways. The standard requiring the test specifies the geometry. The spectral values are then used to calculate weighted and unweighted values in the same way regardless of the geometry used.

#### 12.2.1 Specular spectral reflectance

Measures of specular reflectance alone are made with the light source and the photodetector subtending the same angle to each side of the normal to the test sample. The photodetector is of sufficient size to collect the specularly reflected radiation. Unless otherwise stated, the angles of incidence and reflection shall be less than or equal to 17°.

Specular reflectance may also be measured by subtracting the total reflectance (specular excluded) (see [12.2.3](#)) from the total reflectance (specular included) (see [12.2.2](#)).

#### 12.2.2 Total spectral reflectance (specular included)

The geometry of measurements shall comply with CIE 15:2019, 5.2.1 or 5.2.3 and notes to 5.2.

### 12.2.3 Total spectral reflectance (specular excluded)

The geometry of measurements shall comply with CIE 15:2019, 5.2.2 or 5.2.4 and notes to 5.2.

### 12.2.4 0°/45° and 45°/0° geometry

The test sample is illuminated at an angle of 45° and measured at an angle of 0° or vice versa. The geometry of measurements shall comply with CIE 15:2019, 5.2.7, 5.8, 5.9 or 5.2.10 and notes to 5.2.

## 12.3 Wavelength intervals

Spectral measurements and calculations shall be carried out at intervals no greater than 5 nm ( $\Delta\lambda = 5$  nm) in the ultraviolet and visible region (180 nm to 780 nm) nm and at intervals no greater than 10 nm ( $\Delta\lambda = 10$  nm) in the infrared region (780 nm to 3 000 nm). The necessary weighting data at these intervals are also provided in 5 nm and 10 nm intervals in [Annex D](#).

## 12.4 Test report

The spectral reflectances and the associated uncertainty of measurement shall be reported as required in the standard referencing this test method. The report shall include the measurement geometry.

## 13 Luminous reflectance

### 13.1 Calculations

The calculation of  $\rho_v$  as a percentage is obtained by the ratio of the luminous flux reflected by the test sample  $\Phi_R$  to the incident luminous flux  $\Phi_I$  and with reference to a standard observer and a source or standard illuminant. For the purposes of this document, all calculations use the CIE 2° standard colometric observer (ISO/CIE 11664-1). Depending on the application, CIE standard illuminant A and/or CIE standard illuminant D65 (ISO 11664-2) and/or a Planckian radiator of 1 900 K according to ISO 4007:2018, 3.10.1.43 (see also [C.3.6.1](#)) may be used or the calculation may assume an equal-energy source.

The values of  $S_A(\lambda) \cdot V(\lambda)$ ,  $S_{D65}(\lambda) \cdot V(\lambda)$  and  $E_{1\,900\,K}(\lambda) \cdot V(\lambda)$  are given in [Annex D, Tables D.2 to D.4](#).

### 13.2 Test report

The values of luminous reflectance, the applicable source(s) or illuminant(s), the geometry of the measurement and the associated uncertainties of measurement shall be reported as required in the standard referencing this test method. The report shall include the measurement geometry.

### 13.3 Luminous reflectance of mesh

The appropriate measurement geometry is the total spectral reflectance (specular included), see [12.2.2](#). The requirement of [12.3](#) also applies.

The spectral transmittances  $\tau(\lambda)$  measured according to [Clause 7](#) to calculate the luminous transmittance are required in the calculation.

The method requires the use of a light trap or black surface or light trap of known spectral reflectance behind the mesh under test.

Measure the spectral reflectance (380 nm to 780 nm) of the black surface or light trap  $\rho_{\text{reference black}}(\lambda)$ .

Under the same conditions, measure the spectral reflectance (380 nm to to 780 nm) of the back surface of the mesh backed by the black surface or light trap  $\rho'(\lambda)$ .

Calculate the corrected spectral reflectance, where:

$$\rho(\lambda) = \rho'(\lambda) - \rho_{\text{reference black}}(\lambda) \cdot \tau(\lambda)^2 \quad (7)$$

Using the  $\rho(\lambda)$  values, calculate the luminous reflectance  $\rho_{v,A}$  according to ISO 4007:2018, 3.10.1.43. See also [C.3.6.1](#).

Where the mesh can be shown to have a spectral reflectance that is independent of wavelength, then the method can be carried out with a single spectral reflectance value and spectral transmittance value at the same wavelength rather than calculating the luminous reflectance.

## 14 Scattered light

### 14.1 Wide angle scatter

#### 14.1.1 Principle

A hazemeter or spectrophotometer with integrating sphere is used to measure the amount of light that deviates from an incident beam by being scattered forward when the beam passes through a test sample, compared with the amount scattered by the test instrument and the amount transmitted by the test sample.

#### 14.1.2 Apparatus

**14.1.2.1 Incandescent light source**, approximating CIE standard illuminant A or CIE standard illuminant D65 (ISO 11664-2) as specified in the standard referencing this method.

**14.1.2.2 Hazemeter or spectrophotometer**, with integrating sphere, light trap, photodetector (with monochromator in the case of the spectrophotometer) and reflectance standard (see [Figure 4](#)) as follows:

- a) The integrating sphere shall have:
  - 1) a total port area not exceeding 4,0 % of the total internal reflecting area of the sphere;
  - 2) the entrance and exit ports separated by at least 170°;
  - 3) the exit port subtending 8° at the centre of the entrance port;
  - 4) the photodetector (90 ± 10)° from the entrance port; and
  - 5) all internal surfaces (including the reflectance standard for the exit port) covered with a substance of high reflectance for the wavelengths between 380 nm and 780 nm.

NOTE 1 Barium sulphate paint can be suitable.
- b) The light trap shall have a reflectance of less than 0,1 %.
- c) The photodetector shall provide proportional measurements of the radiant flux to within 1 % of the incident radiation, across the range of intensities used within the test.
- d) These components shall be arranged so that the irradiating beam shall:
  - 1) have the axis of the beam passing through the centre of the entrance and exits ports;
  - 2) be unidirectional, with no ray of the beam deviating from the direction of the axis of the beam by greater than 3°;

- 3) when there is no test sample obstructing the beam, have a circular cross-section at the exit port, while the diameter of the exit port shall exceed the diameter of the irradiating beam so that there is an annular zone around the beam subtending  $(1,3 \pm 0,1)^\circ$  at the entrance port;
- 4) when a test sample covers the entrance port, not form an angle greater than  $8^\circ$  between the axis of the beam and the normal to the surface of the test sample, and
- 5) when there is no test sample obstructing the beam, be completely absorbed by the light trap (if used).

NOTE 2 Although wide angle scatter measurements are made most commonly by the use of a "hazemeter", a spectrophotometer can be used, provided that it meets the geometric and spectral requirements of this clause.

NOTE 3 Some hazemeters can give anomalous results when the luminous transmittance  $\tau_v$  of the test sample is below about 15 %. Spectrophotometers can make the measurements on substantially darker test samples.

#### 14.1.3 Test sample

The size of the test sample will vary with the size of the entrance port and the surface curvature of the integrating sphere. The test sample shall be large enough to cover the entrance port completely but shall be small enough to be approximately tangential to the wall of the integrating sphere. See [Figure 4](#).

#### 14.1.4 Test procedure

Carry out the test procedure as follows:

- a) Measure the incident light ( $\tau_1$ ) without the test sample in position, without the light trap in position and with the reflectance standard in position (some instruments allow adjustment of this value to 1,00 or 100 %, in which case  $\tau_1 = 1,00$  or 100 %).
- b) Measure the total light transmitted by the test sample ( $\tau_2$ ) with the test sample in position, without the light trap in position and with the reflectance standard in position.
- c) Measure the light scattered by the instrument ( $\tau_3$ ) without the test sample in position, with the light trap in position and without the reflectance standard in position.
- d) Measure the light scattered by the instrument and test sample ( $\tau_4$ ) with the test sample in position, with the light trap in position and without the reflectance standard in position.
- e) Repeat step b) so that four readings are obtained, rotating the test sample between readings by  $90^\circ$ .
- f) Repeat step d) so that four readings are obtained at the same positions as in step e).

#### 14.1.5 Calculation

The following shall be calculated:

The mean values of  $\tau_2$  and  $\tau_4$  ( $\bar{\tau}_2$  and  $\bar{\tau}_4$ ).

$$\text{The total transmittance } \tau_t = \frac{\bar{\tau}_2}{\tau_1} \quad (8)$$

The diffuse transmittance  $\tau_d = \left[ \bar{\tau}_4 - \tau_3 \cdot \frac{\bar{\tau}_2}{\tau_1} \right] / \tau_1$  (9)

The wide angle scatter, expressed as a percentage, from the [Formula \(10\)](#):

wide angle scatter =  $\frac{\tau_d}{\tau_t} \times 100$  (10)

Some instruments may make the measurements and calculate  $\tau_d$ .

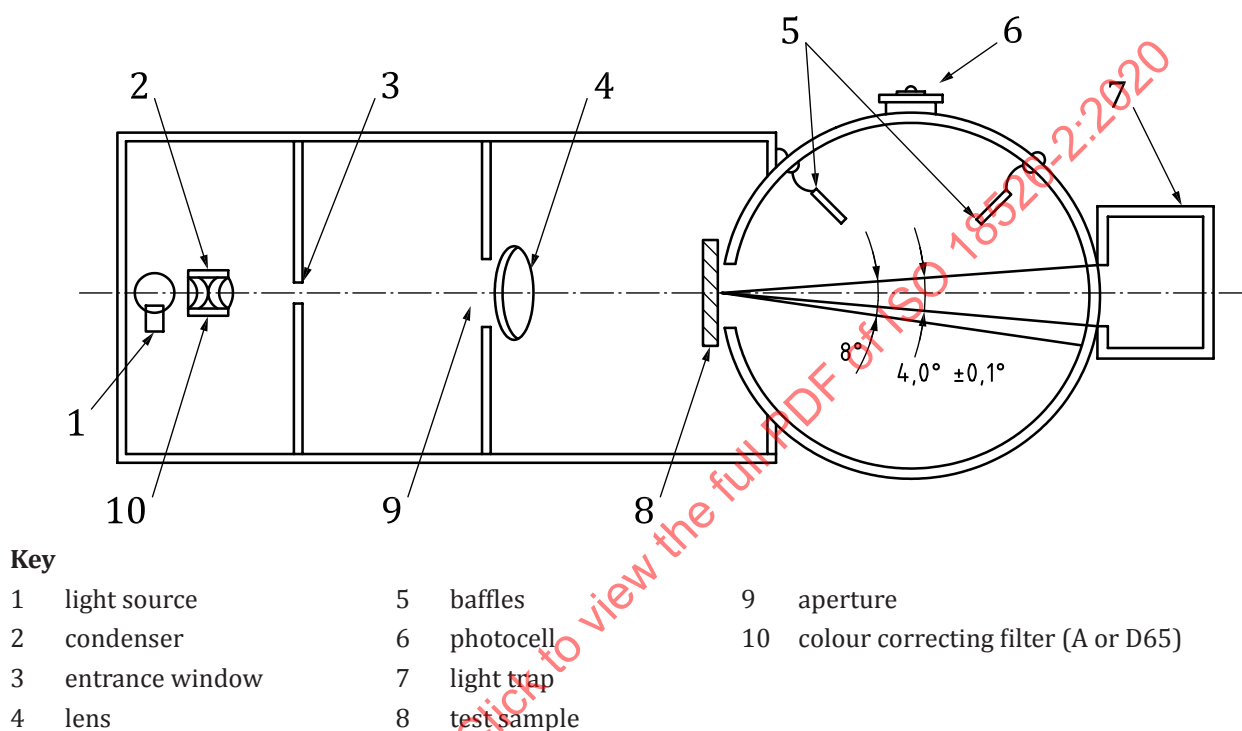


**Figure 4 — Diagram of typical equipment for the measurement of wide angle scatter**

#### 14.1.6 Test report

The values of wide angle scatter (haze), the applicable illuminant(s) and the associated uncertainties of measurement shall be reported as required in the standard referencing this test method.

### 14.2 Narrow angle scatter

#### 14.2.1 Principle

The luminance ( $L_s$ ) of an illuminated test sample is a measure of its narrow angle scatter and is proportional to the illuminance ( $E$ ) on the test sample.

The ratio  $l = \frac{L_s}{E}$  is the luminance coefficient, which is expressed in the units: (cd/m<sup>2</sup>)/lx.

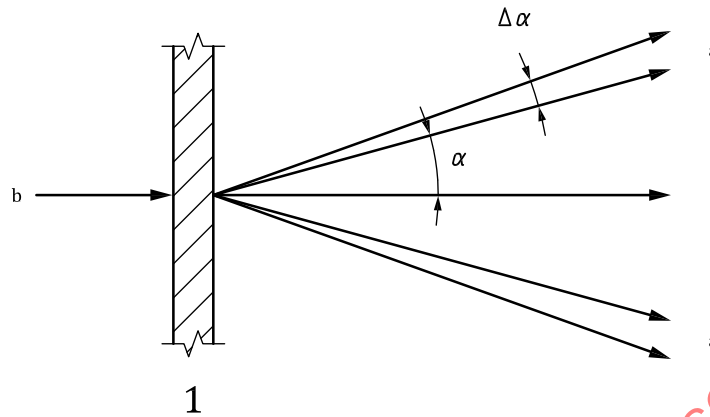
However, this ratio has to be expressed as the reduced luminance coefficient  $l^*$  that is independent of the luminous transmittance  $\tau_v$  of the test sample, such that:

$$l^* = \frac{L_s}{\tau_v \cdot E} \quad (11)$$

where  $\tau_v$  is the luminous transmittance, expressed as a number between 0,0 and 1,0.

This quantity is known as the reduced luminance coefficient and is expressed in the same units as the luminance coefficient.

NOTE Most eye protector lenses and filters have light scattering properties that are symmetrical about the optical axis. For these test samples, the mean value of the reduced luminance coefficient is constant within an angle limited by the two cones shown in cross section in [Figure 5](#).



**Key**

- 1 test sample
- $\alpha$  angle from the direction of the incident beam
- $\Delta\alpha$  angle over which diffusely transmitted light is collected
- a Diffused light.
- b Incident light.

**Figure 5 — Angles of narrow angle scatter**

## 14.2.2 Test methods

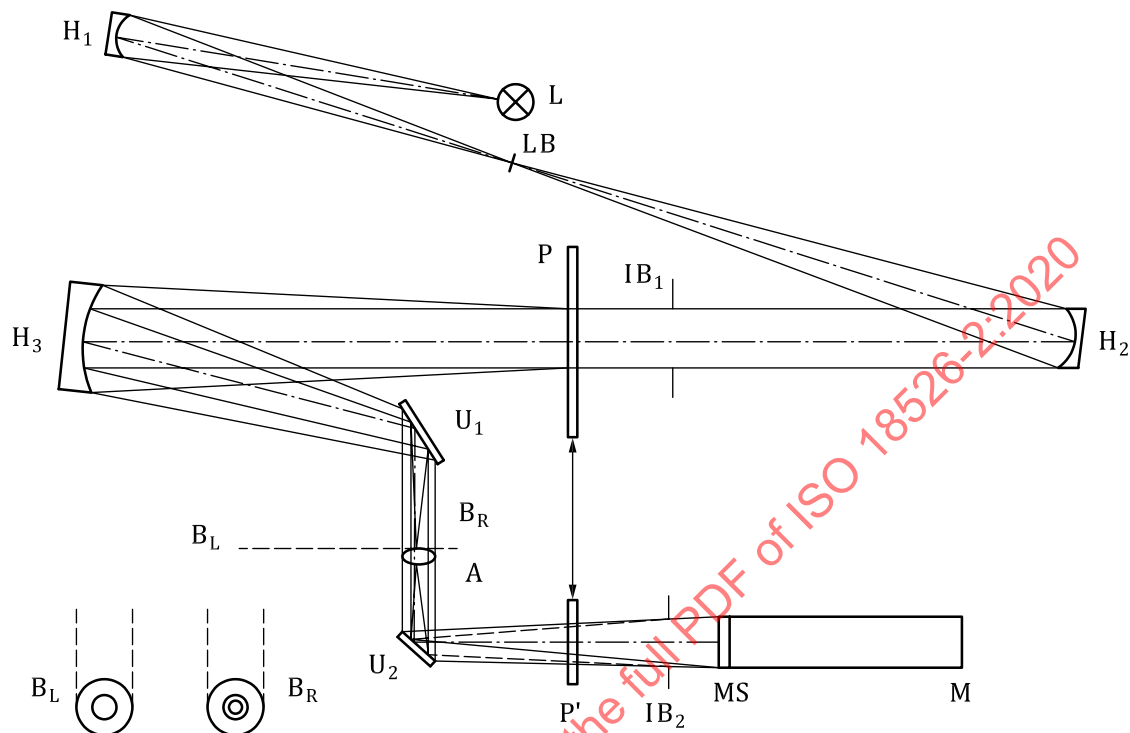
### 14.2.2.1 General

Two test methods are specified, which use the same measurement principle. In the event of dispute, the primary method is the reference method.

