TECHNICAL REPORT

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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

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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".

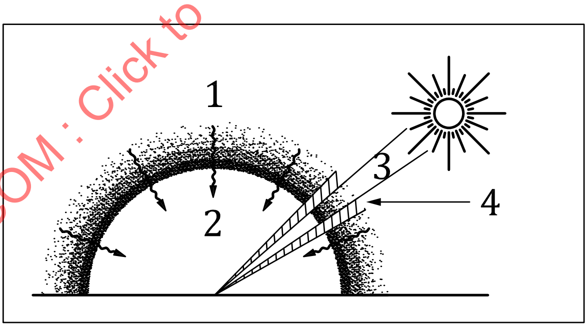
It was generally agreed by the experts involved that the value for x should be small. Suggested values were between 1 % and 4 %.

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.

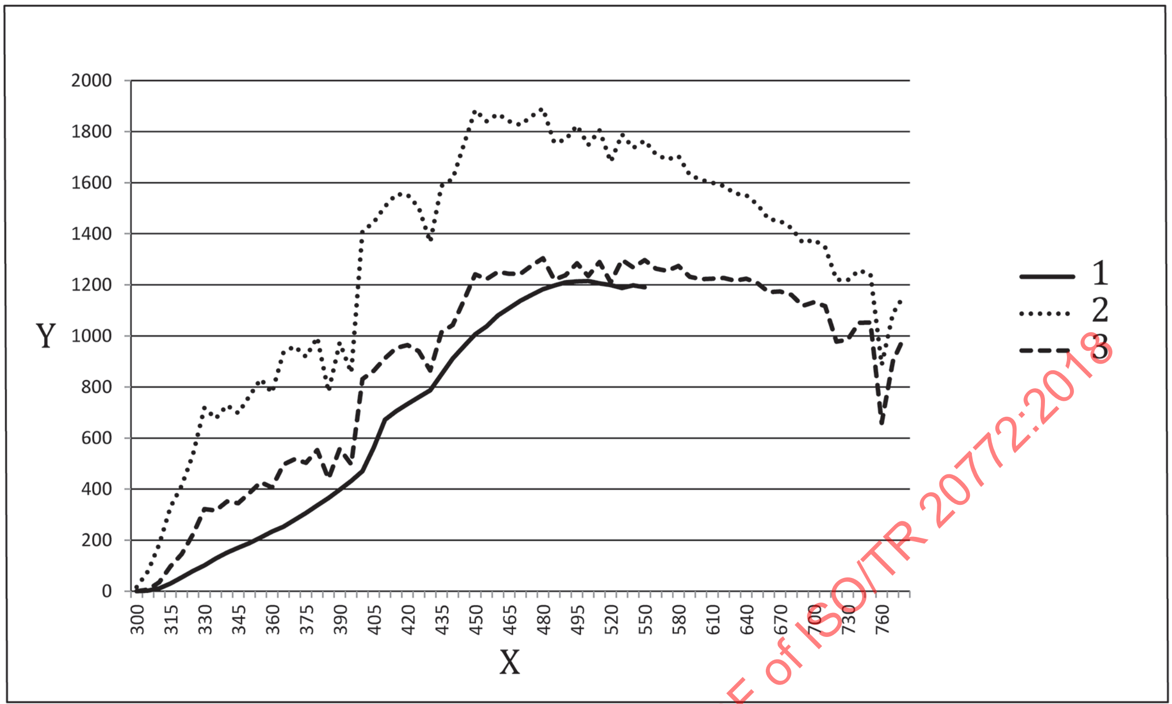
The height of the sun, and hence annual exposure varies with season, time of day and in particular latitude.

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

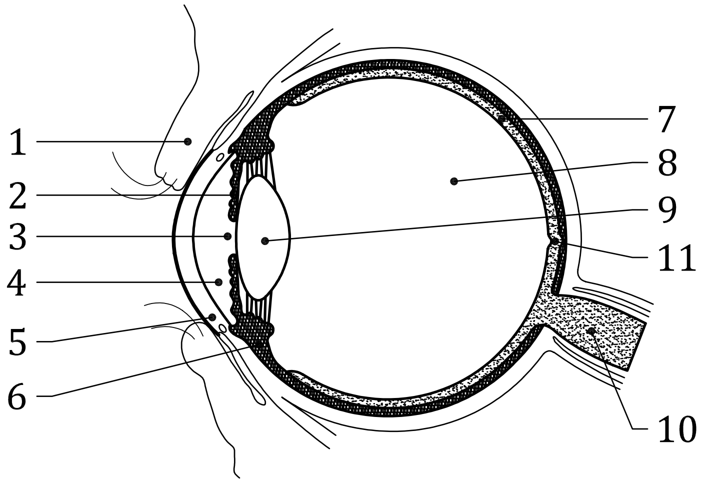
In addition to the direct and diffuse sky irradiances it is important to take into account the significant component from reflecting surfaces.

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.



Key

1 eyelid
2 iris
3 pupil
4 aqueous humour
5 cornea
6 ciliary muscle
7 retina
8 vitreous humour
9 crystalline lens
10 optic nerve
11 macula

Figure 3 — Cross section of the eye

The eye has three main responses to bright light:

— If the brightness is excessive, there is an *aversion response*, i.e. the eyes will close or will look away.

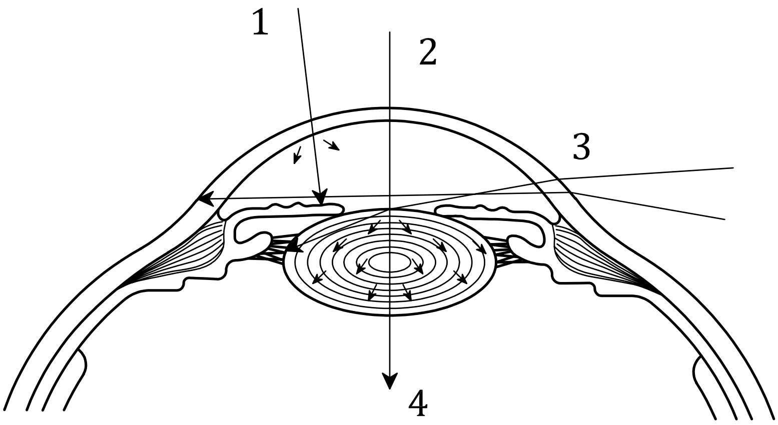
— In more normal situations, the pupil size will *reduce*.

