TECHNICAL
REPORT

ISO/TR
20772

First edition
2018-10

Ophthalmic optics — Spectacle lenses — Short wavelength visible solar radiation and the eye

Optique ophtalmique — Verre de lunettes — L'œil et les radiations solaires visibles de courtes longueurs d'onde

Reference number
ISO/TR 20772:2018(E)

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Published in Switzerland

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Foreword

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

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

This document was prepared by Technical Committee ISO/TC 172, *Optics and photonics*, Subcommittee SC 7, *Ophthalmic optics and instruments*.

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

Introduction

Ongoing concern about unverifiable spectacle lens and sunglass marketing claims for blocking of wavelengths near to and greater than 380 nm (such as UV400 claims) was the main motivation for creating the present Technical Report.

The intention is to explain the specifications related to the filtering effects of lenses and filters that are given in the available International Standards — for the purposes of standardization in the fields of spectacle lenses and sunglasses, 380 nm is generally chosen as both the upper limit of the solar UV range and the lower limit of the visible range — and to provide information about the supporting science as it is best understood today.

The effects of UV radiation on the eye are well known, and have been considered in the technical requirements of the standards relating to tinted spectacle lenses (ISO 8980-3) and sunglasses (ISO 12312-1).

The commitment to create this document came from a resolution of the plenary meeting of ISO/TC 172/SC 7, *Ophthalmic optics and instruments* (responsible for spectacle lens standards) in 2009, and was jointly supported by ISO/TC 94/SC 6, *Eye and face protection* (responsible for sunglass standards). The related standards activity in these two committees is summarized in Clause 4, with more detail on the background and technical context leading up to the decision to create this document.

Ophthalmic optics — Spectacle lenses — Short wavelength visible solar radiation and the eye

1 Scope

This document describes visible solar radiation with wavelengths close to the UV range, its transmission to, within and the effects on the human eye. The wavelengths concerned are from 380 nm to 500 nm, covering the colours of violet, indigo and blue — often referred to as the "blue wavelengths".

It also explains the filtering effects and measurement of spectacle lenses and sunglasses, thereby providing background information to understand the transmittance requirements related to filtering effects of lenses and filters in the available spectacle lens and sunglass standards.

This document does not address the issues of protection from artificial sources of radiation.

This document is intended to be of benefit to any future interest in ISO standardization related to transmission of solar radiation with wavelengths near to and greater than 380 nm.

The Bibliography provides a source of relevant useful references.

2 Normative references

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

ISO 4007, *Personal protective equipment — Eye and face protection — Vocabulary*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4007 and ISO 13666 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 Preliminaries: UV400 and alpha-blocking wavelength in standardization

This is a summary of the standards activity in ISO/TC 172/SC 7, *Ophthalmic optics and instruments* (responsible for spectacle lens standards) and ISO/TC 94/SC 6, *Eye and face protection* (responsible for sunglass standards) relating to claims such as UV400, and the attempts to define the term *alpha-blocking wavelength*. It provides the background leading up to the decision to create this document.

Nominal wavelength regions of the electro-magnetic spectrum have been adopted by various agencies and organizations for convenience in communication. In a number of fields (e.g. CIE, ICNIRP, IEC and disciplines such as cosmetics and dermatology) the UV region is considered to extend to 400 nm, overlapping with the CIE definition of visible light.

For the purposes of standardization in the fields of spectacle lenses and sunglasses, 380 nm is generally chosen as both the upper limit of the solar UV range and the lower limit of the visible range.

The vocabulary documents which govern the terms and definitions for spectacle lens and eye protection standards (including sunglasses) are ISO 13666 and ISO 4007.

In both these International Standards the definition of ultraviolet radiation is "optical radiation with wavelengths shorter than those for visible radiation" while visible radiation is "any optical radiation capable of causing a visual sensation".

So the standards' definitions for the UV and visible bands are based on the limits of photo-detection. The same is true for the upper limit of the visible range where it meets the infrared radiation band.

Since the lower limit of detection is rather imprecise, varying between individuals and often lower than 360 nm, there was an obvious need to decide a single wavelength to define precisely the upper limit of the UV range for application to the spectacle and sunglass standards.

ISO/TC 172, *Optics and photonics* in ISO 20473 made a choice of a single wavelength for all the standards for optics and photonics.

This single wavelength was chosen to be the mid-point in the range of lower limits of the visible range (360 nm to 400 nm) used by CIE (International Commission on Illumination), that is, 380 nm.

This 380 nm definition of the upper limit of the UV ranges was similarly adopted in ISO 4007 for the ISO sunglass standard.

ISO and global national standards for spectacle lenses and sunglasses generally follow this approach.

Over time some uncertainties arose as a result of unclear marketing claims being made which included the term “UV”.

In 1980 the spectacle lens manufacturing company ORC started to use the term “UV-400” for some of their products which absorbed more strongly in the region up to 400 nm than standard products. Following this, “UV400” became commonly used to claim low spectral transmittances up to 400 nm.