The results obtained with the two methods may be considered to be equivalent; whichever method is used, the relative measurement uncertainty for the reduced luminance coefficient shall not be greater than 25 %.

### 14.2.2.2 Primary method

#### 14.2.2.2.1 Apparatus



#### Key

- L high-pressure Xenon lamp (for example XBO 150 W)
- $H_1$  spherical concave mirror; nominal focal length 150 mm; nominal diameter 40 mm
- $H_2$  spherical concave mirror; nominal focal length 300 mm; nominal diameter 40 mm
- $H_3$  spherical concave mirror; nominal focal length 300 mm; nominal diameter 70 mm
- A achromatic lens; nominal focal length 200 mm; nominal diameter 30 mm
- $B_R$  annular diaphragm; diameter of outer circle  $(21,0 \pm 0,1)$  mm, diameter of inner circle  $(15,75 \pm 0,10)$  mm
- $B_L$  circular diaphragm; diameter of aperture  $(7,5 \pm 0,1)$  mm
- M photomultiplier corrected according to curve  $V(\lambda)$
- $IB_1$  iris diaphragm to adjust diameter of field of measurement
- $IB_2$  iris diaphragm to eliminate edge effects from  $IB_1$
- LB circular diaphragm; diameter of aperture  $(1,0 \pm 0,1)$  mm
- P, P' positions of sample under test
- MS diffusing screen
- $U_1$  flat mirror
- $U_2$  flat mirror

**Figure 6 — Arrangement of apparatus for measurement of narrow angle scatter – Primary method**

The arrangement is shown in [Figure 6](#). The spherical mirror  $H_1$  forms an image of lamp L of identical dimensions at diaphragm  $L_B$ . The concave mirrors  $H_2$  and  $H_3$  form an image of diaphragm  $L_B$  in the plane of diaphragms  $B_L$  and  $B_R$ . The achromatic lens A is positioned immediately behind the diaphragm so that a reduced image of the test sample in position P appears on diffusing screen MS. The image of iris diaphragm  $IB_1$  is formed in the plane of the second iris diaphragm,  $IB_2$ .

The arrangement collects all the light originating from the test sample between angles  $\alpha = 1,5^\circ$  and  $\alpha + \Delta\alpha = 2^\circ$  in relation to the optical axis. The diameters of the annular diaphragm's circles shall be measured to an uncertainty not exceeding 0,01 mm in order that the solid angle  $\omega$  may be determined accurately; any deviation from the nominal diameters shall be taken into account by calculation.

#### 14.2.2.2.2 Test procedure

The test sample is placed in the parallel beam at position P, then diaphragm  $B_L$  is put in place. The flux  $\Phi_{1L}$  falling onto the photodetector corresponds to the light transmitted directly by the test sample. Diaphragm  $B_L$  is then replaced by annular diaphragm  $B_R$ ; flux  $\Phi_{1R}$  falling onto the photodetector corresponds to the total diffused light originating from the test sample and from the apparatus. The test sample is then placed at position P'. The flux  $\Phi_{2R}$ , which then falls onto the photodetector, corresponds to the diffused light coming from the apparatus only.

The difference  $\Phi_{1R} - \Phi_{2R}$  corresponds to the light diffused by the test sample. The mean reduced luminance coefficient  $l^*$  for the solid angle  $\omega$  is calculated from the preceding fluxes by means of the [Formula \(12\)](#):

$$l^* = \frac{1}{\omega} \cdot \frac{\Phi_{1R} - \Phi_{2R}}{\Phi_{1L}} \quad (12)$$

where

$\Phi_{1R}$  and  $\Phi_{2R}$  are the luminous fluxes with the annular diaphragm  $B_R$ ;

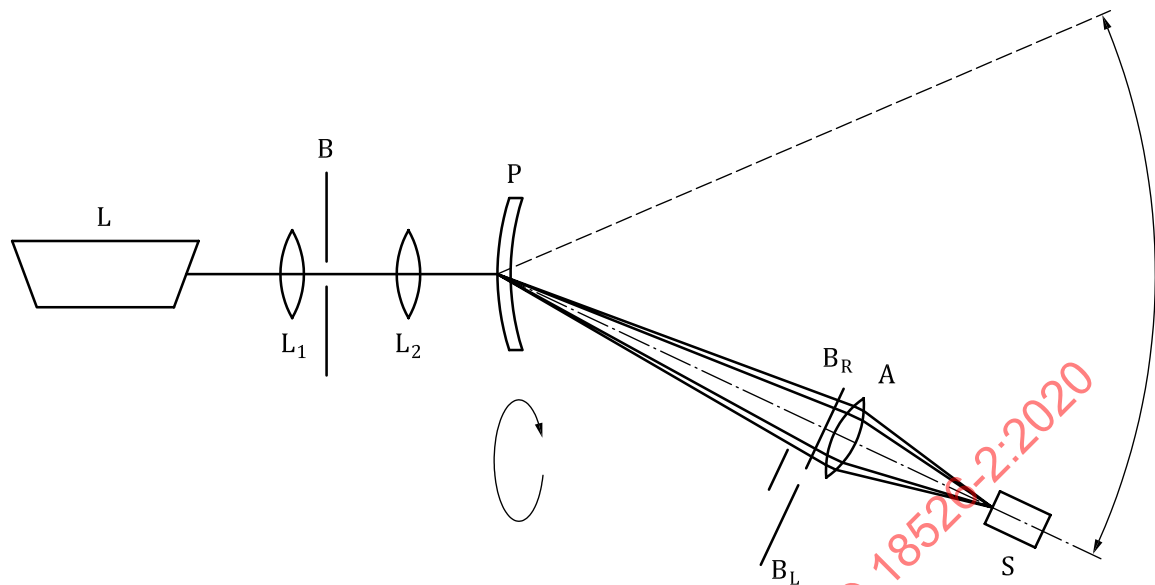
$\Phi_{1L}$  is the luminous flux with the circular diaphragm  $B_L$ ;

$\omega$  is the solid angle subtended by the aperture in the annular diaphragm  $B_R$  at the position of the test sample, P.

#### 14.2.2.3 Secondary method

##### 14.2.2.3.1 Apparatus

The test arrangement is shown in [Figure 7](#).

**Key**

- L laser with wavelength of  $(600 \pm 70)$  nm
- $L_1$  lens; 10 mm nominal focal length
- $L_2$  lens; 30 mm nominal focal length
- B circular diaphragm (a hole of 0,1 mm nominal diameter produces a uniform beam of light)
- P sample under test
- $B_R$  annular diaphragm, the diameter of the outer circle being  $(28,0 \pm 0,1)$  mm and the inner circle  $(21 \pm 0,1)$  mm
- $B_L$  circular diaphragm of 10 mm nominal diameter
- A lens; 200 mm nominal focal length and 30 mm nominal diameter
- S photodetector

**Figure 7 — Arrangement of apparatus for measurement of narrow angle scatter – Secondary method**

The distance between the annular/circular diaphragm  $B_R/B_L$  and the centre of the sample under test P shall be  $(400 \pm 2)$  mm.

The diameters of the annular diaphragm's circles, in  $B_R$ , shall be measured with an uncertainty not exceeding 0,01 mm in order that the solid angle  $\omega$  may be determined accurately; any deviation from the nominal diameters shall be taken into account by calculation.

The beam of the laser L shall be expanded using the two lenses  $L_1$  and  $L_2$  and is directed towards the measuring point of the test sample P. P shall be mounted in such a way that it can rotate around the axis of the beam.

**NOTE** The focal lengths of the lenses are given as a guide only. Other focal lengths can be used, for example, if a wider beam is desired or a smaller image of the sample is to be formed on the photodetector.

The deviation of the beam is a function of the prismatic power at the measuring point. The annular or circular diaphragm, whichever is chosen, is at a distance of  $(400 \pm 2)$  mm from the centre of the test sample. The lens A then produces the image of the centre of the test sample on the photodetector S.

The part of the test arrangement, comprising the diaphragms, the lens A and the photodetector shall be designed to rotate about the vertical axis through the centre of the test sample. The photodetector part of the apparatus shall pivot in order to compensate for any prismatic power of the test sample.

#### 14.2.2.3.2 Procedure

##### 14.2.2.3.2.1 Calibration of the apparatus

The procedure shall be as follows.

- a) Set up the apparatus, the essential features of which are shown in [Figure 7](#), without the test sample under test in place.
- b) Put the annular diaphragm  $B_R$  in place.
- c) Rotate the photodetector part of the apparatus (consisting of a photodetector S, lens A and the annular diaphragm  $B_R$ ) horizontally about P so as to align the light beam from the beam expander (consisting of a lens  $L_1$ , lens  $L_2$  and circular diaphragm B with a pinhole of sufficient size so as to provide a uniform beam) with the centre of the annular diaphragm  $B_R$ .
- d) The flux  $\Phi_{1R}$  falling onto the photodetector S corresponding to the total diffused light.
- e) Replace the annular diaphragm  $B_R$  by the circular diaphragm  $B_L$ .
- f) Measure the flux  $\Phi_{1L}$  falling onto the photodetector corresponding to the total directly transmitted light.
- g) Obtain the reduced luminance coefficient for the apparatus  $l_a^*$  for the solid angle  $\omega$  using the following [Formula \(13\)](#):

$$l_a^* = \frac{1}{\omega} \cdot \frac{\Phi_{1R}}{\Phi_{1L}} \quad (13)$$

where

- $\Phi_{1R}$  is the luminous flux without the test sample under test in the parallel beam and with the annular diaphragm  $B_R$  in place;
- $\Phi_{1L}$  is the luminous flux without the test sample under test in the parallel beam and with circular diaphragm  $B_L$  in place;
- $\omega$  is the solid angle subtended by the aperture in the annular diaphragm  $B_R$  at the position of the test sample P.

##### 14.2.2.3.2.2 Testing the sample

Put the test sample in place at position P and rotate it about the axis of the beam to a position so that any prismatic deviation by the test sample is horizontal.

Rotate the photodetector part of the apparatus so that the light beam falls on the centre of  $B_R$ .

Repeat [14.2.2.3.2.1](#) and obtain the reduced luminance coefficient for the combination of apparatus and test sample  $l_g^*$  for the solid angle  $\omega$  using the following [Formula \(14\)](#):

$$l_g^* = \frac{1}{\omega} \cdot \frac{\Phi_{2R}}{\Phi_{2L}} \quad (14)$$

where

- $\Phi_{2R}$  is the luminous flux with the test sample in the parallel beam and with the annular diaphragm  $B_R$  in place;
- $\Phi_{2L}$  is the luminous flux with the test sample in the parallel beam and with circular diaphragm  $B_L$  in place;
- $\omega$  is the solid angle defined by the annular diaphragm  $B_R$ .

Then calculate the reduced luminance coefficient  $l^*$  of the test sample using the following [Formula \(15\)](#):

$$l^* = l_g^* - l_a^* \quad (15)$$

### 14.2.3 Test report

The values of reduced luminance coefficient, the method used and laser wavelength (if simplified method is used) and the associated uncertainties of measurement shall be reported as required in the standard referencing this test method.

## 15 Polarization

### 15.1 Plane of transmission

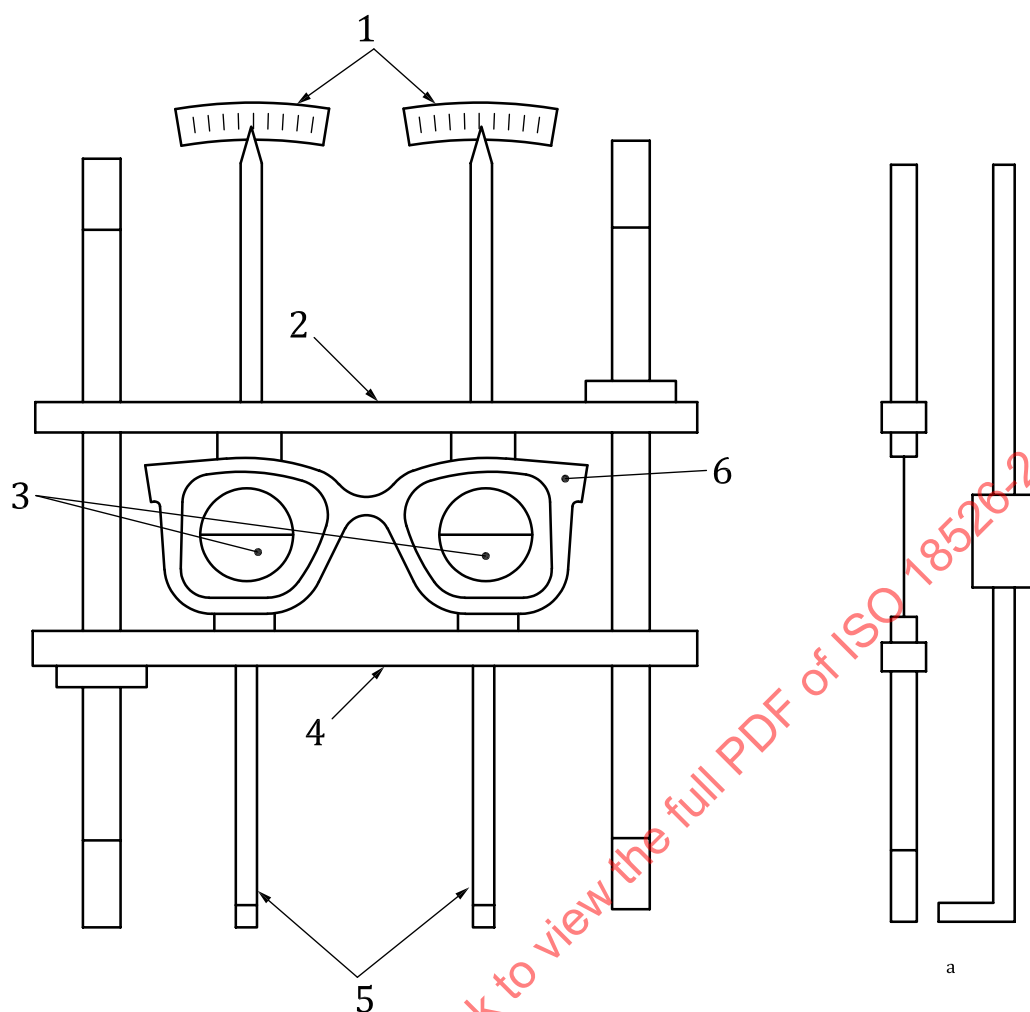
#### 15.1.1 Apparatus

A pair of individually mounted split field polarizers cut to give planes of transmission at a  $+3^\circ$  and a  $-3^\circ$  angle from the horizontal or the meridian specified in the product's requirement standard. The top and bottom halves of the polarizers shall be joined together and glass mounted with the line of the join horizontal or perpendicular to the specified plane of transmission. The polarizers shall be capable of being rotated by means of a lever carrying a corresponding pointer. The pointer transverses a scale calibrated in degrees left or right of zero. The split fields shall be illuminated from behind by a diffused light source (see [Figure 8](#)).

#### 15.1.2 Test procedure

Carry out the procedure as follows.

- a) Mount the test sample on the apparatus with the front towards the split fields and between the top and bottom register bars. Ensure that the split field appears in the centre of the test sample by means of vertical adjustment.
- b) For the left test sample, move the lever from side to side until the top and bottom halves of the illuminated split field appear of equal luminance when viewed through the test sample.
- c) Read off the pointer position to give the deviation in degrees (plus or minus) of the plane of transmission of the test sample from the horizontal or the prescribed orientation. Repeat the procedures for the right test sample.



#### Key

- |   |                        |   |                            |
|---|------------------------|---|----------------------------|
| 1 | scales                 | 4 | bottom register bar        |
| 2 | top register bar       | 5 | split-field rotation lever |
| 3 | split-field polarizers | 6 | test sample                |

a Side view.