— The third response is the *position of the upper lid.* In bright light, the eyes 'squint' or reduce the eyelid aperture so that the brighter the scene, the lower the upper lid. Deaver, et al (1996)[17] measured the upper extremity of the vertical field of view as a method of determining the position of the upper lid for subjects looking 15° down in various situations. The upper limit of the field was typically 55° indoors, 25° to 30° in daylight, reducing to approximately 15° in bright ambient light. Only in very bright light will the lower lid rise to help protect the eye. Perhaps this partly explains why situations with high ground reflectance, e.g. snow, wet sand, are so uncomfortable and also can lead to exposure keratitis.

5.2.5 Peripheral light focusing effects

While the eyelids and a spectacle or sunglass lens can protect the eye from radiation from the front, oblique rays from the side can enter the eye (the Coroneo or peripheral light focusing effect). In addition, radiation can also enter the eye by reflection from the back surface of a spectacle or sunglass lens.

The Coroneo effect, named after the researcher (1993)[22], describes how radiation from 80° to 120° from the temporal side is focused by the cornea on the nasal junction between the cornea and sclera (the limbus). See Figure 4. Calculations show that there can be 20 times higher irradiance nasally as is incident on the temporal cornea. This can be reduced by wearing soft contact lenses with an absorber (Coroneo, 2011)[23]; alternatively, sunglasses with a high face-form angle will also provide protection from the side — indeed there is a requirement in ISO 12312-1 for very dark sunglasses (Category 4, with luminous transmittance τ_V of less than 8 %) to provide lateral protection from radiation.



Key

1 direct blocked ray

2 direct axial ray

3 oblique direct rays

4 <1 % to retina

NOTE Adapted from Sliney[15], reproduced with permission

Figure 4 — Oblique radiation entering the eye

Radiation that is even more oblique will reach the limbus. Although very little UV radiation reaches the retina (<1 %), a higher proportion of the incident radiation will reach the nasal limbus and the nasal lens cortex.

5.2.6 Irradiation of the retina

Solar radiation is a significant hazard to the retina in the wavelength range 380 nm to 500 nm, with small sensitivities above that; ICNIRP 2013[14] recommends evaluating source-radiances from 300 nm to 700 nm.

An image on the macula represents an area of a viewed scene that is centred on the line-of-sight. Its angular subtense is determined by the focusing properties of the eye. The irradiance on the macula is proportional to the average radiance of the imaged source area, modified by attenuations at the surface of the cornea (by reflection, therefore small) and a small attenuation loss within the ocular media in the visible. The largest loss mechanism is absorption (and fluorescence) in the crystalline lens at shorter wavelengths. See Table 1.

Table 1 — Absorption of radiation by the components of the eye and the amount transmitted to the retina — Data representative of a 10 year old eye.

Wavelength nm	Absorption % of the incident radiation				Transmitted to retina %
	Cornea	Aqueous	Lens	Vitreous	
380	25,7	2,3 (3,1)	71,7 (99,7)	0,05 (16,0)	0,2
390	23,4	2,1 (2,8)	73,6 (99,1)	0,06 (14,2)	0,5
400	21,0	1,9 (2,4)	74,5 (96,6)	0,09 (12,5)	2,3

NOTE 1 The values not in brackets are the % of the incident radiation at the cornea that is absorbed, the values in brackets are the % absorption of that incident on the anterior surface of the structure, i.e. the aqueous, lens or vitreous.

NOTE 2 The values transmitted to the retina appear lower than in Figure 5 — this is because the values in this table are derived from experimental measurements, in Figure 5 from an equation intended to simulate the spectral transmittance of the eye.

NOTE Adapted using data from CIE 203:2012[25].

6 Physiological effects on the eye

6.1 Hazards to the eye

Light is necessary for the visual and non-visual functions of the eye. However, any optical radiation may be hazardous to the eye if it is absorbed by the ocular tissues at doses capable of causing photomechanical, photothermal or photochemical reactions. While the eye has progressively evolved to protect itself from light-induced damage, adverse changes from light exposures still exist.

Solar radiation at the earth's surface in the high-energy visible short wavelength ranges has intensities sufficient to cause exposure doses that can approach or exceed the established limit values given in ICNIRP *Guidelines* (and concurring values in ACGIH's[1]) and other organization's publications).

Solar radiation has been identified as a hazard to human eyes. *In vitro* and *in vivo* experiments within the blue range have provided information on spectral irradiances at the threshold levels of *acute* temporary and permanent damage. Some work has also been done on cumulative sub-threshold doses. Solar photo-damage by blue-light on the eye is discussed in 6.3.