Dermatologists in the United Kingdom noted that sunglasses labelled “UV400” were suitable for use by patients undergoing and recovering from skin treatment by PUV-A therapy. A manufacturer of mid-index clear lenses described them as blocking essentially all UV-A radiation, in accordance with the ISO definition of UV-A for spectacle lenses. Some dermatologists questioned this, being accustomed to consider the UV-A range to extend to 400 nm and that there would be some guarantee of spectral blocking at this wavelength.

After this occurred, commercial literature proliferated with claims for UV400, and some sunglasses used the claims of UV420, and even UV440. These claims carry an expectation of a superior degree of blocking of harmful solar radiation. Exactly how superior (if at all) was very unclear.

Some UV400 claims were being made for products on the basis that the solar UV-A transmittance calculated between 315 nm and 400 nm complied with the Australian/New Zealand sunglass standard. However, in some of these cases the spectral transmittance at 400 nm was more than 10 %.

To provide some certainty, ISO/TC 94/SC 6 and ISO/TC 172/SC 7 started to work in parallel and with common leadership on their respective vocabulary documents to create a single comprehensive definition that would enable verification of claims for spectacle and sunglass lenses, such as “UV400”.

The approach taken was to develop definitions using the concepts of “blocking” and “cut-off”. A variety of definitions were discussed which usually required that the spectral transmittance values be not greater than a specified value at and below the cut-off wavelength claimed.

A term XXX-*blocking wavelength* was devised where XXX is the wavelength for which blocking or cut-off is claimed. This term subsequently became known as *alpha-blocking wavelength*.

Work on a definition for alpha-blocking wavelength continued for some years with much debate in both committees. Various definitions were trialled, some complex, some relatively simple.

However, despite useful refinements, it was ultimately not possible to reach agreement for a definition of *alpha-blocking wavelength.* This was the case both in the project group for ISO 13666 and the working group revising ISO 4007.

The simplest and most recent definition of alpha-blocking wavelength (α) discussed in the groups in 2009 was:

— the highest wavelength, α, equal to or greater than 380 nm for which the spectral transmittance is less than x % between 280 nm and α nm.

This provides the means to validate claims such as "UV400” which should correctly be termed “400-blocking”.

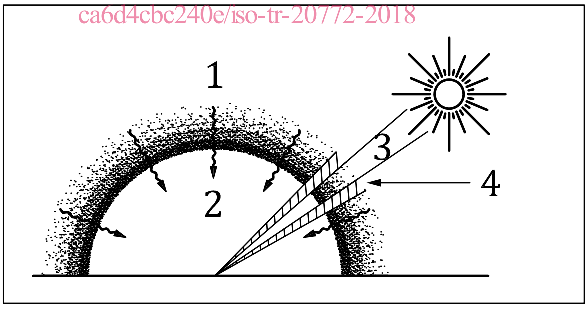
It was generally agreed by the experts involved that the value for x should be small. Suggested values were between 1 % and 4 %.

While the work to define a useful term for validation of these claims was not successful, it was believed in both committees that a Technical Report should be written to promote understanding of the related topics. This document is the result of that work.

5 Solar radiation and exposure of the eye

5.1 Solar radiation and the earth’s atmosphere

Solar radiation is partially absorbed and scattered while passing through the earth's atmosphere. This reduces the irradiance of the direct rays arriving at any location on the earth's surface, but the scattering re-directs rays from the entire sky toward that location. The total irradiance at the location is the sum of the irradiance of the direct rays (direct irradiance) and of the diffusely scattered rays (diffuse irradiance). The total irradiance on a horizontal surface is termed "global irradiance". See Figure 1.



Key

1 earth's atmosphere
2 diffuse
3 direct
4 circumsolar

NOTE Adapted from Sliney and Wolbarsht[24], reproduced with permission.

Figure 1 — Illustration of the term "global irradiance" from the sun

Both the direct and the diffuse irradiances on a horizontal surface depend upon the angle of incidence of the solar rays on the surface. Both vary with the position of the sun. The irradiance on a horizontal surface is reduced by the geometric factor (cosine) of the angle of incidence of each ray, because the area that is irradiated by the pencil of rays from the sun (and from any area of the sky) increases as the angle of incidence increases. Additionally, the path-length through the atmosphere increases with increasing angle of incidence. As a result, absorption and scattering are greater.

The height of the sun, and hence annual exposure varies with season, time of day and in particular latitude.

NOTE People in the tropics experience particularly high levels of annual exposure compared to those at lower latitudes.

Because path-lengths decrease with increasing altitude of the receiving site, atmospheric absorption and scattering diminish. Thus, both the direct and the global irradiances increase, but the irradiances by the scattered radiation decrease.

The term, "air-mass" (AM) is used to represent the path-length in the atmosphere of the direct solar rays. AM-1 is the path where the sun is overhead at zenith, and AM-2 is where the light travels through double the distance through the atmosphere compared with AM-1. AM-2 applies when the sun is at an elevation of 30° above the horizon.