**Figure 8 — Apparatus for the determination of the plane of transmission**

### 15.1.3 Test report

The values of the deviation of the directions of the intended horizontal orientation of the right and left test samples and the value for any misalignment between the two test samples and the associated uncertainties of measurement shall be reported as required in the standard referencing this test method.

## 15.2 Polarizing efficiency

### 15.2.1 Principle

The luminous transmittance for visible light is measured with plane polarized light with the plane of transmission set to provide the maximum and the minimum transmittance of the test sample. This can be done by a spectrophotometric and calculation method (the reference method) or in a broadband method using a photodetector with the sensitivity of the human eye (peak at 555 nm) and a source equivalent to CIE standard illuminant D65.

### 15.2.2 Test procedure for the spectrophotometric method

Carry out the procedure as follows.

- Mount linear polarizers with their planes of transmission parallel in the reference and sample beams of the spectrophotometer. The linear polarizers shall have a polarizing efficiency at least one order of magnitude better than the requirement being tested against [e.g. if the requirement for the test sample is a polarizing efficiency of 80 % (9:1) then the linear polarizers shall have a polarizing efficiency of at least 97,5 % (90:1)];
- Mount the polarizing test sample in the spectrophotometer;
- With the spectrophotometer wavelength set to  $(550 \pm 5)$  nm, rotate the test sample to the point of maximum transmittance;
- At this orientation, measure the spectral transmittances  $\tau_{P,\max}(\lambda)$  in the range 380 nm to 780 nm at 5 nm intervals;
- Rotate the test sample  $90^\circ$  and measure the spectral transmittances  $\tau_{P,\min}(\lambda)$  in the same way;
- Calculate the luminous transmittances for the two conditions in the same way as set out in 7.1 using CIE standard illuminant D65 (ISO 11664-2) providing two values of luminous transmittance  $\tau_{P,\max}$  and  $\tau_{P,\min}$ .
- Calculate the polarizing efficiency using the [Formula \(16\)](#):

$$P = 100 \times \frac{\tau_{P,\max} - \tau_{P,\min}}{\tau_{P,\max} + \tau_{P,\min}} \quad (16)$$

### 15.2.3 Test report

The values of polarizing efficiency of the right and left test samples and the associated uncertainties of measurement shall be reported as required in the standard referencing the test methods of this document.

### 15.2.4 Test procedure for the broadband method

Carry out the procedure as follows:

- Illuminate a photodetector having the approximate sensitivity of the human eye (peak at 555 nm) (ISO/CIE 11664-1) with collimated light from a source and filter combination providing a spectral composition approximating CIE standard illuminant D65 (ISO 11664-2) in the visible (380 nm to 780 nm) region. The output of the photodetector shall be linear with respect to the illuminance.
- Mount the linear polarizer in the collimated beam between the source and photodetector. The linear polarizer shall have a polarizing efficiency at least one order of magnitude better than the requirement being tested against [e.g. if the requirement for the filter is a polarizing efficiency of 80 % (9:1) then the linear polarizer shall have an polarizing efficiency of at least 97,5 % (90:1)];
- Record the signal from the photodetector  $V_0$ ;
- Mount the polarizing filter between the polariser and the photodetector;
- Rotate the linear polarizer until a maximum signal is obtained from the photodetector. Record the value  $V_{\max}$ ;
- Rotate the linear polarizer  $90^\circ$  when a minimum signal should be obtained from the photodetector  $V_{\min}$ ;
- Calculate the luminous transmittances for the two conditions in the same way as set out to provide two values of luminous transmittance  $\tau_{P,\max}$  and  $\tau_{P,\min}$ ;

$$\tau_{P,\max} = \frac{V_{\max}}{V_0} \quad (17)$$

$$\tau_{P,\min} = \frac{V_{\min}}{V_0} \quad (18)$$

h) Calculate the polarizing efficiency using the [Formula \(16\)](#).

### 15.2.5 Test report

The values of polarizing efficiency of the right and left test samples and the associated uncertainties of measurement shall be reported as required in the standard referencing this test method.

## 16 Photochromic lenses

### 16.1 Light source(s) to approximate the spectral distribution of solar radiation for air mass 2 for testing

Testing shall be done with a Xenon high pressure lamp with filters chosen so that the specified illuminance of  $(50\,000 \pm 5\,000)$  lx and the irradiance values (with permitted tolerances) given in [Table 3](#) are reached.

**Table 3 — Source irradiance for testing the darkened state of photochromic lenses**

| Wavelength range<br>nm | Irradiance<br>$\text{W}\cdot\text{m}^{-2}$ | Tolerance<br>$\text{W}\cdot\text{m}^{-2}$ |
|------------------------|--------------------------------------------|-------------------------------------------|
| 300-340                | <2,5                                       | —                                         |
| 340-380                | 5,6                                        | $\pm 1,5$                                 |
| 380-420                | 12,0                                       | $\pm 3,0$                                 |
| 420-460                | 20,0                                       | $\pm 3,0$                                 |
| 460-500                | 26,0                                       | $\pm 2,6$                                 |

#### 16.1.1 Radiation source using one lamp

Use an ozone free high-pressure xenon arc lamp, a heat absorbing filter and a cut-on filter with a nominal spectral transmittance as specified in [Figure 9](#).

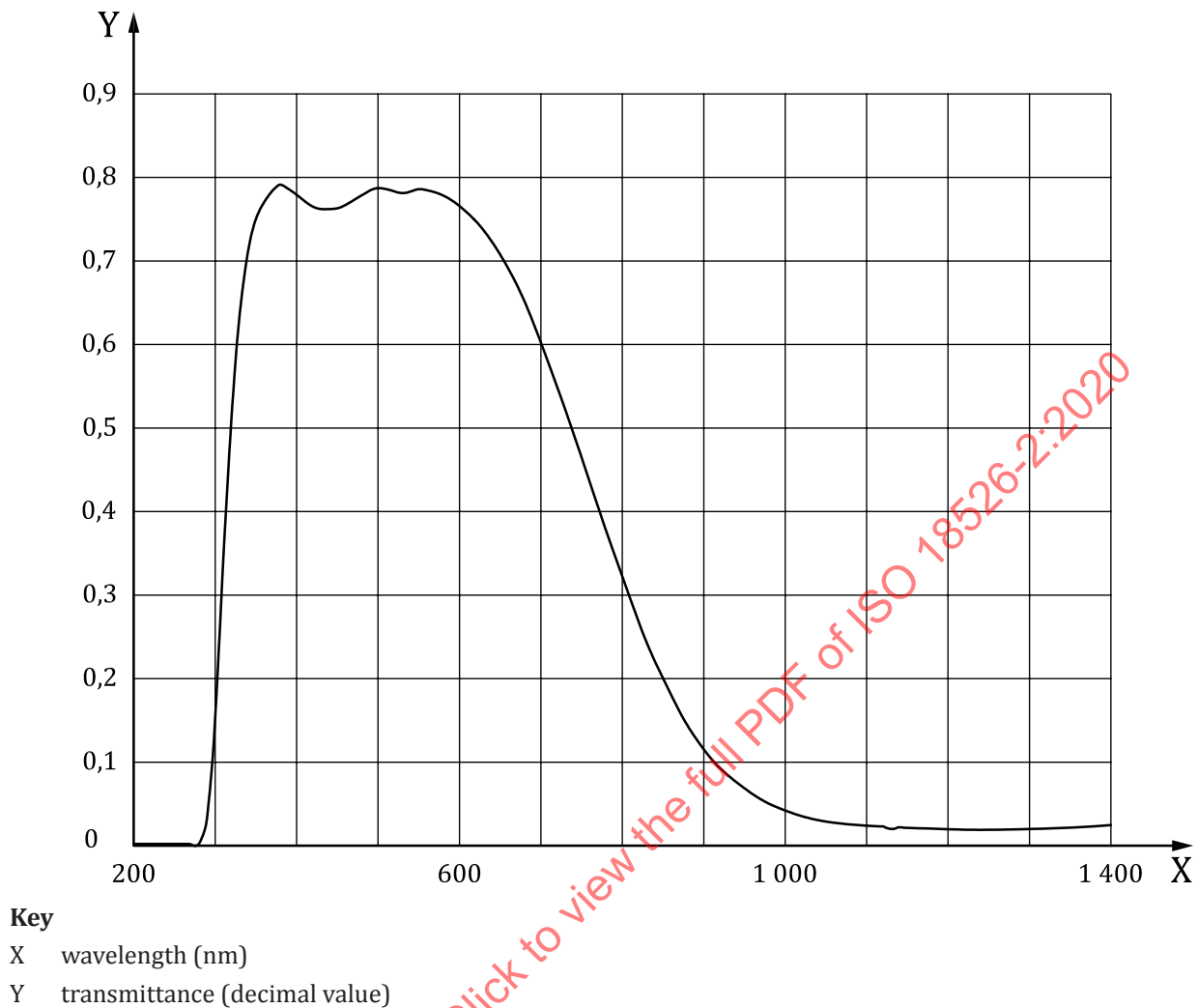


**Figure 9 — Spectral transmittance of the combination of the heat absorbing filter and the cut-on filter for the irradiation of photochromic lenses**

This transmittance curve can be achieved using, for example, a clear white crown glass, e.g. Schott B270<sup>2)</sup> with a thickness of 5 mm and a heat absorbing filter e.g. a Schott KG 2 with a thickness of 3 mm.

#### 16.1.2 Radiation source using two lamps

The solar spectrum can be approximated more closely than with one lamp by using two ozone free high-pressure xenon arc lamps with different filtering in front of them. The radiation from the two lamps is then combined by means of a semi-transparent mirror.

The principle may be expanded by the use of more than two lamps in order to approximate better the solar spectrum in the relevant spectral ranges.

### 16.2 Conditioning for luminous transmittance in the faded state

Unless the manufacturer specifies a different procedure to reach the faded state in the information supplied with the product, photochromic lenses shall be conditioned by the following procedure:

a) Store lenses in the dark at  $(65 \pm 5) ^\circ\text{C}$  for  $(2 \pm 0,2) \text{ h}$ .

2) Schott KG 2 and B270 are trade names of products supplied by SCHOTT AG. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

- b) Store lenses in the dark at  $(23 \pm 5) ^\circ\text{C}$  for at least 12 h.
- c) Expose lenses to  $(15\,000 \pm 1\,500) \text{ lx}$  at  $(23 \pm 1) ^\circ\text{C}$  for 15 min using a source similar to the one described in [16.1](#).
- d) Store lenses in the dark at  $(23 \pm 1) ^\circ\text{C}$  for 60 min.

## 16.3 Measurement

### 16.3.1 Principle

Most photochromic materials respond to normal room lighting and all measurements should therefore be made in absence of extraneous light. Care should be taken to ensure that the radiation used for the measurements does not cause darkening or bleaching of the test sample.

The surface temperature of the filter shall be maintained within  $\pm 1 ^\circ\text{C}$  of the nominated temperature (see [Table 4](#)).

Measurements may be carried out in a water bath. However, immersion of the test sample in water reduces the refractive index change and, therefore, the reflectance at the filter surface, thereby increasing the measured transmittance relative to the transmittance values that would be measured in air. The transmittance values determined using water immersion shall be corrected to provide the equivalent air values. Calibration of the equipment can be checked using a reference sample with a refractive index differing by not more than  $\pm 0,01$  from the refractive index of the filter under test.

The characteristic luminous transmittance values of photochromic filters are defined in ISO 4007:2018, 3.10.1.46 and, unless otherwise stated, are determined for the conditions given in [Table 4](#).

### 16.3.2 Faded state

Measure spectral transmittance from 280 nm to 780 nm (or to 2 000 nm if IR is included) according to [Clause 6](#).

For the requirements specified in the standard referencing this method, calculate

- the luminous transmittance for CIE standard illuminant D65  $\tau_{v,0}$  according to [Clause 7](#),
- the solar UV-A  $\tau_{\text{SUVA } 0}$  and UV-B  $\tau_{\text{SUVB } 0}$  according to [8.4](#) and [8.5](#),
- the solar blue-light transmittance  $\tau_{\text{SB } 0}$  according to [9.1](#),
- the relative visual attenuation coefficient for traffic signal light detection  $Q_{\text{Red } 0}$ ,  $Q_{\text{Yellow } 0}$ ,  $Q_{\text{Green } 0}$  and  $Q_{\text{Blue } 0}$  according to [Clause 11](#) and,
- if required, the solar infrared transmittance  $\tau_{\text{SIR } 0}$  according to [10.4](#).

### 16.3.3 Darkened states

The characteristic luminous transmittance values of photochromic filters are defined in ISO 4007:2018, 3.10.1.46 and, unless otherwise stated, are determined for the illuminance and temperature conditions given in [Table 4](#).

Where testing at 15 000 lx is specified, the spectral irradiance values and the permissible tolerances of these values are those given in [Table 3](#) but multiplied by a factor of 0,3.

**Table 4 — Measurement conditions for the different characteristic luminous transmittance values**

| Characteristic luminous transmittance value | Surface temperature of the test sample<br>°C | Illuminance at the surface of the test sample<br>lx |
|---------------------------------------------|----------------------------------------------|-----------------------------------------------------|
| $\tau_{v,0}$                                | $23 \pm 1$                                   | 0 faded state                                       |
| $\tau_{v,1}$                                | $23 \pm 1$                                   | $50\,000 \pm 5\,000$                                |

The requirements specified in the referencing standards shall be measured and calculated from the spectral transmittance values measured in the darkened state  $\tau_{v,1}$  after irradiation for 15 minutes with  $(50\,000 \pm 5\,000)$  lx at the temperature(s) specified in the product's requirement standards. These requirements are:

- the luminous transmittance for CIE standard illuminant D65  $\tau_{v,1}$  according to [Clause 7](#),
- the solar UV-A  $\tau_{\text{SUVA},1}$  and UV-B  $\tau_{\text{SUVB},1}$  according to [8.4](#) and [8.5](#),
- the solar blue-light transmittance  $\tau_{\text{SB},1}$  according to [9.1](#),
- the relative visual attenuation coefficient for traffic signal light detection  $Q_{\text{Red},1}$ ,  $Q_{\text{Yellow},1}$ ,  $Q_{\text{Green},1}$  and  $Q_{\text{Blue},1}$  according to [Clause 11](#) and,
- if required, the solar infrared transmittance  $\tau_{\text{SIR},1}$  according to [10.4](#).

## 17 Automatic welding filters

### 17.1 General

Automatic welding filters (AWF) present some specific factors in testing. Testing shall be performed in the light and/or dark state(s) as specified by the requirement. The AWF shall be verified to be in the correct state during the period of test. A general description of how to establish the correct state is provided in [Annex E](#).

Unless otherwise stated and when necessary for the correct operation of the AWF, the ambient illumination shall be between 100 lx and 200 lx.

NOTE The ambient illumination is specified for testing test samples with solar or photoelectric power cells. When measuring test samples without solar or photoelectric power cells, ambient illumination is not needed.

The test sample shall be maintained at the temperature specified by the requirement for a minimum of 1 h before testing and during the period of test.

### 17.2 Luminous transmittance in the light state

#### 17.2.1 Measurement

The luminous transmittance of AWFs shall be calculated according to [7.1](#) from spectral transmittance values obtained according to [Clause 6](#) or measured by the broadband method according to [7.3](#).

The spectrophotometric method (see [7.1](#)) shall be taken as the reference method. The luminous transmittance may be determined by a broadband method (see [7.3](#)) or any other suitable method after verification of accuracy by comparison with the spectrophotometric method.

If the position and direction of measurement are not specified, the luminous transmittance of an AWF with a flat filter shall be measured at normal incidence at the geometrical centre of the filter. If the filter is not flat the measurement shall be made at the two reference points along the lines of sight in the as-worn position.

When measuring the luminous transmittance of AWFs, specific consideration shall be made of polarization effects of the test sample and the test method in use. See [B.3.4.6](#).

The AWF shall be verified to be in the light state in the test instrument.

NOTE AWFs can be particularly affected by variations in the angle of incidence and the vergence in the beam. Particular attention needs to be paid to the procedures of [6.4](#).

### 17.2.2 Test report

Report the method of measurement, the luminous transmittance value as both a percentage and calculated as a shade number according to ISO 4007:2018, 3.10.1.5.