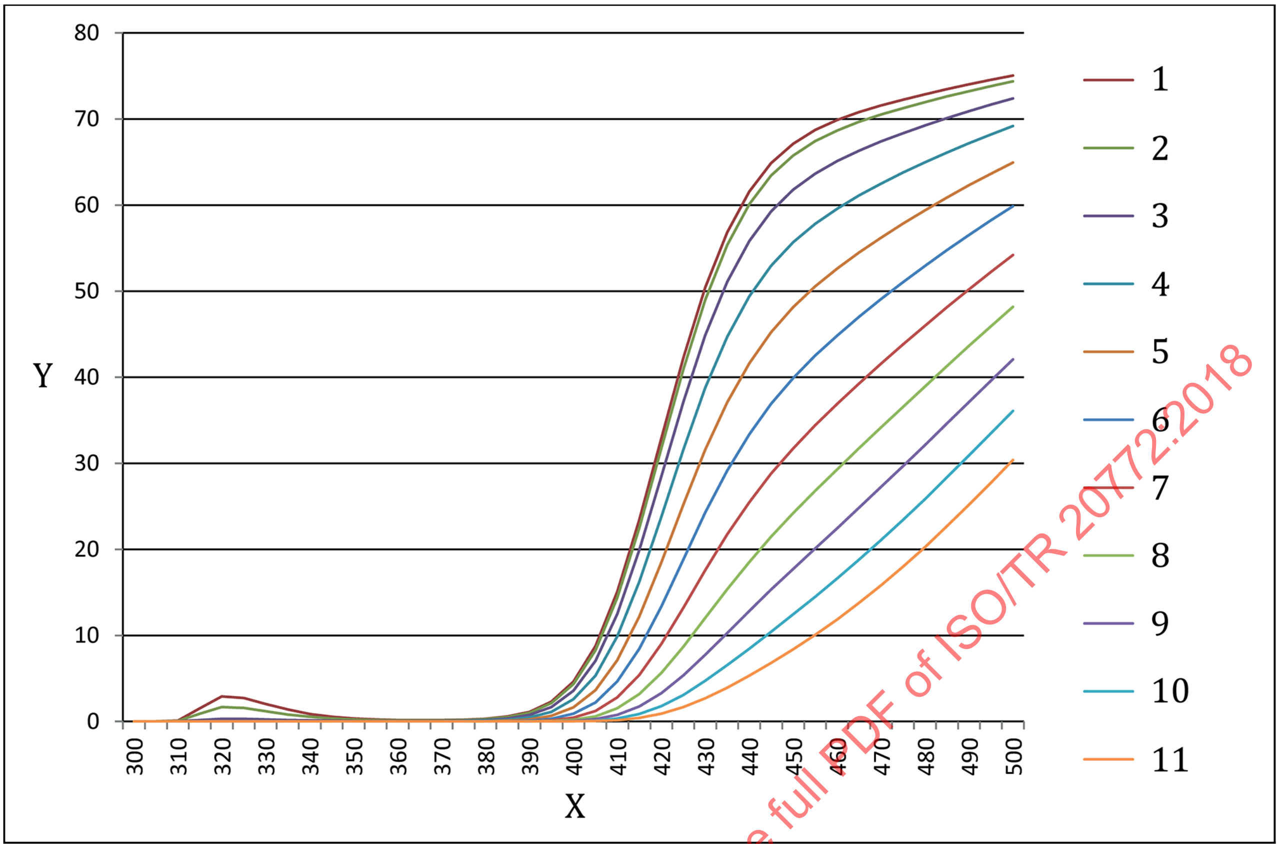
It is generally accepted that the retina is at greatest risk in the blue light spectral range 380 nm to 500 nm for normal individuals.

6.2 Retinas of children's eyes

Although there are differences in the absolute values of transmittance, Figure 5 shows that the crystalline lenses of children are more transparent than those of older people, particularly in the short wavelength ranges, therefore more radiation is transmitted to the retina. Children may also be exposed to significantly more solar radiation since they usually have more opportunities to be outside than many adults.

This suggests that a different blue-light hazard function could be created using the average lens-transmittances for the decade of age from 10 years old to 19 years old. ICNIRP recommends the use of an aphakic hazard function $A(\lambda)$ for children aged below 2 years (ICNIRP 2013[14]).

1) ACGH: American Conference of Governmental and Industrial Hygienists.



Key

X wavelength (nm)
Y transmittance (%)

1	1 year old	7	60 years old
2	10 years old	8	70 years old
3	20 years old	9	80 years old
4	30 years old	10	90 years old
5	40 years old	11	100 years old
6	50 years old		

NOTE 1 The data do not take into account cataract surgery beyond 60 years old.

NOTE 2 Drawn from data from CIE 203:2012[26].

Figure 5 — Total spectral transmittance of the human eye at various ages

6.3 Retinal blue phototoxicity

6.3.1 General

While age, smoking, macular pigments and genetics are strong risk factors for accelerated aging of the macula, cumulative and prolonged short wavelength light can induce retinal photochemical injuries. Photochemical damage of the retina depends on the light spectrum and distribution, the ocular exposure geometry, the eye media transmittance as well as the exposure duration, the irradiance levels, and the action of repair processes.

6.3.2 Blue light in solar radiation

Sun radiance is more than 100 times higher than the radiance of standard artificial lighting. It can reach several billion cd.m^{-2} at midday.

The blue light proportion of sunlight within the visible range varies between 25 % and 30 %, based on the sunlight D65 normative spectrum defined in ISO 11664-2:2007. This source is intended to simulate average daylight and has a Correlated Color Temperature (CCT) of approximately 6,500K. Comparatively, incandescent lamps, with a low CCT at around 2,700K, emit less than 5 % blue light.

6.3.3 Eye media transmittance

Optical radiations are either reflected, absorbed or transmitted by the successive eye media, which modifies the spectral and absolute irradiance at the retina. The absorption properties of the eye media were mostly studied in the 1960’s to the 1990’s. See the Bibliography.

Unlike UV radiation, visible light reaches the retina in high proportions, as reported by CIE 203:2012[26]. The highest energy visible light that reaches the retina is blue light. The retinal blue transmittance decreases with age but remains important all through life (see Figure 5).

6.3.4 Sunlight irradiance reaching the retina

In Reference [27], Yves Le Grand estimated the sunlight irradiance reaching the retina. The calculations have been adapted in Reference [28]. The light source is described by its radiance measured in the pupil direction and its emitting surface. The source is assumed to be small compared to the distance between the source and the cornea. See Figure 6. After calculations, the sunlight irradiance reaching the retina is proportional to the sunlight energy radiance, to the eye media transmittance and to the pupil area. As mentioned earlier in the section on “the eye’s response to bright light”, the geometrical factors also highly affect the amount of light received by the retina.

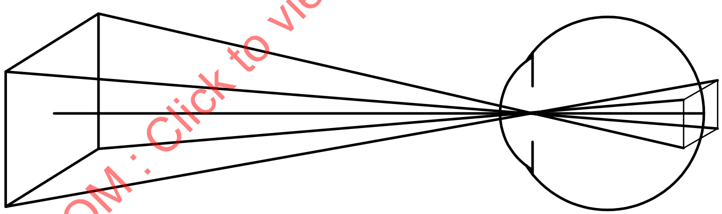


Figure 6 — Eye/light source model

6.4 Retinal studies

6.4.1 General

Retinal photo-damage has been studied for a half century, starting with the landmark paper of Noell demonstrating blue retinal phototoxicity in rodents exposed to white fluorescent lamps[29]. Studies have focused on the period of exposure, short versus long term, with recovery intervals also found to affect photodamage.

In 1972, Marshall, Mellerio and Palmer showed visible light damage in the cones of pigeons[30].

Remé (2005)[31] has shown that intense white light can cause damage to the photoreceptors, and that bleaching products from the rod pigment (rhodopsin) “strongly absorb in the blue and near UV range, and possibly induce detrimental photochemical lesions in photoreceptors”.