Calculations of solar transmittance in spectacle lens and sunglass standards have been based on the AM-2 spectral power distribution of the radiation reaching the eye directly from the sun. When energy scattered by the atmosphere is included, i.e. the “global irradiance”, there is a higher proportion of blue light incident upon a person's face than when using the direct values. There are some experts who consider that when calculating the blue light hazard, the AM-1 or AM-2 global spectral distribution should be used in place of the direct AM-2 currently applied to the standards, see Figure 2. One should also consider the specular reflection of radiation rich in short-wavelength light from the sun reflected from auto windshields at midday (Sliney 2002)[15].

Key

X wavelength (nm)

Y spectral irradiance (mW.cm^{-2}·nm^{-a})

1 Moon AM-2

2 CIE AM-1

3 CIE AM-2[a]

[a] The values of CIE AM-2 have been adjusted because the CIE data represents the irradiance falling on a horizontal surface compared with the values from P Moon for perpendicular incidence. Hence the component due to the direct irradiance has been doubled to compensate for this and added to the value for the scattered light. The values from Moon's article are given in many ISO standards including ISO 13666 and ISO 4007.

Figure 2 — Comparison of the values of the global CIE AM-1 and AM-2 with the direct Moon AM-2 irradiance

5.2 Geometrical factors

5.2.1 General

Photobiological effects on the human retina, cornea and lens are highly dependent on the exposure geometry as well as the spectral characteristics of the exposure. The variable sensitivity of the eye to light enables it perform well in very low night-time illumination levels and it also is able to adapt to extremely bright environments where light exposures are greater by many orders of magnitude. The eye has evolved to protect itself reasonably well against excessive exposure in bright environments. The retina is minimally exposed in extremely bright environments and the cornea and lens are surprisingly well protected in harsh environments. Although these protective mechanisms are good, they are not perfect and the risk of adverse changes from both acute and chronic exposures to sunlight still exist. These geometrical factors are well described by Sliney (2005)[16].

5.2.2 Exposure and solar altitude

Although the solar irradiance on a horizontal surface reaches its maximum at mid-day when the sun is high in the sky, the eyes are protected by the eyebrows and upper lids, the latter closing significantly if the illuminance on the eyes is high (Deaver, et al, 1996)[17]. The lower lids, however, may continue to be exposed to solar radiation even when the sun is higher in the sky, since they are not shielded by the eyebrows.

Sasaki, et al (2011)[18] demonstrated an interesting relationship between eye irradiance and sun elevation. They exposed a rotating model head tilted down 15° measuring solar UV-B with photoreceptors in the eye position and back of the head at a moderate latitude (*Kanazawa, Japan*). They found that the solar irradiance on the eyes facing the summer sun reaches its maximum mid-morning and mid-afternoon when the sun's elevation is around 40°. There is a decline in irradiance of the eye at midday in summer attributed to protection by the brow, showing the irradiance at the eye during the day has a bimodal function.

In the winter months, this bimodal function was not demonstrated. In this case, peak irradiance is at midday because the sun's maximum elevation is insufficient for the brow to give much protection.

Similar results are expected for short wavelength visible radiation.

5.2.3 Reflection from surfaces

In addition to the direct and diffuse sky irradiances it is important to take into account the significant component from reflecting surfaces.

Because ISO standards for spectacles (ISO 8980-3) and general purpose sunglasses (ISO 12312-1) exclude direct observation of the solar disc, the strongly forward-scattered radiation in the immediate vicinity of the disc is automatically excluded as well. Therefore, exposure of the eyes to solar radiation is by way of scattering by the atmosphere and by reflection from the ground. Because ground-reflectances have large local variations, a representative average diffuse reflectance is assigned for tabulated solar global irradiance spectral compositions. Ground-reflected radiation is additional to the radiance of the sky. The lower lids may continue to be exposed to solar radiation even when the sun is higher in the sky as they may not be shielded by the brow.

The *diffuse irradiance* component from the sky, on a horizontal surface at sea level, is equal to the *global solar irradiance* minus the *direct solar irradiance*[15][17]. From this, the *average radiance of the sky on a clear day* is: π^{-1} (= 0,314*)* times the total sky diffuse irradiation on a horizontal surface at sea level. The effective solid angle of the entire sky is equal to π (= 3,141 6). Kondratyev[19] notes that the radiance of the clear sky increases from the zenith to the horizon; and measurements generally showed an increase by a factor of nearly two-fold[20][21]. Therefore, the factor by which the radiance of the horizon sky exceeds the *average* radiance of the sky must be smaller. Kondratyev also states that, although limited clouds in a particular configuration slightly increase global irradiation, a long-term average of varied cloudiness shows that clouds should generally be assumed always to decrease global irradiance (hence, too, average sky radiance).

5.2.4 Exposure of the eye and its response to bright light

To assess potential biological effect, it is necessary to estimate irradiances of the retina, cornea, and lens of an eye that is exposed to solar radiation in selected exposure situations. The spectral transmittances of the ocular media (cornea, aqueous, crystalline lens and vitreous) affect exposures of subsequent structures. The brow ridge and lids modify the exposure geometry. See Figure 3.