## 17.3 Luminous transmittance in the dark state

### 17.3.1 Measurement

The luminous transmittance of AWFs shall be calculated according to [7.1](#) from spectral transmittance values obtained according to [Clause 6](#) or measured by the broadband method according to [7.3](#).

The luminous transmittance can also be determined by a broadband method (see [7.3](#)) or any suitable method after verification of accuracy by comparison with fixed shade number welding filters for which calibrations of luminous transmittance have been obtained.

If the position and direction of measurement is not specified, the luminous transmittance of an AWF with a flat filter shall be measured at normal incidence at the geometrical centre of the filter. If the filter is not flat, the measurement shall be made at the two reference points along the lines of sight in the as-worn position.

When measuring the luminous transmittance of AWFs, specific consideration shall be made of polarization effects of the test sample and the spectrophotometric method in use. See [B.3.4.6](#).

The AWF shall be verified to be in the dark state in the test instrument. A method of establishing this is provided in [Annex E](#).

NOTE 1 AWFs can be particularly affected by variations in the angle of incidence and the vergence of the beam. Particular attention needs to be paid to the requirements of [6.4](#).

NOTE 2 The trigger light source can be a suitable AC-driven UV, visible or IR emitting diode capable of switching the test sample from the light to the dark state.

### 17.3.2 Test report

The method of measurement, the luminous transmittance value as both a percentage and a shade number, calculated according to ISO 4007:2018, 3.10.1.5, and the associated uncertainties of measurement shall be reported as required in the standard referencing this test method.

## 17.4 Shade number of welding filters with automatic shade number setting

### 17.4.1 Principle

This procedure specifies the method for determining the shade number setting of welding filters with automatic shade number setting. The test shall measure the shade number of a welding filter at different illumination levels.

### 17.4.2 Apparatus

The test apparatus shall consist of three different light sources: a light source with variable luminance, a trigger light source, a light source of CIE standard illuminant A (see ISO 11664-2), a photodetector and a recording device.

A lamp suitable for measuring luminous transmittance, for example the broadband method described in 7.3, shall be used.

A trigger light source suitable for simulating the intended welding use may be used for triggering the photodetectors of the test sample to switch from the light state to the dark state.

A suitable lamp shall be used as a source of radiation producing variable illuminance. The minimum range of variation shall be between  $(500 \pm 50)$  lx and  $(30\,000 \pm 3\,000)$  lx. A suitable method for measuring luminous transmittance shall be used.

NOTE If feasible, any of the light sources can be combined with any other one.

The photodetector and recording device shall be capable of detecting and recording the light from the measurement light source transmitted by the test sample.

### 17.4.3 Test procedure

All measurements are performed at the geometrical centre of the test sample. The test sample shall be set up so that the plane of the photodetector(s) of the test sample is at  $(90 \pm 10)^\circ$  to the light beam including the divergence of the beam. The transmittance light source shall be shielded from the light source of variable illuminance.

Measure the luminous transmittance at the illuminance applicable for the shade numbers according to the product's requirement standard within the range specified by the manufacturer. The tolerance of the illuminance values shall be  $\pm 10\%$ .

Perform the measurements at the appropriate test temperatures. Before testing, the test sample shall be maintained at the appropriate test temperature for a minimum of 1 hour and during the period of test. Calculate the shade number from the luminous transmittance and check for each test temperature if the requirement of the product's requirement standard is met. Plot a graph of shade number against illuminance.

At double the illuminance value applicable for the darkest state shade number, check that the luminous transmittance of the test sample corresponds to the range of the darkest state shade number.

NOTE The meaning of "darkest dark state shade number" is the highest shade number specified by the manufacturer.

### 17.4.4 Test report

Report whether the requirements of the product requirement standard are met as required in standard(s) referencing this test method.

## 17.5 Luminous transmittance variation over time

### 17.5.1 Principle

This procedure specifies the method for determining the variation of luminous transmittance of an AWF over a one minute period. The AWF shall be triggered for more than one minute and luminous transmittance readings shall be taken at 1 second intervals.

### 17.5.2 Apparatus

Perform the measurement using a suitable method for measuring luminous transmittance, for example the broadband method described in 7.3. The integration time for the luminous transmittance measurements shall be nominally 100 ms.

A trigger light source suitable for simulating the intended welding use shall be used for triggering the photodetectors of the test sample.

### 17.5.3 Test procedure

The luminous transmittance of an AWF with a flat filter shall be measured at normal incidence at the geometrical centre of the filter. If the filter is not flat, the measurement shall be made at the two reference points along the lines of sight in the as-worn position.

Use the trigger light source to activate the test sample. Make the first measurement of the luminous transmittance 3 seconds after activation. Make sixty more measurements at 1 s intervals. The test sample shall remain triggered during the complete series of measurements.

### 17.5.4 Test report

Divide the lowest measured value of the luminous transmittance by the highest measured value and express the difference of this ratio to 1, as a percentage. Record this percentage  $r$  as the luminous transmittance variation over time.

$$r = 100 \times (1 - \tau_{\min} / \tau_{\max}) \% \quad (19)$$

## 17.6 Blue-light transmittance for artificial sources

### 17.6.1 Measurement

The blue-light transmittance is measured in the light and dark states using either the spectral values (see 9.2.1) or the broadband method (see 9.2.2).

The AWF shall be verified to be in the correct state as specified by the product's requirements standard during the period of test. A general description of how to establish the correct state is provided in Annex E.

### 17.6.2 Test report

Calculate and report the blue-light transmittance for artificial sources in the light and dark states and the method used.

## 17.7 Uniformity of luminous transmittance for flat filters

### 17.7.1 Filter covering both eyes

#### 17.7.1.1 Test method

Scan the areas defined in 7.4.2.1 with a 5 mm nominal diameter light beam of white light or a narrow spectral band with a maximum spectral energy at  $(555 \pm 25)$  nm incident normally to the surface of the filter and measure the luminous transmittance with a photodetector whose spectral responsivity approximates that of the CIE 2° standard observer (ISO/CIE 11664-1).

All measurements shall be made normal to the filter and the distance between two measurement points shall not exceed 5 mm.

For left and right areas, measure and record the maximum value of luminous transmittance  $\tau_{v,\max}$  and the minimum value of luminous transmittance  $\tau_{v,\min}$ .

Measurements shall be made in the light and/or dark states as specified in the product's requirement standard.

#### 17.7.1.2 Calculations

Calculate the value of  $\Delta F_R$  and  $\Delta F_L$  for the right and left scanned areas, as a percentage, with [Formula \(5\)](#) in [7.4.2.2](#).

#### 17.7.1.3 Test report

The values of  $\Delta F_R$  and  $\Delta F_L$  for the right and left scanned areas as a percentage, the applicable illuminant(s) or source(s) and the associated uncertainty of measurement shall be reported as required in standard(s) referencing this method.

### 17.8 Angular dependence of luminous transmittance for flat filters

#### 17.8.1 Principle

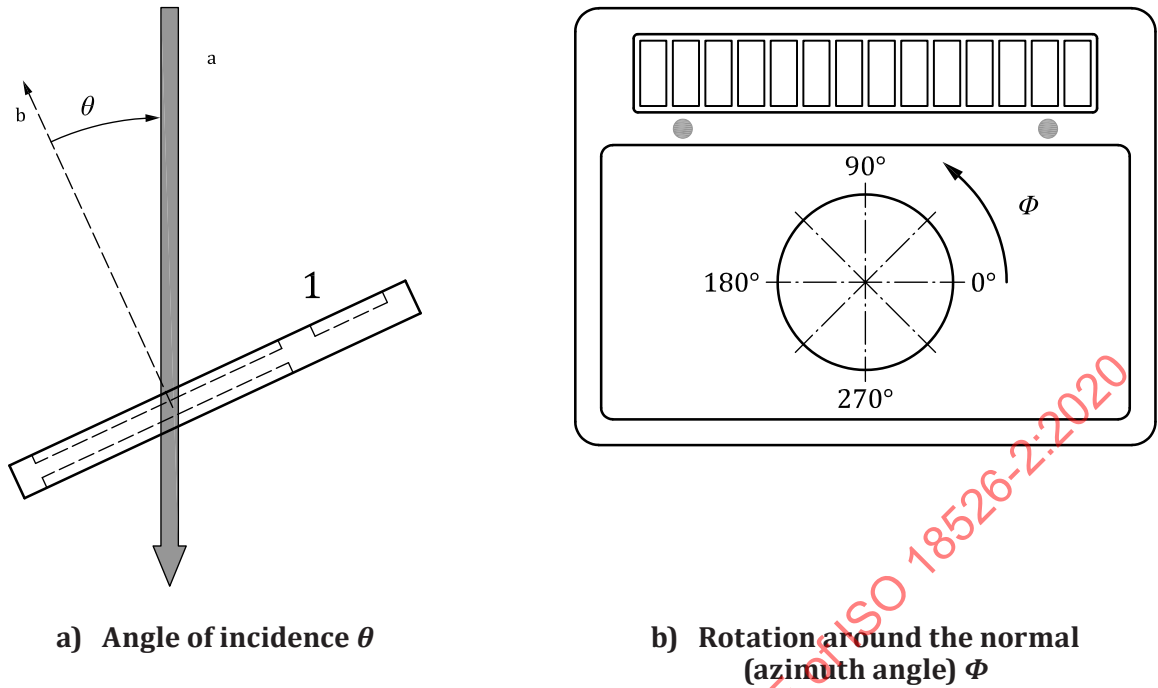
This procedure specifies the method for determining the angular dependence of luminous transmittance for a flat AWF with line of sight at normal incidence to the filter. The test shall measure the luminous transmittance variations within the viewing cone of angles between normal incidence and up to and including both 15° and 30° to the normal to the test sample.

#### 17.8.2 Apparatus

A broadband method for measuring luminous transmittance, for example the one described in [7.3](#), shall be used. Particular attention needs to be paid to the vergence and direction of the light beam and the requirements of [Clause 6](#).

A support for positioning the test sample in the light beam is required that enables the orientation of the test sample to vary relative to the light beam. It shall be possible to vary the angle between the normal to the test sample and the incident light (angle of incidence) from 0° to 30° as well as the incident light rotation around the normal to the test sample (azimuth angle) from 0° to 360° (see [Figure 10](#)). For example, a dual rotary support having the first rotation axis perpendicular to the light beam and the second rotation axis oriented normal to the test sample.

NOTE Other types of goniometer methods can be used provided the angles tested are transformed from one goniometer type to the other. See Reference [\[8\]](#) and [\[9\]](#) for information on goniometer types.



**Key**

- |          |                    |   |                                    |
|----------|--------------------|---|------------------------------------|
| 1        | test sample        | a | Incident light beam.               |
| $\theta$ | angle of incidence | b | Normal to the test sample surface. |
| $\phi$   | angle of rotation  |   |                                    |

**Figure 10 — Rotation of the test sample around the incident light beam direction**

**17.8.3 Test procedure**

The angular dependence of luminous transmittance is measured in the light and dark states. The AWF shall be verified to be in the correct state during the period of test. A general description of how to establish the correct state is provided in [Annex E](#). All measurements are performed at the geometrical centre of the test sample.

Measure the luminous transmittance at angles of incidence  $\theta$  from 0° to 30° to the normal in steps of 2,5° and angles of rotation  $\phi$  around the line of sight from 0° to 360° as set out in [Table 5](#) and [Figure 11](#), in order to establish the maximum and minimum luminous transmittance. The tolerance of the angle of incidence shall be  $\pm 1^\circ$  or better.

Table 5 — Location of measurements for test of angular dependence. See also [Figure 11](#)

|                                         |        | Angle of incidence $\theta$ |     |     |     |      |      |      |      |      |      |      |      |      |   |
|-----------------------------------------|--------|-----------------------------|-----|-----|-----|------|------|------|------|------|------|------|------|------|---|
|                                         |        | degrees (°)                 |     |     |     |      |      |      |      |      |      |      |      |      |   |
|                                         |        | 0                           | 2,5 | 5,0 | 7,5 | 10,0 | 12,5 | 15,0 | 17,5 | 20,0 | 22,5 | 25,0 | 27,5 | 30,0 |   |
| Angle of rotation $\Phi$<br>degrees (°) | 0      |                             | √   | √   |     | √    | √    |      | √    |      | √    |      | √    |      | √ |
|                                         | 11,25  | 191,25                      |     |     |     |      | √    |      | √    |      | √    |      | √    |      |   |
|                                         | 22,50  | 202,50                      |     |     | √   |      | √    |      | √    |      | √    |      | √    |      | √ |
|                                         | 33,75  | 213,75                      |     |     |     |      | √    |      | √    |      | √    |      | √    |      |   |
|                                         | 45,00  | 225,00                      |     | √   |     | √    | √    |      | √    |      | √    |      | √    |      | √ |
|                                         | 56,25  | 236,25                      |     |     |     |      | √    |      | √    |      | √    |      | √    |      |   |
|                                         | 67,50  | 247,50                      |     |     | √   |      | √    |      | √    |      | √    |      | √    |      | √ |
|                                         | 78,75  | 258,75                      |     |     |     |      | √    |      | √    |      | √    |      | √    |      |   |
|                                         | 90,00  | 270,00                      |     | √   |     | √    | √    |      | √    |      | √    |      | √    |      | √ |
|                                         | 101,25 | 281,25                      |     |     |     |      | √    |      | √    |      | √    |      | √    |      |   |
|                                         | 112,50 | 292,50                      |     |     | √   |      | √    |      | √    |      | √    |      | √    |      | √ |
|                                         | 123,75 | 303,75                      |     |     |     |      | √    |      | √    |      | √    |      | √    |      |   |
|                                         | 135,00 | 315,00                      |     | √   |     | √    | √    |      | √    |      | √    |      | √    |      | √ |
|                                         | 146,25 | 326,25                      |     |     |     |      | √    |      | √    |      | √    |      | √    |      |   |
|                                         | 157,50 | 337,50                      |     |     | √   |      | √    |      | √    |      | √    |      | √    |      | √ |
|                                         | 168,75 | 348,75                      |     |     |     |      | √    |      | √    |      | √    |      | √    |      |   |
|                                         | 180,00 |                             |     | √   |     | √    | √    |      | √    |      | √    |      | √    |      | √ |

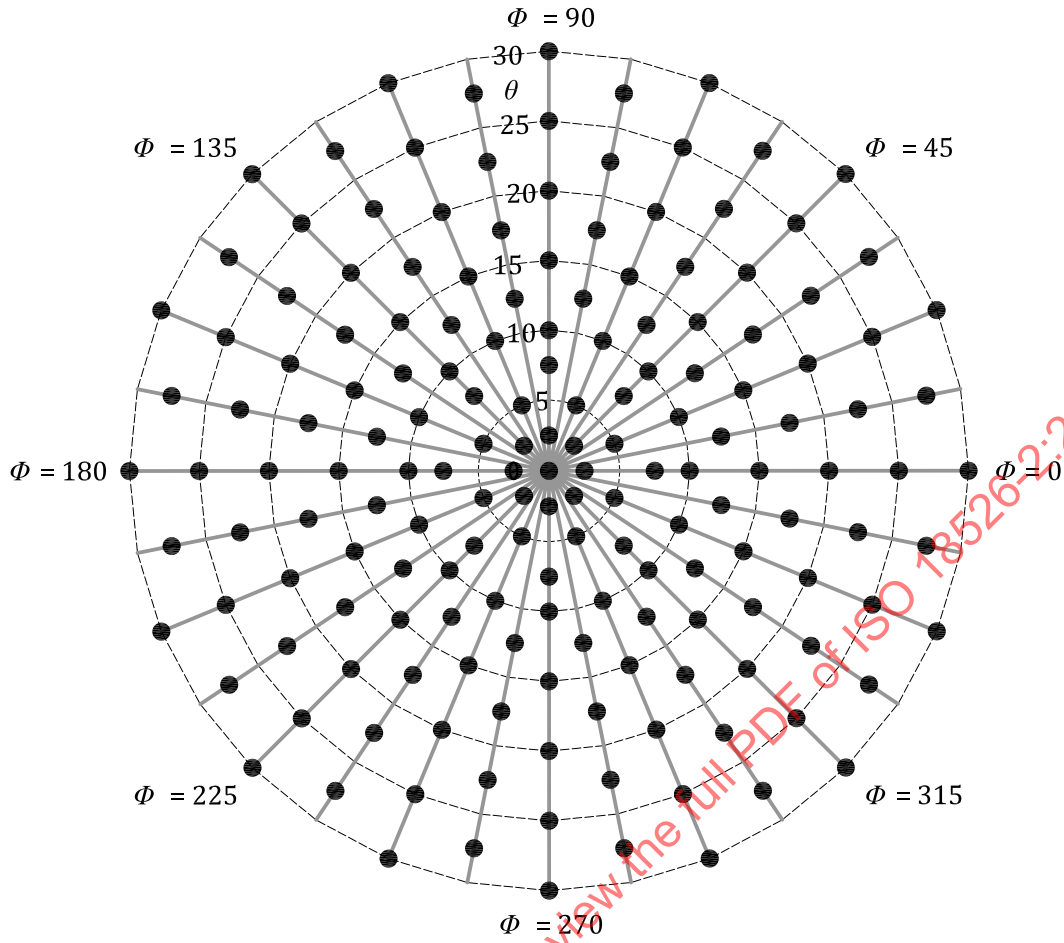


Figure 11 — Location of measurements for test of angular dependence. See also [Table 5](#).