Understanding of retinal blue phototoxicity damage is largely modelled on animal and cellular models. *In vivo* experiments revealed that photochemical damage exhibits lower dose thresholds in the UV range and in the blue range than for green or red light on the retina of humans[32], of monkeys[33][34], rats[35][36][37] and rabbits[38][39][40][41][42].

The harmful effect of blue light was also modelled on living Retinal Pigment Epithelium (RPE) cells loaded with either oxidized photoreceptor outer segment[43], purified lipofuscin[44], or synthesized A2E[45][46][47][48][49]. A2E and lipofuscin are compounds that accumulate in the RPE cells and increase with age. A greater toxicity of blue light was demonstrated by exposing human RPE loaded with lipofuscin over 48 h with violet-blue-green light (390 nm to 550 nm, 2,8 mW/cm^2) compared with yellow-red light (550 nm to 800 nm, 2,8 mW/cm^2)[44]. RPE cell death induced by blue light exposure was further explained in References [50] and [51].

In Reference [28], the authors identified the acute phototoxic action spectrum of RPE within the blue-green range in solar physiological retinal exposure on an *in vitro* model of Age-related Macular Degeneration (AMD). The narrow 415 nm to 455 nm spectral range was highlighted as the greatest phototoxic risk to RPE cells. Whilst longitudinal studies of the phototoxic effect of blue light are not feasible outside of an in vitro model, this study is consistent the photobiological action spectrum peaking near 445 nm evidenced by Ham, Mueller and Sliney in 1976[52].

No consensus regarding the link between sunlight exposure and AMD has emerged from epidemiology studies. Nevertheless, several studies suggest the correlation[53][54][55][56][57][58][59][60][61][62][63][64][65][66][67].

The EUREYE study found significant association between blue light exposure and neovascular AMD in individuals having the lowest antioxidant level[57].

In the Chesapeake Bay study performed on 838 watermen, AMD patients — compared with age-matched controls — were significantly more highly exposed to blue over the preceding 20 years but equally exposed to UV, suggesting that blue light exposure is related to AMD[54].

The Beaver Dam Eye Study reported a correlation between sunlight and 5-year incidence of early AMD changes. Leisure time spent outdoors while teenagers (13 to 19 years) and in their 30s (30 to 39 years) was significantly associated with the risk of early age-related macular changes[68].

A recent meta-analysis concluded that adult individuals with more sunlight exposure are at a significantly increased risk of AMD[61]. Fourteen studies were identified. Twelve studies reported an increasing risk of AMD with greater sunlight exposure, six of which evidenced significant risks.

6.4.2 Phototoxic effect near 405 nm

Very little research has been done in this area, however there have been some observations by Reidenbach, et al[70] reporting unusually persisting after-effects for short exposure to a 405 nm (violet) laser. These observations accord with some anecdotal data relating to retinal exposures in this range for patients who see all objects tinged with red. This raises the question of appropriate limits for laser exposure, but at this time no studies in this area have been carried out.

6.5 The mechanisms of retinal damage

Depending on irradiance levels and exposure durations, light can result in retinal damage through photomechanical, photothermal and photochemical mechanisms. Brief exposure to extremely bright light can induce mechanical or thermal injuries. For photomechanical mechanisms, compressive and tensile forces can induce permanent damage or be lethal for retinal cells. Photothermal damage is associated with a temperature increase characterized by an increase in mean kinetic energy. Photochemical damage is the most common mechanism by which light exposure induces retinal damage. It is associated with moderate irradiance levels and long exposure durations and is wavelength-dependent. It is cumulative retinal damage and induces cell death activity. In this report, we focus on the photochemical retinal mechanisms.

Absorption of a photon by the visual pigments begins a cascade of biochemical reactions, known as the visual cycle, whereby the photopigment is regenerated by the conversion of all-*trans*-retinal into 11-*cis*-retinal. Prolonged cumulative and/or bright blue light exposure may modify the visual cycle and progressively and irreversibly alter the retina. All-*trans*-retinal may accumulate in the Photoreceptor Outer Segments (POS). This compound is highly sensitive to blue-violet light with a decreasing profile between 400 nm and 450 nm. Its blue photo-activation may induce oxidative stress within the POS. This stress is normally compensated by retinal antioxidants, but environmental factors (such as tobacco consumption or a poor diet) and age progressively reduce anti-oxidative defences, thus failing to compensate for the oxidative stress. The POS progressively oxidize, consequently the absorption and impact of this on the Retinal Pigment Epithelium (RPE) is more challenging as their membrane components are difficult for the RPE to break down. Thus, intracellular digestion is incomplete and generates an accumulation of residual lipofuscin in the RPE[69]. Lipofuscin is sensitive to blue-violet light. The lipophilic extract of lipofuscin contains a photosensitizer, which forms a triplet excited state with a maximum of absorption in blue at 440 nm. Blue photoactivation may generate reactive oxygen species. When the number of these species exceeds cellular defence capacity, the RPE cells die.

Deprived of these support cells, the photoreceptors deteriorate in turn, contributing to the loss of vision diagnosed in patients suffering from AMD. Accumulation of lipofuscin in the RPE is a major feature of ageing and AMD.

Older retinas contain significantly more of the waste product lipofuscin that is thought to sensitize the retina to damage by optical radiation. Hence, although the young retina may be receiving more radiation, this may produce much less of the damaging reactive oxygen species compared with that in the mature person[57]. Conversely, the reduced transmittance of the lens at short wavelengths in the older person may be regarded as a natural method to help protect the retina.

6.6 Blue light & non-visual functions

Photons received by the eye are useful for controlling many non-visual biological functions, including management of circadian rhythms and resetting our biological clock. These non-visual irradiance detection tasks are triggered by a third photoreceptor discovered in 2002, the intrinsically photosensitive retinal ganglion cell, ipRGC, using melanopsin associated pigment[71]. Melanopsin pigment absorption peaks at around 480 nm. When these ganglion cells are activated by blue-turquoise light, they transmit a nerve signal that runs along the optic nerve and triggers multiple nonvisual structures and regulates the sleep/wake state (melatonin synthesis), the pupil light reflex, cognitive performance, mood, locomotor activity, memory, body temperature, etc. [72][73][74] [75][76]

6.7 Blue light transmittance of spectacle and sunglass lenses

6.7.1 Existing standards requirements for claims regarding blue light transmittance

For spectacle lenses, ISO 8980-3:2013 in its Annex E "Spectral radiation risks", has E.1 "Blue-light hazard" the first paragraph of which reads “If solar radiation on the ground is evaluated with currently used limit values even under extreme illuminance conditions (e.g. snow surfaces) a risk by the blue part of the radiation is not to be expected. Therefore, this part of ISO 8980 contains no specification in this respect but opinion is divided whether there could be a risk. In order to allow a correct description of the blue-light attenuation, a definition of the blue-light transmittance is included.”.