Calculate  $V_{15}$ , by

$$V_{15} = \max \left[ \frac{\max(\tau_{\theta, \phi})}{\tau_{0,0}}, \frac{\tau_{0,0}}{\min(\tau_{\theta, \phi})} \right] \quad (20)$$

where

$\tau_{\theta, \phi}$  are the transmittances at the positions  $\theta, \phi$  for  $0^\circ < \theta \leq 15^\circ$

$\tau_{0,0}$  is the transmittance at position 0,0

Calculate  $V_{30}$ , by

$$V_{30} = \frac{\max(\tau_{\theta, \phi})}{\tau_{0,0}} \quad (21)$$

where

$\tau_{\theta, \phi}$  are the transmittances at the positions  $\theta, \phi$  for  $0^\circ < \theta \leq 30^\circ$

$\tau_{0,0}$  is the transmittance at position 0,0

$V_{15}$  and  $V_{30}$  may be also expressed as shade numbers

$$SN_{\Delta} = SN_{0,0} - SN_{\theta, \phi} \quad (22)$$

$$V_{15} = \max \left( 10^{\frac{3}{7} \cdot SN_{\Delta}}, 10^{-\frac{3}{7} \cdot SN_{\Delta}} \right) = \max \left( 10^{\frac{3}{7} \cdot |SN_{\Delta}|} \right) \quad 0^{\circ} < \theta \leq 15^{\circ} \quad (23)$$

$$V_{30} = \max \left( 10^{\frac{3}{7} \cdot |SN_{\Delta}|} \right) \quad 0^{\circ} < \theta \leq 30^{\circ} \quad (24)$$

#### 17.8.4 Test report

Report the values  $V_{15}$  and  $V_{30}$  and the associated uncertainties of measurement as required in the standard referencing this test method.

### 17.9 Angular dependence and uniformity of luminous transmittance for curved filters

#### 17.9.1 Principle

This procedure specifies the method for determining the angular dependence of luminous transmittance for an automatic welding filter that is not flat. The transmittance matching at right and left reference points are calculated in 17.10 using some of the same data. In the test the luminous transmittance variations seen from an eye position and within a viewing cone of angles up to and including  $15^{\circ}$  to the line of sight and within the viewing cone of angles up to and including  $30^{\circ}$  to the line of sight are measured.

#### 17.9.2 Apparatus

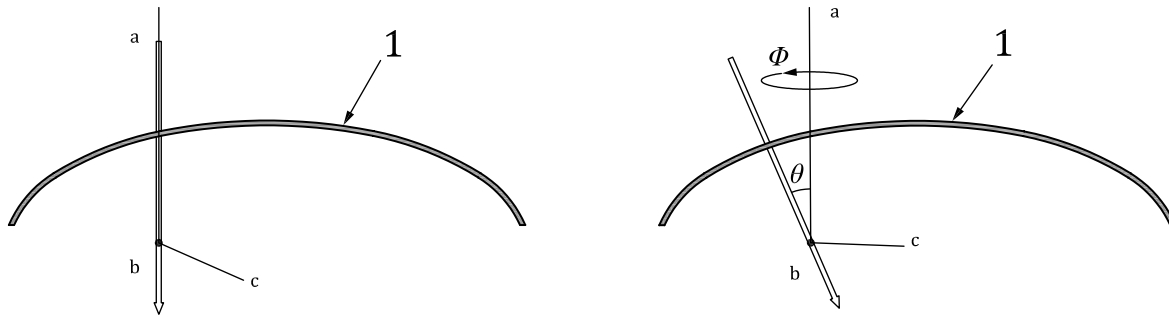
The broadband method for measuring luminous transmittance in 7.3 shall be used. Particular attention needs to be paid to the vergence and direction of the light beam and the general requirements of Clause 7.

A support for positioning the test sample in the light beam is required that enables the test sample to rotate around the reference point located in the light beam. It shall be possible to vary the angle between the direction of measurement and the light beam (angle of incidence) from  $0^{\circ}$  to  $30^{\circ}$  as well as the direction of measurement rotation around the light beam (azimuth angle) from  $0^{\circ}$  to  $360^{\circ}$  (see Figure 12). For example, a dual rotary support having the first rotation axis (V) perpendicular to the light beam and the second rotation axis (H) perpendicular to first rotation axis may be used. Angles  $\alpha$  and  $\beta$  around the V and H axes corresponding to different angle of incidence ( $\theta$ ) and azimuth angles ( $\phi$ ) can be calculated using the following formulae:

$$\alpha = \arctan (\tan \theta \cdot \cos \phi) \quad -90^{\circ} < \alpha \leq 90^{\circ}$$

$$\beta = \arctan (\tan \theta \cdot \sin \phi) \quad -90^{\circ} < \beta \leq 90^{\circ}$$

NOTE Other types of goniometer methods can be used provided the angles tested are transformed from one goniometer type to the other. See References [8] and [9] for information on goniometer types.



- a) Angle of incidence is  $0^\circ$  when light beam coincides with line of sight
- b) Angle of incidence  $\theta$  and rotation around the line of sight (azimuth angle)  $\Phi$

**Key**

|          |                    |   |                    |
|----------|--------------------|---|--------------------|
| 1        | test sample        | a | Line of sight.     |
| $\theta$ | angle of incidence | b | Light beam.        |
| $\Phi$   | angle of rotation  | c | Measurement point. |

**Figure 12 — Measurement of uniformity and angular dependence**

### 17.9.3 Procedure

The combined uniformity and angular dependence of luminous transmittance is measured in the light and dark states. The automatic welding filter shall be verified to be in the correct state during the period of test. A general description of how to establish the correct state is provided in [Annex E](#). The measurements are made with the reference point located at the right and left positions in the as-worn position. If the as-worn position is not known the reference points shall be located 50 mm behind the reference points as defined in ISO 4007:2018, 3.8.9 and with the line of sight parallel to the normal to the welding filter at its geometric centre.

Measure the luminous transmittance at angles of incidence  $\theta$  from  $0^\circ$  to  $30^\circ$  in steps of  $2,5^\circ$  and angles of rotation  $\Phi$  around the line of sight from  $0^\circ$  to  $360^\circ$  as set out in [Table 5](#) and [Figure 11](#), in order to establish the maximum and minimum luminous transmittances. The tolerance of the angle of incidence shall be  $\pm 1^\circ$  or better. Measurements outside the test sample area as well as within a 5 mm wide portion around the edge of the test sample shall be excluded from the evaluation.

Calculate  $C_{15}$  for the right and left reference points by

$$C_{15} = \max \left[ \frac{\max(\tau_{\theta,\Phi})}{\tau_{0,0}}, \frac{\tau_{0,0}}{\min(\tau_{\theta,\Phi})} \right] \quad (25)$$

where

$\tau_{\theta,\Phi}$  are the transmittances at the positions  $\theta, \Phi$  for  $0^\circ < \theta \leq 15^\circ$

$\tau_{0,0}$  is the transmittance at position 0,0

Calculate  $C_{30}$  for the right and left reference points by

$$C_{30} = \frac{\max(\tau_{\theta,\Phi})}{\tau_{0,0}} \quad (26)$$

where

$\tau_{\theta,\phi}$  are the transmittances at the positions  $\theta, \phi$  for  $0^\circ < \theta \leq 30^\circ$

$\tau_{0,0}$  is the transmittance at position 0,0

#### 17.9.4 Test report

Report the values  $C_{15}$  and  $C_{30}$  for both the right and left reference points and the uncertainties of measurement as required in standard referencing this test method.

### 17.10 Transmittance matching at right and left reference points

#### 17.10.1 Procedure

For the right and left reference points, record the values of the luminous transmittance measured at angle of incidence  $0^\circ$  in [17.7](#) (for flat filters) or [17.9](#) (for curved filters).

$$\tau_{v,L} = \tau_{0,0,L}$$

$$\tau_{v,R} = \tau_{0,0,R}$$

Calculate  $\Delta P$  using [Formula \(6\)](#) in [7.5.2](#).

#### 17.10.2 Test report

Report the value of  $\Delta P$  and the uncertainties of measurement as required in standard referencing this test method.

### 17.11 Switching time

#### 17.11.1 Principle

This procedure specifies the method for determining the switching time from the light state to a dark state of an AWF. In order to determine the switching time, the reduction in luminous transmittance of an AWF is recorded over time, while it is exposed to radiation from a trigger light source.

#### 17.11.2 Apparatus

The test apparatus shall consist of a light source, a trigger light source, a detector and a recording device.

The light source shall be a source of CIE standard illuminant A in accordance with ISO 11664-2.

A trigger light source suitable for intended welding use and capable of a rise time at switch-on of less than or equal to 10 % of the switching time required for the shade number difference being measured. See ISO 16321-2:2020, Table 8.

NOTE The trigger light source can be a suitable AC-driven UV, visible or IR emitting diode capable of switching the test sample from light state to dark state.

The light detector and recording device shall be capable of detecting and recording the light transmitted by the test sample with a rise time shorter or equal to 10 % of the switching time required for the shade number difference being measured.

#### 17.11.3 Procedure

The test sample shall be maintained at the appropriate test temperature for a minimum of 1 hour before testing and during the period of test.

Set up the measurement light source and the test sample so that the plane of the test sample is at  $(90 \pm 1)^\circ$  to the measurement beam. Solar or photoelectric power cells shall be shielded from the transmittance light source beam. With the transmittance light source switched on, the trigger light source shall be activated to its high illumination state to switch the test sample to its dark state. Record the measurement light transmitted through the test sample during the switching period.

Calculate the switching time  $t_s$  from the formulae given in ISO 4007:2018, 3.10.3.9.

#### 17.11.4 Uncertainty of measurement

The uncertainty of measurement associated with the method of test shall be established according to ISO/IEC Guide 98. The value of this estimate shall not exceed  $\pm 10\%$ .

#### 17.11.5 Test report

Report the switching time  $t_s$  and the uncertainty of measurement.

### 17.12 Holding time

#### 17.12.1 Principle

This procedure specifies the method for determining the time for which the dark state of an AWF is maintained after cessation of the trigger light source. The test shall measure the time interval between the cessation of the trigger light source and the luminous transmittance of an AWF rising to 3,0 times the transmittance value in the dark state. For an automatic welding filter with adjustable dark state, this test applies to the setting with the darkest dark state.

This may be carried out in a single procedure with [17.11.3](#).

#### 17.12.2 Apparatus

The test apparatus shall be that described in [17.11.2](#).

#### 17.12.3 Procedure

The procedure is the same as in [17.11.3](#) except that the trigger light source shall be deactivated from its high illumination state to change the test sample to its light state. Record the measured light transmitted through the test sample during the switch off period.

Calculate the holding time according to ISO 4007:2018, 3.10.3.10.

#### 17.12.4 Uncertainty of measurement

The uncertainty of measurement associated with the method of test shall be established according to ISO/IEC Guide 98. The value of this estimate shall not exceed  $\pm 10\%$ .

#### 17.12.5 Test report

Report the holding time  $\tau_{ho}$  and the uncertainty of measurement as required in standard referencing this test method.

### 17.13 Manual control of dark state

#### 17.13.1 Procedure

If manual control of the dark state scale number is provided, inspect that there is a digital indication of every scale number in the range in steps of 1.

### 17.13.2 Test report

Report whether or not there is a digital indication of every scale number in the range in steps of 1.

## 17.14 Optical sensitivity of welding detection

### 17.14.1 Principle

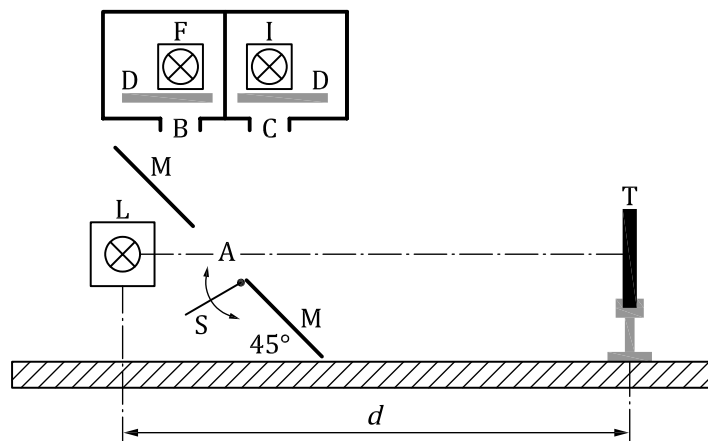
This procedure specifies the method for determining the sensitivity of the welding detection of an AWF. The test shall confirm that the AWF switches from the light to the dark state when a defined light source is switched on, stays in the dark state during the time of illumination and returns to the light state when the light source is switched off.

### 17.14.2 Apparatus

This apparatus, as shown in [Figure 13](#) consists of a trigger light source (L) comprising a xenon arc lamp and a mechanical shutter (S), a light source comprising a combination of an artificial light source (F) and an incandescent light source (I) with diffusers (D) and corresponding diaphragms (B and C). The incandescent light source (I) driven with a high DC current serves as a high intensity source and the incandescent source driven at a low DC current with the fluorescent source driven with mains supply AC serve as the low intensity source. See [17.14.4](#), [17.14.6](#) and [17.14.7](#) for details of the trigger source (L), higher (I) and lower (F) intensity sources.

The light sources (L, F, I) have to be turned on during the entire test in order to generate a stable output light intensity and light spectrum. Their absolute and relative light intensities at the position of the test sample (T) are adjusted by means of the diaphragms (B, C) as well as by the appropriate positioning of the test sample from the xenon arc lamp (d).

The trigger light source (L) simulates a welding arc (TIG at 30A). The lower intensity light source (F and I) simulates indoor ambient lighting (e.g. an adequate combination of sunlight and artificial light sources) while the high intensity light source simulates outdoor ambient light (e.g. sunlight and daylight). The light from the light sources is combined at the location of the test sample (T) by means of the mirror (M) with a circular opening (A) and a built-in mechanical shutter (S) simulating the on/off status of the welding arc.

**Key**

|   |                                   |          |                                             |
|---|-----------------------------------|----------|---------------------------------------------|
| A | circular opening in the mirror    | B, C     | diaphragms                                  |
| D | diffuser                          | M        | mirror                                      |
| S | mechanical shutter                | <i>d</i> | distance from trigger source to test sample |
| F | fluorescent light source          | I        | incandescent light source                   |
| L | Xenon arc triggering light source | T        | test sample                                 |

NOTE See also a more detailed description in Reference [5].

**Figure 13 — Apparatus for testing the optical sensitivity of welding detection – Schematic**

### 17.14.3 Measuring equipment

The following measuring equipment and procedures are necessary for evaluating and calibrating the light sources of the apparatus shown in [Figure 13](#):

- 1) Calibrated illuminance meter;
- 2) Broadband radiometer comprising:
  - a) silicon photodiode with a matched built-in optical filter providing a nominally flat spectral response in the range 475 nm to 975 nm,
  - b) current to voltage converter with a frequency range: DC to 10 kHz;
- 3) Dedicated electronic instruments:
  - a) low-pass filter with the following characteristics: pass band gain: 0 dB; cut-off frequency: 1 Hz; slope rate: 12 dB/octave; filter type: Bessel;
  - b) calibrated instrument to evaluate the average value of the output from the low-pass filter;
  - c) band-pass filter (I) with the following characteristics: pass band gain 0 dB; low cut-off frequency (–3 dB) 50 Hz; high cut-off frequency (–3 dB) 6 000 Hz; slope rate 18 dB/octave; filter type Bessel;
  - d) calibrated instrument to determine the RMS value of the output from the band-pass filter (I). The instrument should have flat frequency response from 20 Hz to 10 kHz;
  - e) band-pass filter (II) with the following characteristics: pass band gain 0 dB; low cut-off frequency (–3 dB) 400 Hz; high cut-off frequency (–3 dB) 6 000 Hz; slope rate 18 dB/octave; filter type: Bessel;
  - f) calibrated instrument to determine the peak value of the output from band-pass filter (II);

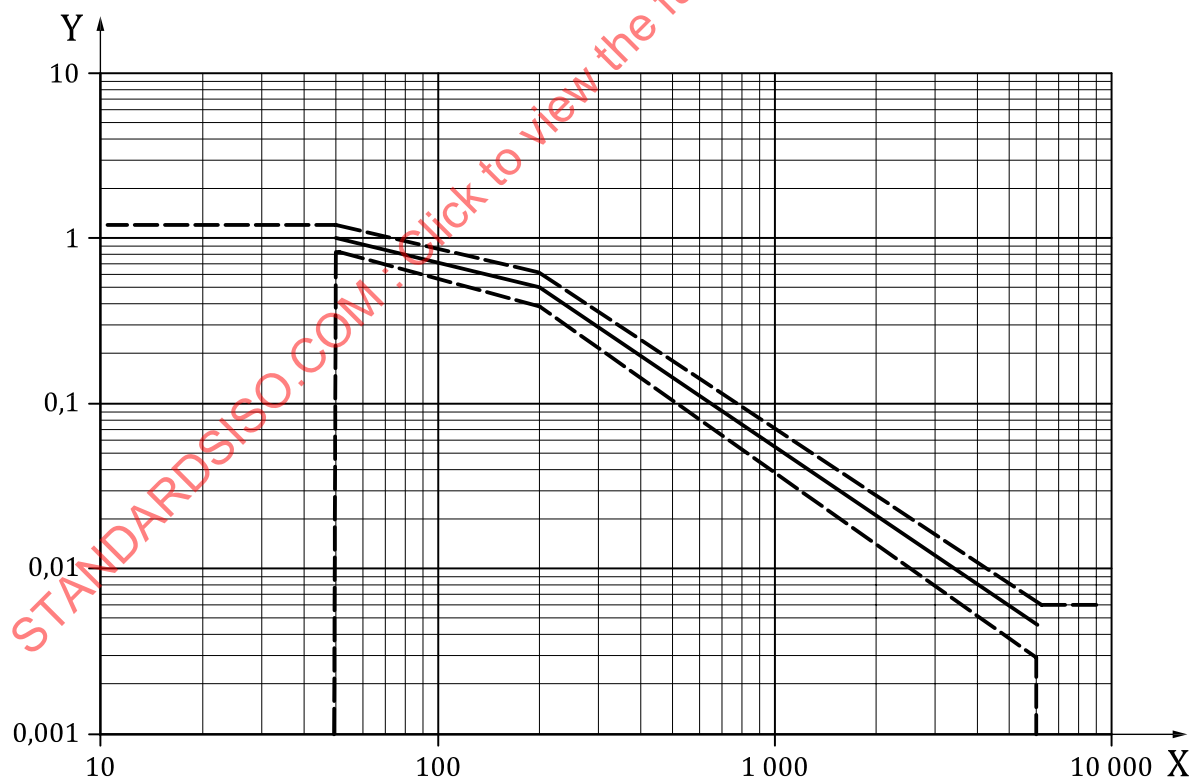
- g) instrument for the evaluation of the frequency spectrum (COBISS, SI-ID 23568167<sup>[5]</sup>).
- 4) Visual inspection may be used to determine whether the test sample is in the untriggered or dark state.

#### 17.14.4 Trigger light source (L)

The trigger light source (L) comprises a xenon arc lamp and a mechanical light shutter (S) that simulates the on/off status of the welding arc. The xenon arc lamp (Xe) with power rating of 75 W is driven by a power stabilized driver having a capability of amplitude modulation in order to simulate a broad frequency spectrum as exhibited by a welding arc. The required relative intensity frequency spectrum of the trigger light source is shown in Figure 14 with tolerances indicated by the dashed lines. The mathematical representation of the relative frequency spectrum is given in Table 6.

**Table 6 — Relative intensity frequency spectrum of the trigger light source**

| Frequency<br>$f$<br>Hz | Relative Intensity<br>$RI$ | Tolerance          |
|------------------------|----------------------------|--------------------|
| $f < 50$               | $\leq 1,1$                 | —                  |
| $50 \leq f < 200$      | $7,07 f^{0,50}$            | $\pm 10\%$ of $RI$ |
| $200 \leq f < 6\,000$  | $750 f^{1,38}$             | $\pm 10\%$ of $RI$ |
| $6\,000 < f$           | $\leq 0,006$               | —                  |



**Key**

- $X$  frequency  $f$  (Hz)  
 $Y$  relative intensity

**Figure 14 — Frequency spectrum of trigger light source (L) with tolerances**

NOTE The relative frequency spectrum is based on measurements of 5 state-of-the-art low power DC TIG welding devices (COBISS, SI-ID 23568167[5]).

### 17.14.5 Calibration procedure for the trigger light source (L)

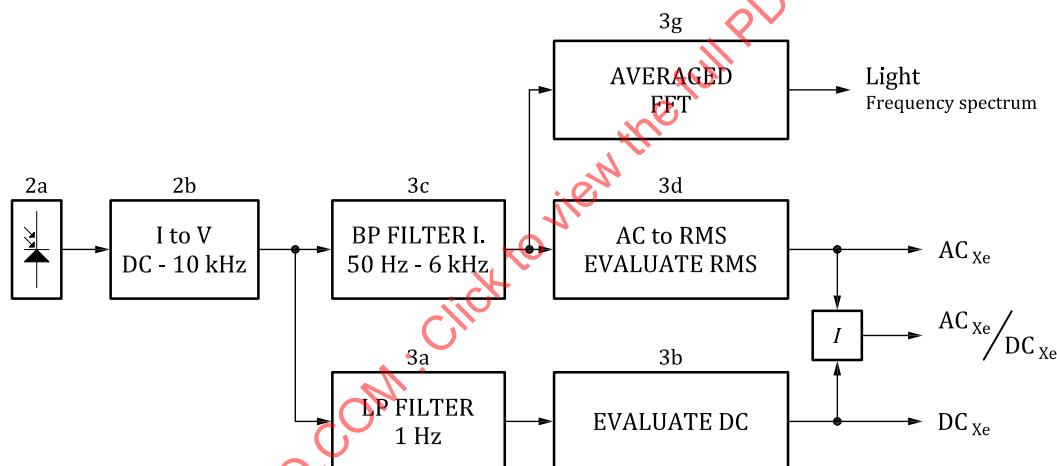
Turn on the xenon arc lamp of the trigger light source (L) and let it stabilize. Open the light shutter (S).

Measure the frequency spectrum as follows with the dedicated measuring equipment defined in 17.14.3 to confirm compliance with the required relative intensity frequency spectrum given in Table 6 and presented in Figure 14.

A schematic diagram of the instrumentation for the trigger light source calibration is shown in Figure 15.

Measure the illuminance given by the xenon arc lamp (Xe) at the position of the test sample using the calibrated illuminance meter [17.14.3 – 1)]. Adjust the distance  $d$  between the xenon arc lamp (Xe) and the position of the test sample to achieve the illuminance  $(132 \pm 10)$  lx. At the same position measure the DC level ( $DC_{Xe}$ ) of the light from the xenon arc lamp (L) with the broad band radiometer [17.14.3 – 2 a)] measuring the signal electrically filtered by the low-pass filter [17.14.3 – 3 a) and 3 b)]. Turn on the modulation and measure the RMS value of the light signal ( $AC_{Xe}$ ) with the broad band radiometer [17.14.3 – 2 a)] measuring the signal electrically filtered by a band-pass filter [17.14.3 – 3 c) and 3 d)].

Adjust the amplitude of the modulation until the  $AC_{Xe}/DC_{Xe}$  ratio is  $(0,39 \pm 0,02)$  %.



#### Key

- |    |                              |    |                             |
|----|------------------------------|----|-----------------------------|
| 2a | silicon photodiode           | 3c | band-pass filter            |
| 2b | current to voltage converter | 3d | RMS detector                |
| 3a | low-pass filter              | 3g | frequency spectrum analyser |
| 3b | DC detector                  |    |                             |

NOTE The numbering corresponds to the fuller description given in 17.14.3.

Figure 15 — Block diagram for trigger light source (TLC) calibration

### 17.14.6 Higher intensity light source (I)

#### 17.14.6.1 General

The higher intensity light source simulates the behaviour of sunlight and consists of one or more halogen incandescent lamps driven by a DC current at the lamp nominal rating. The calibration of the optical output from the higher intensity light source is made by an adjustable diaphragm (C) to give a

specific illuminance at the position of the test sample. A diffuser (D) is used to diffuse the light output at the position of the test sample. See [Figure 13](#).

#### 17.14.6.2 Calibration procedure for the higher intensity light source

Turn on the incandescent source (I) at its nominal high current and let it stabilize.

Measure the illuminance in the plane of the test sample with the calibrated illuminance meter [17.14.3 -1)]. Adjust the diaphragm (C) in front of the lamps until the measured illuminance is  $(2\,000 \pm 200)$  lx.

#### 17.14.7 Lower intensity light source (F)

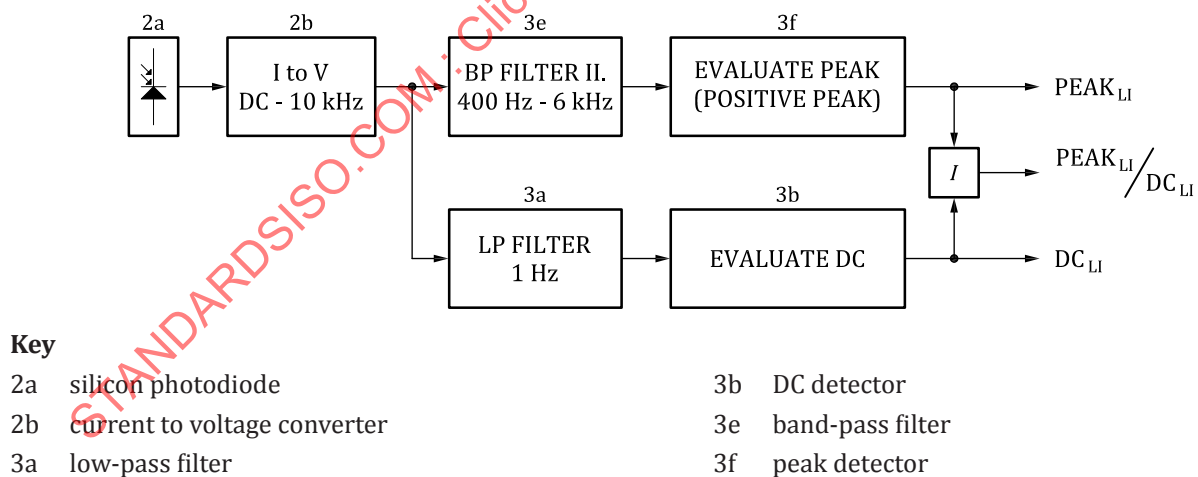
##### 17.14.7.1 General

The lower intensity light source simulates indoor lighting conditions, where most of the working place illumination is provided by AC driven, mains powered light source (e.g. artificial lighting) and possibly mixed with some daylight. This light source comprises a combination of an AC-driven fluorescent light source (F) with passive inductive ballast and an incandescent light source (I). Their relative intensities are adjusted by means of diaphragms (B and C).

NOTE Fluorescent light sources and passive inductive ballasts may become unobtainable. A white LED without integrated electronics and driven with a half-wave rectified current source may be an appropriate substitute. See paragraph 3 of [Clause 1](#).

A block diagram for lower intensity light ripple ratio measurements is shown in [Figure 16](#). The calibration procedure shall not only pay attention to the average light level but also to the peak ripple signal level in a specific range of frequencies. The ripple signal is measured with the broad band light meter comprising band-pass filter [17.14.3 - 2a), 2b), 3a), 3b)] and a peak detector [17.14.3 - 2a), 2b), 3e), 3f)].

The  $PEAK_{LI}/DC_{LI}$  ratio is the maximum (repetitive) peak signal at the output of the band-pass filter [17.14.3 - 3f)] divided by the unfiltered average light signal measured with the broad band light meter [17.14.3 - 3b)].



NOTE The numbering corresponds to the fuller description given in [17.14.3](#).

**Figure 16 — Block diagram for lower intensity light ripple ratio measurements**

##### 17.14.7.2 Calibration procedure for the lower intensity light source

Turn on the lower intensity light source (LI) and let it stabilize.

Measure the illuminance [17.14.3 - 1)] and the  $PEAK_{L,I}/DC_{L,I}$  ratio at the position of the test sample. Adjust the diaphragms (B, C) in front of the fluorescent lamp (F) and the incandescent lamp (I) until the illuminance is  $(200 \pm 10)$  lx and the  $PEAK_{L,I}/DC_{L,I}$  ratio is  $(0,12 \pm 0,02)$  %.

#### 17.14.8 Test procedure

The test shall be performed on the test sample set to the shade number 9, or the lowest shade number higher than 9. In the case of a welding filter with variable delay, the shortest delay setting shall be selected.

In the case of the welding filter with adjustable sensitivity, select the highest sensitivity that keeps the test sample in its light state. This adjustment has to be made for each ambient light source separately.

- a) Testing at lower intensity light source conditions: with the lower intensity light source switched on and stabilized, the trigger light source (L) shall be activated (by the use of the shutter (S)) to illuminate the test sample. After 20 seconds the trigger light source (L) is deactivated. Establish that the test sample is in its light state before the trigger source is activated, stays in the dark state while the trigger source is activated and returns to its light state after the trigger source is deactivated.
- b) Testing at higher intensity light source conditions: with the higher intensity light source switched on and stabilized, the trigger light source (L) shall be activated (by the use of the shutter (S)) to illuminate the test sample. After 20 seconds the trigger light source (L) is deactivated. Establish that the test sample is in its light state before the trigger source is activated, stays in the dark state while the trigger source is activated and returns to its light state after the trigger source is deactivated.

#### 17.14.9 Test report

For lower intensity light source conditions and higher intensity light source conditions report whether or not:

- the test sample remains in the light state when either the lower intensity light or the higher intensity light is switched on and the trigger light source is not yet activated;
- the test sample changes from the light to the dark state when the trigger light source is activated;
- the test sample stays in the dark state during the time of illumination from the trigger light source; and
- the test sample returns to the light state after the trigger light source (L) has been deactivated.

## Annex A (normative)

### Application of uncertainty of measurement

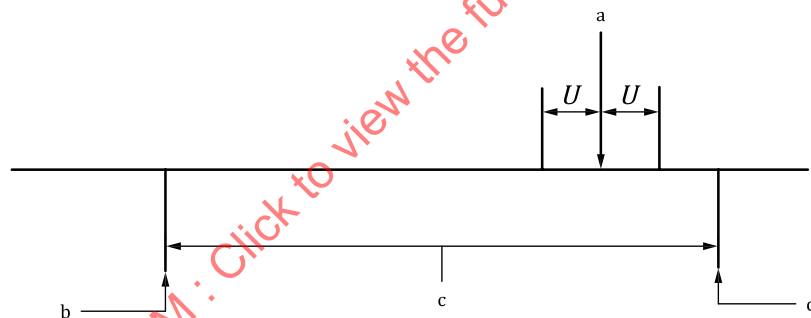
#### A.1 General

This annex sets out how uncertainty of measurement shall be taken into account when stating compliance

#### A.2 Procedure

In order to determine whether or not the measurement made in accordance with the test methods complies with the specification limits given in eye and face protection product's requirement standards, the following protocol shall be applied.

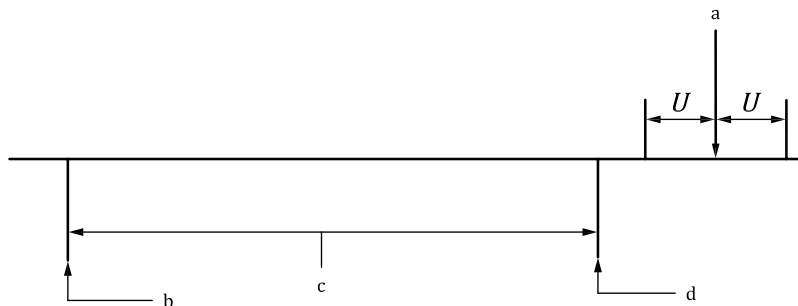
If the measurement (test result), plus or minus the uncertainty of measurement  $U$  falls completely inside or outside the specification zone for the particular test given in the product's requirement standard, then the result shall be deemed to be a straightforward pass or fail (see [Figures A.1](#) and [A.2](#)).