For sunglasses, ISO 12312-1:2013 introduces a means to verify claims on blue light absorption or transmittance based on the blue light transmittance, τ_{SB}, calculated across the entire blue spectral range 380 nm to 500 nm according to the following equation:

$$\tau_{SB} = 100 \times \frac{\int_{380}^{500} \tau(\lambda) \cdot E_s(\lambda) \cdot B(\lambda) \cdot d\lambda}{\int_{380}^{500} E_s(\lambda) \cdot B(\lambda) \cdot d\lambda} = 100 \times \frac{\int_{380}^{500} \tau(\lambda) \cdot W_B(\lambda) \cdot d\lambda}{\int_{380}^{500} W_B(\lambda) \cdot d\lambda}$$

where

$E_S(\lambda)$ is the solar radiation at sea level for air mass 2;

$B(\lambda)$ is the blue light hazard function;

$W_B(\lambda)$ is the complete weighting function.

6.7.2 Relevant spectral bandwidth and transmittance characteristics

This document does not provide a dedicated characteristic to describe blue light transmittance and associated limits for product specifications. Nevertheless, according to the photobiological state of the art (Arnault and Diaz), it might be relevant to consider a narrower harmful blue bandwidth to characterise the blue light transmittance of a lens. Optimization might be achieved by maximum light attenuation in a narrow blue bandwidth, typically between 400 nm and 455 nm, and conversely to maximise transmittance at wavelengths above 475 nm. A possible distinction between clear and tinted lenses on the expected protection level might be also discussed.

Blue light filtering may have significant consequences on global lens transmittance within the visible spectral range. We can distinguish the effects between clear and tinted lenses.

6.7.3 Effects of blue light filtering on clear lenses

Blue light filtering by clear lenses need not have a significant effect on global visual transmittance, especially if the attenuation of blue light is focused on the (400 nm to 455 nm) potentially harmful range. Nevertheless, the most probable effect is a yellow coloured appearance, both a cosmetic one for the onlooker and a visual one to the wearer. This residual colour may be masked by adding a blue dye resulting in a faintly grey lens that may be objectionable to some. This residual cosmetic colour may also be reduced if a dedicated selective filtering function providing high transmittance around 480 nm is used instead.

6.7.4 Effects of blue light filtering on tinted lenses

Blue light absorption by tinted lenses may modify the subjective appreciation of colour and possibly its disruption, for example, blue skies and other blue objects may appear discoloured. In addition, attenuation of blue light may have significant influence on both the visibility of blue lights from emergency vehicles and on the recognition of the colour of traffic signal lights, particularly the green for colour deficient individuals. This is expressed technically by the traffic signal light attenuation coefficients (Q signal) for red, yellow, green and blue light. Blue light attenuation may lead to a significant reduction in the Q signal for blue light, with the risk of not complying with the standards' requirements for driving defined in ISO 8980-3 for spectacle lenses and in ISO 12312-1 for sunglasses. Although attenuation of shorter wavelengths in the blue range may be beneficial for the retina, longer wavelengths in the blue range are important for the circadian rhythm as mentioned in 6.6.

7 Spectral weighting functions

7.1 General

The *International Commission on Non-Ionizing Radiation Protection* (ICNIRP) provides two **Guidelines** for limiting exposure doses to optical radiation in the wavelength range 180 nm to 1 mm, covering ultraviolet (UV), visible, and infrared (IR) regions of the electromagnetic spectrum. These are:

— Guidelines on Limits to Exposure to Ultraviolet Radiation of Wavelengths between 180 nm and 400 nm (Incoherent Optical Radiation)[12] (hereafter referred to as ICNIRP 2004);

— ICNIRP Guidelines on Limits of Exposure to Incoherent Visible and Infrared Radiation[14] (hereafter referred to as ICNIRP 2013).

Older versions and updates of these Guidelines are referenced in the Bibliography for historical purposes as ICNIRP 1985[8], ICNIRP 1989[9], and ICNIRP 1997[11].

The purposes of the respective Guidelines are:

— **ICNIRP 2004** "to provide basic principles of protection against non-coherent ultraviolet radiation, so that they may serve as guidance to the various international and national bodies or individual experts who are responsible for the development of regulations, recommendations, or codes of practice to protect workers and the general public from the potentially adverse effects of [ultraviolet radiation]", and

— **ICNIRP 2013** "to establish the maximum levels of exposure to incoherent optical radiation from artificial and natural sources with the exception of lasers. The guidelines assist the development of principles of protection to the eyes and the skin against optical radiation hazards."

A *hazard* is a physical or chemical agent that has the potential to cause a specified harm. *Risk* is the probability that such harm will occur in a given circumstance. The evaluation of risk involves measurement of the effective dose (maximum accessible exposure), comparison with the acceptable maximum (maximum permissible dose) and consideration of the consequences of excessive exposure (which may be significant or trivial). Risks are generally evaluated as acceptable or unacceptable (and, therefore, requiring action)."