#### Key

- $U$  uncertainty of measurement
- a Measured value.
- b Lower specification limit.
- c Specification zone.
- d Upper specification limit.

**Figure A.1 — Result pass**



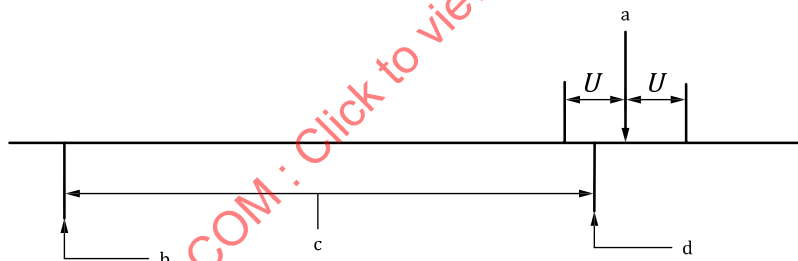
**Key**

- $U$  uncertainty of measurement
- a Measured value.
- b Lower specification limit.
- c Specification zone.
- d Upper specification limit.

**Figure A.2 — Result fail**

If the measurement (test result), plus or minus the uncertainty of measurement  $U$  overlaps a specification limit value (upper or lower) for the particular test given in the product's requirement standard, then the assessment of pass or fail shall be determined on the basis of safety for the wearer of the device; this means that the result shall be deemed to be a failure (Figures A.3 and A.4).

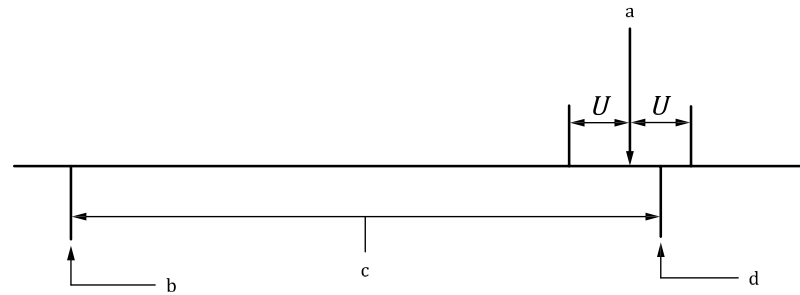
**NOTE** As a consequence of the requirements of this Annex, minimizing uncertainty of measurement (smaller values of  $U$ ) results in increased compliance.



**Key**

- $U$  uncertainty of measurement
- a Measured value.
- b Lower specification limit.
- c Specification zone.
- d Upper specification limit.

**Figure A.3 — Result fail**

**Key**

- $U$  uncertainty of measurement  
a Measured value.  
b Lower specification limit.  
c Specification zone.  
d Upper specification limit.

**Figure A.4 — Result fail**

## **Annex B** **(informative)**

### **Sources of uncertainty in spectrophotometry and their estimation and control**

#### **B.1 General**

There are many appropriate methods and instruments for measuring the spectral transmittance of eye and face protectors. There is no instrument or technique that can be singled out as particularly superior. Accordingly, the approach in this document is to specify maximum uncertainties of measurement that are acceptable in this context.

The methods of evaluating the components of uncertainty are set out in ISO/IEC Guide 98-3. This annex addresses the issues of sources of uncertainty in spectrophotometry, their minimization and evaluation.

The issues are the same regardless of the wavelength region used or the calculation that the spectral transmittance data are subsequently used in (e.g. to calculate luminous transmittance, ultraviolet transmittance, colour,  $Q_{\text{signal}}$ ).

#### **B.2 Principles of spectrophotometers**

Spectrophotometers are generally described as:

- a) one beam or two beam;
- b) scanning or diode array;
- c) ratio recording or null-point;
- d) single or double monochromator;
- e) monochromatic illumination or polychromatic illumination.

In a single-beam instrument there is only a single sample position. The measurement result is obtained from sequential comparison of the transmissions of the test sample and an open beam. For greatest accuracy, the test sample and open beam measurements should be made as close as possible in time to one another.

In a double-beam instrument, the measurement result is obtained from a simultaneous comparison of the test sample transmission with the reference transmission; hence the test sample is placed in one of two separate light paths. Measurement is effected either by simultaneous direction of the light through the two paths onto two photodetectors, or by alternate transmission of light from the two paths to a single photodetector, at a sufficiently high frequency as to simulate simultaneous comparison effectively.

A scanning instrument makes measurements successively though the spectrum as the wavelength of the beam is altered.

A diode-array spectrophotometer disperses the beam onto an array of photodiodes to measure at selected wavelengths simultaneously. Diode array instruments are usually single beam and always use polychromatic illumination.

Ratio recording spectrophotometers measure the amplitude of the signal generated by the alternation between test sample and open reference beam. The electronics of the amplifier determines the linearity of response.

Null-point spectrophotometers introduce a variable attenuator into the reference beam until the difference in signal with the sample beam is removed. The characteristics of the attenuator determine the linearity of response.

Double monochromator instruments use two diffraction gratings or a prism and grating combination.

The stray light elimination characteristics of a double monochromator are markedly superior (typically 1/100th to 1/1 000th of a single grating). This is particularly important at the short wavelength end of the ultraviolet spectrum or where there is rapid change of transmittance with wavelength.

The beam can pass through the monochromator before or after the test sample, so the test sample is irradiated with monochromatic radiation or with polychromatic radiation, respectively.

When dealing with products like eye protection, this difference is probably insignificant. The difference may be very significant if some constituent of the test sample is fluorescent.

In addition, spectrophotometers can be fitted with different photodetectors. For ultraviolet-visible (190 nm to 830 nm) measurements, they are typically a photomultiplier or a silicon photodiode. The photomultiplier is a more sensitive photodetector and provides measurements for darker test samples whereas the silicon photodiode is a robust and a less expensive option and provides measurement typically to 1 100 nm. If the instrument also provides near infrared measurements, another photodetector is required.

Lead Sulfide typically provides measurements to 3 000 nm and Indium Gallium Arsenide (InGaAs) currently to 2 500 nm.

## B.3 Sources of uncertainty

### B.3.1 General

Uncertainty in the measurement of spectral transmittance can usefully be considered to have three types of component:

- errors that result in a contribution that is independent of the transmittance of the test sample and make a contribution to the uncertainty of a constant absolute size ( $\alpha$ );
- errors that result in a contribution to the uncertainty that is a proportion of the transmittance measured ( $\beta$ );
- errors that result from wavelength inaccuracies in the instrument ( $\gamma$ ).

The combined uncertainty ( $u$ ) of the transmittance ( $\tau(\lambda)$ ) can be stated in the form:

$$u = \alpha + \beta \cdot \tau(\lambda) + \gamma \cdot \frac{d\tau(\lambda)}{d\tau} \quad (\text{B.1})$$

### B.3.2 Sources of uncertainty from calibration

#### B.3.2.1 Stray light

Stray light is typically caused by scattering in the optics of the instrument, particularly in the gratings. It is also caused by the partial overlap of higher order spectra with the first order that is used for measurement. It is particularly reduced in double monochromator instruments. As an instrument ages, deposits on the optical components tend to increase stray light. This can be minimized by attention to the cleanliness of the environment. Cleaning the optics is a skilled job and should be carried out by people certified by the instrument supplier.

Stray light is particularly significant at shorter wavelengths and most spectrophotometers automatically insert a short wavelength pass filter and use a deuterium discharge source for measurements below about 350 nm.

Stray light is assessed by the use of suitable aqueous solutions or glass filters with a long wavelength band pass.

Solutions used in the relevant wavelength range include those shown in [Table B.1](#).

Any measurable transmittance in the wavelength range nominated is to be taken to be stray light and minimized and accounted for under factor  $\alpha$ .

**Table B.1 — Solutions for use in wavelength ranges**

| Compound          | Typical concentration used | Wavelength range (optical density >3) (spectral transmittance <0,1 %) |
|-------------------|----------------------------|-----------------------------------------------------------------------|
| Potassium iodide  | 1 %                        | <260 nm                                                               |
| Sodium iodide     | 1 %                        | <260 nm                                                               |
| Lithium carbonate | Saturated                  | <227 nm                                                               |

#### B.3.2.2 0 % baseline

When the sample beam is covered with an opaque object, there may be a consistent reading other than the expected zero. This should, preferably, be subtracted from any actual transmittance reading or accounted for under factor  $\alpha$ . When the 0 % baseline is repeated, some variations in the values are recorded. This is most likely due to electrical noise in the system and there is little the user can do about this. An assessment of the magnitude of the error is made by repeated scans of the baseline and a calculation of the 95<sup>th</sup> percentile limits made. This is then factored into  $\alpha$ .

#### B.3.2.3 100 % baseline

Much the same processes are used as in accounting for the 0 % baseline. Any discrepancy from 100 % should be eliminated by scaling the result to 100 % or accounted for in factor  $\beta$ . Repeats of the 100 % baseline also show variation and need to be assessed as in the 0 % baseline and factored into  $\beta$ . The sources of noise in the 100 % baseline are much more numerous.

The noise in the 100 % baseline is greater when the response of the photodetector is low. This can be because the amount of radiation reaching the photodetector is low. This occurs at the limits of the wavelength region where the energy from the source can be low and/or the efficiency of the grating is low. The response can also be low near the limits of the wavelength region because the photodetector's spectral responsivity is low.

The magnitude and wavelength range of the problem vary depending on the instrument and are mainly beyond the control of the operator. Noise can be reduced by increasing the amount of radiation incident on the photodetector by increasing wavelength half bandwidth, increasing the integration time (which can be linked to slowing the scan rate in some instruments) or increasing the amplifier gain in the instrument.

Some instruments automatically vary the extra high tension (EHT) voltage to a photomultiplier in response to the total amount of light incident, some vary the amplifier gain and some automatically control the half bandwidth.

#### B.3.2.4 Wavelength accuracy

Wavelength accuracy is a function of the mechanics of the scanning mechanism or the location of the photodetectors in a diode array. It is not normally modifiable. It should be assessed and an estimate of  $\gamma$  made.

There are two principal methods. The first is the more accurate and involves introducing a line source (usually mercury discharge and neon discharge sources) in place of the built-in sources and monitoring the output of the photodetector in single beam mode. The mercury discharge spectrum has useful lines in the ultraviolet and visible to the yellow region while neon has many lines in the red region. [Table B.2](#) lists the principal lines of the mercury spectrum and the neon spectrum. Some closely spaced lines cannot be individually resolved when the half bandwidth is not substantially smaller than the wavelength difference of the lines. In addition, many spectrophotometers have built-in deuterium sources for the UV region. This source produces a combination of a broad band distribution and some lines, most notably at 656,1 nm (but also at 486,0 nm, 434,0 nm and 410,1 nm). This line is often used as a one-point check of wavelength accuracy, possibly automatically on start up in some instruments. Once a full check has been carried out, this one-point check should be sufficient to ensure that no change has taken place.

Set the wavelength 5 nm higher than the intended line and scan slowly across the line at the smallest wavelength interval possible. Identify the wavelength of maximum energy. Repeat for each available line. This method is necessary when wavelength accuracies  $\leq 0,5$  nm are being claimed. Wavelength accuracies  $< 0,1$  nm can be validated if the FWHM (full width half maximum) is small enough.

The second method involves the use of solutions such as holmium perchlorate or glass filters containing holmium oxide or didymium. These have narrow and deep absorption bands with typical wavelengths of peak absorption. The typical wavelengths of peak absorption are set out in [Table B.3](#). The actual wavelengths vary with the bandwidth and the thickness of the filter and should be obtained from a calibration laboratory for a particular solution or filter. Set the wavelength 5 nm higher than the intended absorption band and scan slowly across the band at the smallest wavelength interval possible. Identify the wavelength of minimum transmittance or maximum absorbance. The calibration uncertainty depends on the source of the calibration and the transfer calibration can be done typically  $\pm 0,3$  nm, resulting in a combined uncertainty of around 0,5 nm for small FWHM.

**Table B.2 — Wavelengths (in air) of the line spectra from mercury and neon**

| Wavelength in air<br>nm | Source | Wavelength in air<br>nm | Source | Wavelength in air<br>nm | Source |
|-------------------------|--------|-------------------------|--------|-------------------------|--------|
| 226,22                  | Hg     | 366,33                  | Hg     | 630,48                  | Ne     |
| 237,83                  | Hg     | 404,66                  | Hg     | 633,44                  | Ne     |
| 248,20                  | Hg     | 407,78                  | Hg     | 638,30                  | Ne     |
| 253,65                  | Hg     | 435,84                  | Hg     | 640,23                  | Ne     |
| 265,20                  | Hg     | 533,08                  | Ne     | 650,65                  | Ne     |
| 280,35                  | Hg     | 534,11                  | Ne     | 653,29                  | Ne     |
| 289,36                  | Hg     | 540,06                  | Ne     | 659,90                  | Ne     |
| 296,73                  | Hg     | 546,07                  | Hg     | 667,83                  | Ne     |
| 302,15                  | Hg     | 576,96                  | Hg     | 671,70                  | Ne     |
| 312,57                  | Hg     | 579,07                  | Hg     | 692,95                  | Ne     |
| 313,17                  | Hg     | 585,25                  | Ne     | 702,41                  | Ne     |
| 334,15                  | Hg     | 588,19                  | Ne     | 703,24                  | Ne     |
| 336,99                  | Ne     | 594,48                  | Ne     | 705,91                  | Ne     |
| 341,79                  | Ne     | 597,55                  | Ne     | 717,39                  | Ne     |
| 344,77                  | Ne     | 603,00                  | Ne     | 724,52                  | Ne     |
| 346,66                  | Ne     | 607,43                  | Ne     | 743,89                  | Ne     |
| 347,26                  | Ne     | 609,62                  | Ne     | 748,89                  | Ne     |
| 352,05                  | Ne     | 614,31                  | Ne     | 753,58                  | Ne     |
| 359,35                  | Ne     | 616,36                  | Ne     | 754,41                  | Ne     |
| 365,02                  | Hg     | 621,73                  | Ne     | 837,76                  | Ne     |
| 365,44                  | Hg     | 626,65                  | Ne     |                         |        |

**Table B.3 — Main wavelengths (in air) of peak absorption**

| Reference                       | Wavelengths of peak absorption<br>nm |       |       |       |       |       |       |       |       |
|---------------------------------|--------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| Holmium perchlorate<br>solution | 241,1                                | 250,0 | 278,2 | 287,1 | 333,5 | 345,5 | 361,4 | 385,4 | 416,3 |
|                                 | 450,8                                | 486,2 | 536,6 | 640,6 |       |       |       |       |       |
| Holmium oxide filter            | 279,4                                | 287,5 | 360,9 | 418,7 | 453,2 | 536,2 | 637,5 |       |       |
| Didymium filter                 | 572,9                                | 585,3 | 684,6 | 740,8 | 807,0 |       |       |       |       |

For neutral coloured test samples, wavelength accuracy is not a large determinant of uncertainty in spectral transmittance; wavelength accuracies of 1 nm are perfectly adequate. On the other hand, the sharp cut-offs often seen in the UV region and rapid changes of transmittance with wavelength in highly coloured test samples can lead to large uncertainties with wavelength. For instance, a change of 50 % transmittance (absolute) in 10 nm is not unusual in the UV region and a wavelength accuracy of 1 nm means an uncertainty of 5 %.

### B.3.2.5 Precision (repeatability)

The assessments of noise in the baseline are measures of precision. Similar assessments can be carried out at different values of transmittance of a test sample. Where a test sample is not totally uniform, measures of repeatability can also involve removing and replacing the test sample and repeating the measurements. In this case the repeatability is not just a function of the instrument but also the uniformity of the test sample and the repeatability of the method of locating the test sample in the instrument. Repeatability normally factors into  $\beta$ .

### B.3.2.6 Photometric accuracy (linearity)

The assessment of photometric accuracy involves the measurement of a sample of known transmittance (values provided by a calibration laboratory) and the discrepancies either corrected out mathematically or incorporated into the uncertainty, usually  $\beta$ . Typically, the reference samples are glass filters, but perforated metal gauzes can also be used; care needs to be exercised to ensure their uniformity.

## B.3.3 Sources of uncertainty from methodology

### B.3.3.1 Wavelength limits for specification and measurement

Spectral measurements should be made over the range specified in the referencing standard and this will vary with application.

In principle, the visible spectrum, as defined by the CIE data, extends from 360 nm to 830 nm. In practice, the sensitivity of the eye at the limits of the spectrum is so low that excluding those regions from the calculation makes no practical difference. In some applications, limits of 400 nm to 700 nm are accepted as adequate. However, comparisons of calculations made on the same test sample for different limits show a variation and an accepted wavelength range for an application is normally set. For eye and face protection calculations, the wavelength limits for measurement and specification of eye and face protection have been generally set as 380 nm to 780 nm.

Similarly, there is variation in the regions accepted that are defined as the bands of ultraviolet and infrared limits for specification and measurement.

Since a standard wavelength range is adopted, any discrepancies from the full range are generally ignored and not factored into the uncertainties.

### B.3.3.2 Wavelength step

In principle, the smaller the wavelength step, the more accurate the calculation. The CIE system is specified in 1 nm increments. Making the measurements and calculations at larger intervals has no consequence when the test sample is neutral in colour and the spectral transmittance changes little with wavelength, but it has a consequence where the spectral transmittance changes rapidly with wavelength.

For this document, the calculations and the measurements should be made at the same intervals as specified in the standard referring to the test methods of this document. The wavelength step should be set as 5 nm and any discrepancies with measurements made at 1 nm intervals ignored. Smaller wavelength steps (and a correspondingly smaller FWHM) may be necessary where weighting functions change rapidly with wavelength and this different wavelength step should be specified.

### B.3.3.3 Bandwidth of the measuring device

The band width of the measuring device is normally described as the Full Width Half Maximum bandwidth (FWHM) or spectral half bandwidth.

In principle, the smaller the spectral half bandwidth FWHM (bandwidth), the more accurate the measurement. Making the measurements and calculations at large FWHM bandwidths has no consequence when the test sample is neutral in colour and the spectral transmittances changes little with wavelength. It has a consequence where the spectral transmittance changes rapidly with wavelength when transmittance peaks tend to be lower and troughs shallower with increasing FWHM bandwidth.

On the other hand, smaller FWHM bandwidths reduce the amount of energy reaching the photodetector and increase the signal noise. Good measurement practice is to set the FWHM bandwidth no greater than the wavelength step (5 nm in this application). Two nm is a typical setting for fixed bandwidth instruments. When dealing with dark test samples and reference beam attenuation (see [B.3.4](#)), it may

be necessary to increase the bandwidth beyond 5 nm to minimize noise and this needs to be factored in to the uncertainty.

When using large bandwidths, the combined effects of photodetector sensitivity, source energy and grating efficiency can mean that energy is not uniformly or symmetrically distributed in the wavelength band and the wavelength with greatest energy can be some nanometres from the nominal centroid wavelength. In this case, wavelength accuracy needs to be re-evaluated.

### **B.3.4 Sources of uncertainty from test sample characteristics**

#### **B.3.4.1 Beam displacement by test sample**

The beam in the spectrophotometer can be displaced when a test sample is tilted with respect to the incident beam or the test sample includes even a small amount of prism (including “decentred” lenses). The beam can then fall partially outside the photodetector and an incorrectly lower transmittance is recorded. In some instruments, the beam is small compared with the photodetector (under filling) and a large amount of displacement is necessary for a spurious result to be recorded. This tends to be true more often of photomultiplier photodetectors that generally have large windows. Conversely, if the beam is large compared with the photodetector (over filling) it also takes a significant displacement for the beam to fail to fill the photodetector and, as long as the beam is uniform, displacement has relatively little effect. In practice many instruments just under fill the photodetector and a small displacement can have significant effects. The effects are most noticeable with curved, rather than flat, test samples.

If the effect is significant, it can be identified by:

- a) tilting a test sample with respect to the incident beam and observing an apparent rise in transmittance (usually it should fall);
- b) rotating a (non-polarizing) test sample with the incident beam as the axis and observing larger than expected changes in transmittance;
- c) moving a uniformly tinted test sample laterally and observing larger than expected changes in transmittance;
- d) moving the test sample from the front to the back of the sample chamber and observing a change in apparent transmittance (this can also be a sign of a test sample with significant diffuse transmittance);
- e) checking with a curved test sample of known transmittance.

The effect cannot be avoided in many instruments. In order to minimize the problem, the test sample should be placed as close to the photodetector as possible to minimize displacement of the beam. The use of an integrating sphere to collect the beam helps if the beam is small compared with the entrance port of the sphere (as it normally is). Otherwise the effect needs to be factored into  $\beta$ .

#### **B.3.4.2 Fluorescence**

For reasons described in [B.2](#), fluorescence in test samples contributes to errors that are particularly evident when the test sample is irradiated with monochromatic radiation in the UV. Visual examination under a UV-A source should alert the operator to the presence of fluorescence. Appropriate filters placed in the test beam between the photodetector and the test sample permit valid measurements.

#### **B.3.4.3 Test sample tilt**

The reference point for measurement is defined in ISO 4007 and the requirement is to measure with a normally incident beam. Tilting of the test sample causes a greater path length to be traversed in the test sample, which will reduce the transmittance, and displacement of the beam with respect to the photodetector, which may move the beam to a point of greater or lesser sensitivity on the

photodetector or cause the beam to fall partially or completely outside the photodetector. These will result in erroneous readings.

#### **B.3.4.4 Test sample location**

This is not particularly critical with uniformly tinted lenses, but with gradient tint lenses it is critical.

The position of the test sample should be repeatable to within  $\pm 0,5$  mm.

#### **B.3.4.5 Sample beam size and shape**

This is also not particularly critical with uniformly tinted lenses, but with gradient tint lenses it is critical. If the beam extends a significant distance in the direction of the gradient and the gradient is not a constant transmittance change, then it becomes difficult to know exactly what point is being measured.

Along the direction of the gradient, the beam size should be as small as practicable. In instruments with a rectangular beam, the test sample should be orientated so that the short dimension is along the gradient change. The dimension along the gradient should not exceed 5,0 mm.

#### **B.3.4.6 Polarization**

The process of monochromating the beam with a grating also introduces some partial polarization. The magnitude and orientation of polarization varies through the spectrum. Some instruments have a depolarizer that can be used. In the absence of such an attachment, the measurement of spectral transmittance of linear polarizers should be made at two mutually perpendicular orientations of the test sample. The absolute orientation is not important, but the mutual perpendicular requirement is. The spectral transmittance is the mean of the two measured spectral transmittances. The measurement of non-linear polarizers (e.g. circularly or elliptically polarized) should be made with a depolarizer or made by a broadband method.

## Annex C (informative)

### Definitions in summation form

#### C.1 Explanation

ISO 4007 defines the processes of convolving spectral data to an integrated value as an integral with the symbols  $\int$  and  $d\lambda$ . In an integral, the variables, such as  $\tau(\lambda)$ ,  $V(\lambda)$ ,  $S(\lambda)$ , are mathematical functions. While each of these variables may be fitted with a mathematical function, the more usual process in making this calculation is to carry out a summation at a given wavelength interval  $\Delta\lambda$  within the defined wavelength range. The standards referring to these test methods require the use of a wavelength interval of 5 nm or less in the ultraviolet and visible regions and 10 nm in the infrared region. The calculations are therefore, in practice, represented as summations using the symbols  $\Sigma$  and  $\Delta\lambda$ .

The following are the definitions from ISO 4007:2018, with the processes expressed as summations and with the results expressed in percentages.

#### C.2 Key to symbols

|                                                |                                                                                                                                               |
|------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| $\lambda$                                      | is the wavelength of radiation in nanometres;                                                                                                 |
| $\tau(\lambda)$                                | is the spectral transmittance of the test sample;                                                                                             |
| $\rho(\lambda)$                                | is the spectral reflectance of the test sample;                                                                                               |
| $V(\lambda)$                                   | is the CIE 2 spectral luminous efficiency function for photopic vision (see ISO/CIE 11664-1);                                                 |
| $S_A(\lambda)$                                 | is the spectral distribution of incident radiation of CIE standard illuminant A (see ISO 11664-2);                                            |
| $S_{D65}(\lambda)$                             | is the spectral distribution of incident radiation of CIE standard illuminant D65 (see ISO 11664-2);                                          |
| $S_{1\,900\,K}(\lambda)$                       | is the spectral distribution of incident radiation from a Planckian black body radiator at 1 900 K, (see ISO 4007 or ISO 11664 or CIE S 012); |
| $E_S(\lambda)$                                 | is the solar spectral power distribution at sea level for air mass 2 <sup>[3]</sup> ;                                                         |
| $E_{\text{signal}}(\lambda)$                   | is the accepted measured value of the relative spectral distribution of luminance of the traffic signal light;                                |
| $S(\lambda)$                                   | is the relative spectral effectiveness function for UV radiation <sup>[4]</sup> defined by ICNIRP;                                            |
| $W(\lambda) = E_S(\lambda) \cdot S(\lambda)$   | is the complete weighting function of this product;                                                                                           |
| $B(\lambda)$                                   | is the blue-light hazard function <sup>[6]</sup> defined by ACGIH;                                                                            |
| $W_B(\lambda) = E_S(\lambda) \cdot B(\lambda)$ | is the complete weighting function of this product.                                                                                           |

The values of  $V(\lambda)$ ,  $S_A(\lambda)$ ,  $S_{D65}(\lambda)$ ,  $S_{1\,900\,K}(\lambda)$ ,  $E_S(\lambda)$ ,  $S(\lambda)$ ,  $B(\lambda)$  and commonly used products of these functions are listed in ISO 4007 and [Annex D](#).

### C.3 Definitions in summation form

#### C.3.1 Luminous transmittance

See ISO 4007:2018, 3.10.1.32.

$$\tau_{vA} = 100 \times \frac{\sum_{380}^{780} \tau(\lambda) \cdot S_A(\lambda) \cdot V(\lambda) \cdot d\lambda}{\sum_{380}^{780} S_A(\lambda) \cdot V(\lambda) \cdot d\lambda} \quad (C.1)$$

$$\tau_{vD65} = 100 \times \frac{\sum_{380}^{780} \tau(\lambda) \cdot S_{D65}(\lambda) \cdot V(\lambda) \cdot d\lambda}{\sum_{380}^{780} S_{D65}(\lambda) \cdot V(\lambda) \cdot d\lambda} \quad (C.2)$$

$$\tau_{v1900K} = 100 \times \frac{\sum_{380}^{780} \tau(\lambda) \cdot S_{1900K}(\lambda) \cdot V(\lambda) \cdot d\lambda}{\sum_{380}^{780} S_{1900K}(\lambda) \cdot V(\lambda) \cdot d\lambda} \quad (C.3)$$

#### C.3.2 Ultraviolet

##### C.3.2.1 Solar UV transmittance

See ISO 4007:2018, 3.10.1.28.

$$\tau_{SUV380} = 100 \times \frac{\sum_{280}^{380} \tau(\lambda) \cdot E_s(\lambda) \cdot S(\lambda) \cdot d\lambda}{\sum_{280}^{380} E_s(\lambda) \cdot S(\lambda) \cdot d\lambda} = 100 \times \frac{\sum_{280}^{380} \tau(\lambda) \cdot W(\lambda) \cdot d\lambda}{\sum_{280}^{380} W(\lambda) \cdot d\lambda} \quad (C.4 a)$$

$$\tau_{SUV400} = 100 \times \frac{\sum_{280}^{400} \tau(\lambda) \cdot E_s(\lambda) \cdot S(\lambda) \cdot d\lambda}{\sum_{280}^{400} E_s(\lambda) \cdot S(\lambda) \cdot d\lambda} = 100 \times \frac{\sum_{280}^{400} \tau(\lambda) \cdot W(\lambda) \cdot d\lambda}{\sum_{280}^{400} W(\lambda) \cdot d\lambda} \quad (C.4 b)$$

##### C.3.2.2 Solar UV-A transmittance

See ISO 4007:2018, 3.10.1.29.

$$\tau_{SUV A380} = 100 \times \frac{\sum_{315}^{380} \tau(\lambda) \cdot E_s(\lambda) \cdot S(\lambda) \cdot d\lambda}{\sum_{315}^{380} E_s(\lambda) \cdot S(\lambda) \cdot d\lambda} = 100 \times \frac{\sum_{315}^{380} \tau(\lambda) \cdot W(\lambda) \cdot d\lambda}{\sum_{315}^{380} W(\lambda) \cdot d\lambda} \quad (C.5 a)$$

$$\tau_{SUV A400} = 100 \times \frac{\sum_{315}^{400} \tau(\lambda) \cdot E_s(\lambda) \cdot S(\lambda) \cdot d\lambda}{\sum_{315}^{400} E_s(\lambda) \cdot S(\lambda) \cdot d\lambda} = 100 \times \frac{\sum_{315}^{400} \tau(\lambda) \cdot W(\lambda) \cdot d\lambda}{\sum_{315}^{400} W(\lambda) \cdot d\lambda} \quad (C.5 b)$$

##### C.3.2.3 Solar UV-B transmittance

See ISO 4007:2018, 3.10.1.30.

$$\tau_{SUVB} = 100 \times \frac{\sum_{280}^{315} \tau(\lambda) \cdot E_s(\lambda) \cdot S(\lambda) \cdot d\lambda}{\sum_{280}^{315} E_s(\lambda) \cdot S(\lambda) \cdot d\lambda} = 100 \times \frac{\sum_{280}^{315} \tau(\lambda) \cdot W(\lambda) \cdot d\lambda}{\sum_{280}^{315} W(\lambda) \cdot d\lambda} \quad (C.6)$$

#### C.3.2.4 Mean UV-A transmittance

See ISO 4007:2018, 3.10.1.26.

$$\tau_{\text{mUVA380}} = 100 \times \frac{\sum_{315}^{380} \tau(\lambda) \cdot d\lambda}{\sum_{315}^{380} d\lambda} \quad (\text{C.7 a})$$

$$\tau_{\text{mUVA400}} = 100 \times \frac{\sum_{315}^{400} \tau(\lambda) \cdot d\lambda}{\sum_{315}^{400} d\lambda} \quad (\text{C.7 b})$$

#### C.3.2.5 Mean UV-B transmittance

See ISO 4007:2018, 3.10.1.27.

$$\tau_{\text{mUVB}} = 100 \times \frac{\sum_{280}^{315} \tau(\lambda) \cdot d\lambda}{\sum_{280}^{315} d\lambda} \quad (\text{C.8})$$

#### C.3.2.6 Mean 380 nm to 400 nm transmittance

See ISO 4007:2018, 3.10.1.31.

$$\tau_{\text{m380-400}} = 100 \times \frac{\sum_{380}^{400} \tau(\lambda) \cdot d\lambda}{\sum_{380}^{400} d\lambda} \quad (\text{C.9})$$

### C.3.3 Blue-light

#### C.3.3.1 Solar blue-light transmittance

See ISO 4007:2018, 3.10.1.35.

$$\tau_{\text{SB}} = 100 \times \frac{\sum_{380}^{500} \tau(\lambda) \cdot E_s(\lambda) \cdot B(\lambda) \cdot d\lambda}{\sum_{380}^{500} E_s(\lambda) \cdot B(\lambda) \cdot d\lambda} = 100 \times \frac{\sum_{380}^{500} \tau(\lambda) \cdot W_B(\lambda) \cdot d\lambda}{\sum_{380}^{500} W_B(\lambda) \cdot d\lambda} \quad (\text{C.10})$$

#### C.3.3.2 Blue-light transmittance

See ISO 4007:2018, 3.10.1.36.

$$\tau_{\text{B}} = 100 \times \frac{\sum_{380}^{500} \tau(\lambda) \cdot B(\lambda) \cdot d\lambda}{\sum_{380}^{500} B(\lambda) \cdot d\lambda} \quad (\text{C.11})$$

### C.3.4 Infrared

#### C.3.4.1 Near IR transmittance

See ISO 4007:2018, 3.10.1.39.

$$\tau_{\text{NIR}} = 100 \times \frac{\sum_{780}^{3000} \tau(\lambda) \cdot d\lambda}{\sum_{780}^{3000} d\lambda} \quad (\text{C.12})$$