7.2 ICNIRP 2013

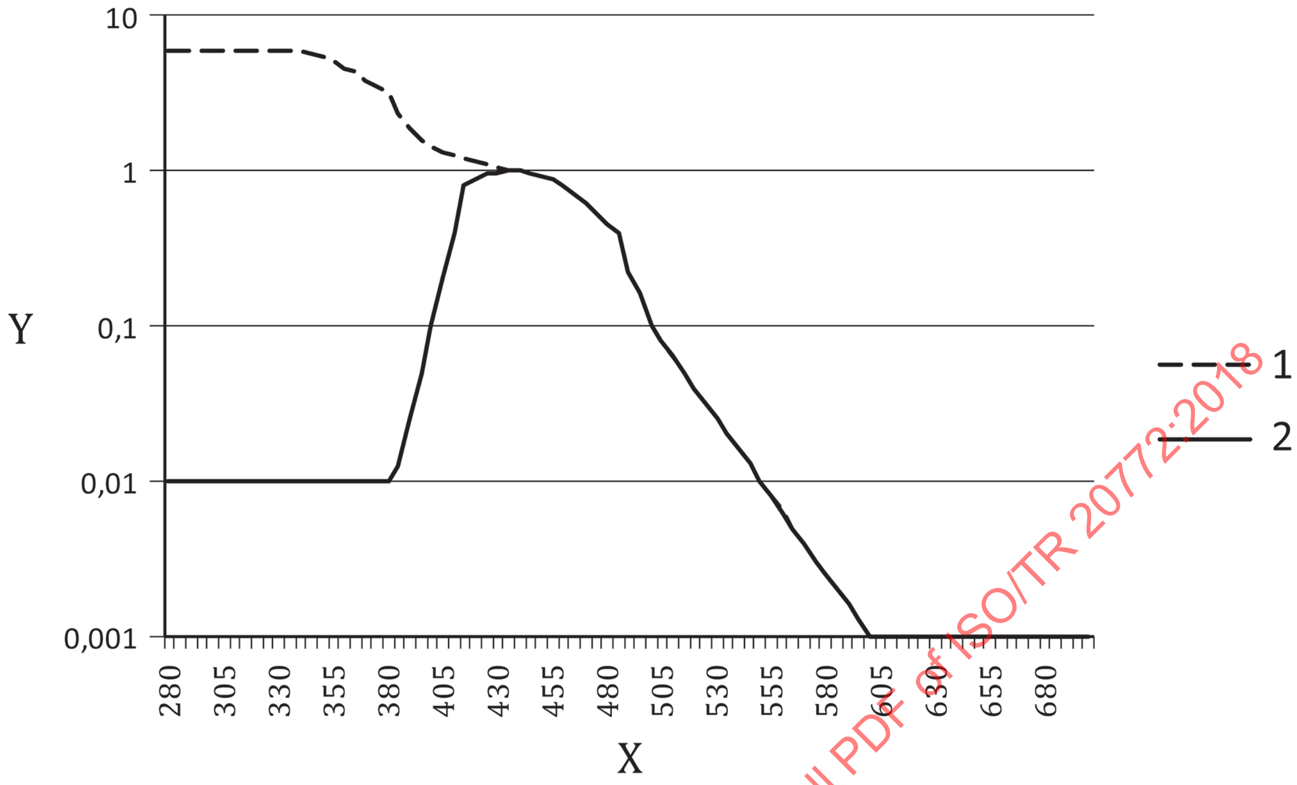
The primary concern of these Guidelines is protection of the retina from wavelengths shorter than 500 nm. The spectral weighting values of the retinal blue light hazard function for photochemical injury, $A(\lambda)$ Aphakic, are based on the work of Ham, et al. and others (see references in ICNIRP 2013[14]). Ham's values were derived from the acute hazard on aphakic monkey eyes, and the function is appropriate for individuals who are aphakic, i.e. lacking a crystalline lens following cataract surgery without implantation of an artificial intraocular lens. The media in this case readily transmit wavelengths down to 300 nm. See the curve, $A(\lambda)$ Aphakic, in Figure 7.

The lens in infants aged less than 2 y transmits more than the adult lens and the $A(\lambda)$ Aphakic hazard function may be more appropriate in this case of the developing retina.

The more appropriate blue light hazard function for most adult patients, $B(\lambda)$ Adult, allows for the reduced illuminance/irradiance of the retina after passage through a typical adult cornea and crystalline lens. It was obtained by multiplying the spectral values of the aphakic hazard function with a synthetic function that is intended to represent the spectral transmittance of the human cornea and lens from 300 nm to 700 nm. The product function is normalized to unity at 440 nm; see the blue light hazard function curve, $B(\lambda)$ Adult, in Figure 7. Comparing these two functions, the aphakic weighting function values are increased for wavelengths below 440 nm.

Blue light, with a peak wavelength of approximately 440 nm, can potentially cause or exacerbate several retinal problems. In the short term, directly viewing a sufficiently bright source, such as the sun or certain welding arcs, without proper eye protection will result in photochemically-induced photoretinopathy. Long-term exposure to normal light levels has been suggested to accelerate retinal aging and to cause or exacerbate age-related macular degeneration in susceptible individuals[77].

The ICNIRP Guidelines also identify potential thermal damage from specific wavelength bands: to the cornea, from approximately 1 400 nm to 1 mm; to the iris, from approximately 380 nm to 1 400 nm; to the crystalline lens, from approximately 800 nm to 3 000 nm; and to the retina, from approximately 380 nm to 1 400 nm. Nonetheless, thermal damage from visible and IR sources results primarily from specific artificial sources, such as welding arcs and lasers, and is very unlikely from sunlight alone or most common non-industrial light sources.



Key

X wavelength (nm)

Y weighting factor

1 aphakic weighting factor, $A(\lambda)$

2 adult weighting factor, $B(\lambda)$

NOTE Drawn from data in ICNIRP 2013[14].

Figure 7 — The $A(\lambda)$ and $B(\lambda)$ functions

7.3 Application of ICNIRP specifications to standards for spectacle lenses and sunglasses

The ISO standards for spectacle lenses exclude non-prescription sunglasses. These standards and the ISO standard for sunglasses exclude those applications that are addressed by standards for sports eyewear, direct solar viewing, and industrial eye protection (which include protection against artificial sources of radiation). Sunlight is the principal optical radiation hazard of concern in standards for spectacle lenses, sunglasses and occupational eye protection against sunglare.

For spectacle lens and sunglass applications, the lens manufacturer or appliers of lens treatments, such as tints and coatings, should be able to conduct precise spectral transmittance measurements. The spectral weighting function listed in ICNIRP 2013[14] is applied to lens materials and treatments by manufacturers who claim to protect the wearer from the blue light hazard.

The International Standards mentioned above all have separate functions for UV and blue light. The $B(\lambda)$ function is "normalised" or scaled so that its maximum value is unity at 440 nm. The risk for wavelengths greater than 500 nm is probably too low in the natural environment to be of significance. The values are shown in Figure 7.

As already described in this document, some authors are concerned that short wavelength blue light may have a cumulative effect on damaging the retina, even when present at irradiances very much lower than required for an acute hazard. Unfortunately, there is no action spectrum for age-related macular degeneration, although the blue light hazard function, $B(\lambda)$ Adult, may be a good choice for now [see also 6.6].

6.6 describes the function of the intrinsically photosensitive or melanopsin retinal ganglion cells responsible for necessary non-visual biological functions with peak absorption is at 480 nm. There may now be sufficiently reliable data from recent studies to allow a revision of the $B(\lambda)$ function reducing its value between, say, 460 nm and 500 nm. This wavelength band is also critical to the visibility of the flashing blue LED signal lamps used on some emergency vehicles, see 6.7.4.

8 Filtering materials and measurement

8.1 General

This section gives information about different kinds of filtering materials which provide protection from short wavelength radiation. These include polarising and photochromic lenses, anti-reflection lenses, and sharp cut-off filters. Information is also given about the relationship between the physical properties of filters and their transmission, reflection and absorption. An introduction to the principles of spectral transmittance measurement with spectrophotometers is also given.

8.2 Materials for lenses and filters, including special treatments for filter properties

Both mineral glasses and plastics are used to make clear and tinted prescription and non-prescription (plano-power) lenses. Dissolved mineral colourants and organic dyes, respectively, provide wavelength-selective absorptions of optical radiations. A wide selection of colours and optical densities can be provided. Absorptions at longer ultraviolet wavelengths than those intrinsic to the base materials can also be provided. Absorptions vary in accordance with the nature and intended uses of the eyewear. Tinted (including strongly coloured) lenses are used to reduce glare and provide visual comfort; some tints improve contrast and, in some cases, improve the sharpness of focus. Lenses having light tints are called "fashion" or "comfort" eyewear. Those with darker tints are known as "sunglasses".

Crown glass and plastics are used for the same ophthalmic applications. All plastic lenses contain ultraviolet absorbing dyes to protect lenses from degradation by solar radiation of wavelengths below about 360 nm. Additional dyes can be added to glass or plastic lenses to give the functional ability to absorb at wavelengths higher than 360 nm.

Polarising lenses are made by incorporation of dyes or reflectors on the surface or imbedded in the lens material. These dyes or reflectors are in linear alignment in a grating pattern. The plane of transmission is held in close alignment with the vertical meridian of a mounted lens.

Photochromic lenses have the property of darkening to block portions of the visible spectra when exposed to short wavelength radiation, and then reverting to their faded or light (high transmittance) state when removed from the activating exposure. The photochromic agents are specifically chosen to be compatible with the lens material in which they are incorporated.

Anti-reflection coatings can be applied to one or to both surfaces of a lens. Single-layer coatings and multi-layer coatings are used. For the reflectance to be essentially constant over the full visible wavelength band, the anti-reflection coating must be composed of multiple layers, the refractive indices and thicknesses being adjusted according to principles of optics.

A sharp cut-off filter is used to provide essentially total isolation from all incident radiation that is on one side of the cut-off wavelength and to transmit as much as possible of the incident radiation that is on the other side of the cut-off wavelength. When the high transmittances occur at longer wavelengths than the cut-off, the filter is designated a "high-pass filter", or "long-pass filter", or "long wavelength pass filter". Corresponding terms are used for filters that have their high transmittance side at shorter wavelengths of the cut-off, e.g. "low-pass filter".

It should be noted that while most protection is of course given by the filtering properties of the lens, the frame itself can be a significant absorber of harmful radiation. Further, the extent to which the lens/frame design gives protection, is important.

It is possible for quite high levels of harmful radiation to reach the eye bypassing the lens and frame, that is, passing directly to the eye around the frame without any filtration. This applies especially in the case of the darker lenses with high glare reduction since these allow the iris to dilate, thereby allowing more radiation to reach the retina not having passed through the filtering lens.

Frame/lens designs with high face-form angle that fit the face closely or with broad sides will minimise the extent to which harmful radiation can reach the eye directly around the frame. Designs with small lenses should be avoided.

8.3 How the physical properties of lenses/filters affect transmission, reflection, and absorption of solar radiation

Transmission, reflection, and *absorption* are physical *processes*. The corresponding dimensionless physical *quantities* are *transmittance, reflectance,* and *absorptance*. Each is a ratio: the quotient of the amount of radiation that remains after the process of interaction with a filter, divided by the amount of radiation that was incident on the filter. The geometry of the radiant beam must be specified as a qualification for defining the "–ance" quantity. By the first law of thermodynamics, i.e. the conservation of energy, the sum: transmittance plus reflectance plus absorptance is equal to 1 (unity), or $T + R + A = 1$. This is true both spectrally and as the spectrally integrated summation.

The physical properties of filter lenses that affect their interaction with solar radiation are: index of refraction; spectral absorption coefficient; figure (surface-curvatures and thickness); surface treatments (anti-reflection and scratch-resistant coatings); and scattering. Polarisation and photochromic properties can be considered to be special features (variants) of the absorption coefficient.

Radiation incident upon a surface of a filter is partly transmitted through the surface, partly reflected from the surface and partly absorbed between the surfaces. Only rays that follow paths determined by specular reflection and by regular transmission are considered. The topic of scattering is covered in a later paragraph.

The filter-lens is assumed to be immersed in air. If the two surfaces are identical (i.e. have identical surface treatments), the reflectances are the same at each. Reflection at the first surface is external, and at the second surface, it is internal. Practically, the internally reflected radiation can be considered lost; even if absorption is negligible, too little of this radiation emerges in either the forward or the backward direction to modify effectively any visual discernment.

In the following paragraphs, the rays are assumed to be incident normally (perpendicularly) on the surfaces of the lens. Surface reflectances increase with angles of incidence greater than about 60°.

Reflectance at the interface between two media depends upon their indices of refraction. Therefore, they vary with wavelength. However, the variation is small enough over the visible spectrum that it can be ignored for filter-lenses. It increases more rapidly with decreasing wavelength in the ultraviolet. The index of air can be taken to be exactly 1 (one) for our purposes. The reflectance at a single interface that is not anti-reflection coated is:

$$R_s = \left[(n-1)/(n+1) \right]^2 \quad (1)$$

The transmittance through the surface is $T_S = (1 - R_S)$, and for two identical surfaces:

$$T_0 = T_{s1} \times T_{s2} = T_s{}^2 \quad (2)$$

The net transmittance of the filter is $T_0 \times T_i$, where T_i is the internal transmittance of the filter:

$$T_i(\lambda) = 10^{-a(\lambda) \cdot x} \quad (3)$$

where $a(\lambda)$ is the spectral absorption coefficient, and x is the path length of the ray through the body of the lens. For rays at essentially normal incidence, x can be taken as equal to the thickness of the lens. Tinted lenses made from tinted material, i.e. so-called solid tinted lenses, with strong power will have a gradient of colouration from the centre to the edge.

The spectral absorption coefficient $a(\lambda)$ varies with the type and concentration of the absorbing species. The *colour* of a lens is a function of both the variation of the spectral absorptivity of the absorbing colourant and of its concentration.

Polarised lenses are *linearly* polarised (in contrast to circularly or elliptically polarized filters). Direct sunlight is unpolarised.

Unpolarised light reflected at high angles of incidence on a dielectric (i.e. non-metallic) surface (e.g. a road surface; the window of an automobile) acquires a substantial degree of polarisation. The ray's vertical component is largely transmitted into the medium and not reflected, so the electric vector of most of the reflected rays is oriented horizontally. The plane of transmission of a polarising lens is oriented vertically; therefore, it provides high transmittance for rays having their electric vectors vertical. Light with its electric vector horizontal is strongly absorbed by the polarizing lens. This reduces the glare caused by reflected light.

Haze is the aspect of appearance that results from scattering of rays out of the intended image-forming paths. It occurs at irregularities (e.g. scratches) on the surfaces of a lens and at small internal objects that have different indices of refraction from that of the matrix. Examples of such in mineral glasses are seeds (gas bubbles), stones (solid particles), and cord (streaks of inhomogeneous composition). Similar inhomogeneities occur in plastic lenses. The effects of haze are to cause a slight veiling glare. Back-scattered light gives the appearance a whitish overlay; it is considered a cosmetic defect. Forward scattered light reduces the colour- and edge-contrasts on the retina.

8.4 Measuring spectral transmittances

8.4.1 Principles of the measurements

Several clauses of ISO 12311 are very informative for aspects of measuring spectral transmittances of lenses, filters and/or oculars. In particular, ISO 12311:2013, Clause 7, *Test methods for measuring spectrophotometric properties,* and all of its subclauses provide specific methodology for all measurements that are of importance to this document. Also included are specific procedures for wide angle scatter, polarising filters, and photochromic filters.

For determining luminous transmittances, the typical specification is a step-width of 10 nm. For UV-B and UV-A transmittances, a step-width of 5 nm is used. For blue-light transmittances, the step-width is required to be not greater than 5 nm.

For determining good accuracy for the cut-off wavelength of a sharp-cut-off filter, a spectral bandwidth of 1 nm is desirable. Many spectrophotometers have fixed bandwidths; e.g. 2 nm is typical, nevertheless it will probably be adequate for ophthalmic and sunglass filter lenses

8.4.2 Factors important to the accuracy of measurement

The best configuration is to measure a filter without any optical power (i.e. plano-power) according to recommendations of current standards, ISO 8980-3 and ISO 12311 in particular. In the plano-power form, the optical beam is not converged or diverged to a significant extent. It may be deviated (by so-called decentered lenses). It is important to ensure that the beam is still all collected by the detector. The most common method of measuring powered lenses is with the use of an integrating sphere that collects all the transmitted radiation. However, the method also results in much lower irradiances at the detector so that the signal is lower and this introduces sources of error. ISO 12311:2013, Annex B (informative), *Sources of uncertainty in spectrophotometry and their estimation and control* can be consulted for a detailed discussion on the numerous considerations of measurement equipment and their role on the accuracy of spectral measurements.

9 Summary

The authors of this document hope it will inform those who have an interest in the topic, and that it serves as a useful document for those who might wish to create standards in this area in the future.

Some of the more interesting information in the document includes:

a) Solar radiation in the short wavelength visible range has sufficient energy to cause damage to the components of the human eye. In particular there is potential for harm to the retina. The wavelengths that are responsible for solar radiation damage are yet to be unambiguously identified.

b) It is very important that the protective needs of spectacle and sunglass lens wearers be taken appropriately into account by carrying out a hazard analysis to identify the necessary protection.

c) The location and extent of possible damage in the eye is wavelength, radiance and time dependent across the blue range of visible radiation.

d) The data and methods of calculation of protective requirements that are most often used for eyewear standards come from ICNIRP (International Commission on Non-Ionizing Radiation Protection).

e) ISO standards do not yet contain the means to verify claims for enhanced absorption in the short wavelength visible range (such as UV400 claims). This remains a topic of ongoing interest.

f) There are a variety of ways during lens manufacture to reduce the optical radiation incident on and entering the eye. This is usually achieved by modifying the transmittance and reflectance properties of the lens by choice of material, by tinting or coating.

g) As in every field related to protection, the data on which the standards are based is not perfect. Over time, improved data coming from research relating to exposures and eye damage will be most useful to more confidently base the definitions, requirements and test methods in future ISO eyewear standards.

Bibliography

International Standards

[1] ISO 8980-3:2013, *Ophthalmic optics — Uncut finished spectacle lenses — Part 3: Transmittance specifications and test methods*

[2] ISO 12311:2013, *Personal protective equipment — Test methods for sunglasses and related eyewear*

[3] ISO 12312-1:2013, *Eye and face protection — Sunglasses and related eyewear — Part 1: Sunglasses for general use*

[4] ISO 12312-2:2015, *Eye and face protection — Sunglasses and related eyewear — Part 2: Eye protectors for direct observation of the sun*

[5] ISO 14889:2013, *Ophthalmic optics — Spectacle lenses — Fundamental requirements for uncut finished lenses*

[6] ISO 11664-2:2007, *Colorimetry — Part 2: CIE standard illuminants*

[7] ISO 20473:2007, *Optics and photonics — Spectral bands*

NOTE 1 ISO 8980-3 and ISO 14889 are for spectacle lenses and are closely related. ISO 14889 carries the legal requirement for Europe, while ISO 8980-3 carries the technical details.

NOTE 2 The transmittance requirements in ISO 8980-3 (for spectacle lenses) and ISO 12312-1 (for sunglasses) are almost identical. The only difference relates to the recognition/detection of blue signal lights.

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2) All these ICNIRP documents are available, free of charge, from the ICNIRP website: http://www.icnirp.de/PubOptical.htm. They were all originally published in the Journal of the Health Physics Society.