# Hazards to the Eyes from Optical Radiation

## 1 Introduction

Optical radiation can have an effect on human eyes and human skin. The effect depends on how deeply the radiation penetrates the eye, which in turn depends on the wavelength, intensity, duration, and the frequency of its impact. The factors involved can often be quite complex in their relationship to one another. This report provides an overview of the most substantial hazards to the eyes from optical radiation.

*Optical radiation refers to those parts of the electromagnetic spectrum subdivided into ultraviolet (UV) rays with wavelengths of $\lambda$ = 100-380nm, visible (VIS) radiation ($\lambda$ = 380-780nm), and infrared (IR) radiation ($\lambda$ = 780nm - 1mm). UV radiation is further subdivided into UVC ($\lambda$ = 100-280nm), UVB ($\lambda$ = 280-315nm), and UVA ($\lambda$ = 315-380nm), whereas IR radiation is subdivided into IRA ($\lambda$ = 780 - 1400nm), IRB ($\lambda$ = 1400 - 3000nm), and IRC ($\lambda$ = 3000nm - 1mm).*

The main parts of the eye are depicted in Figure 1 (also see [1]):

- Cornea
- Conjunctiva
- Anterior chamber
- Iris
- Lens
- Vitreous body
- Retina, with the fovea – the area of sharpest vision
- Choroid
- Sclera

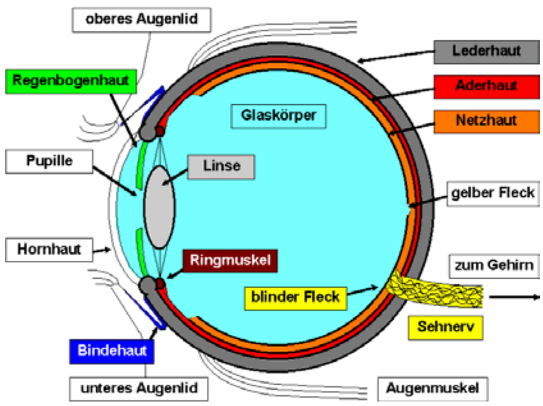


Figure 1: Cross-section of the human eye

*Translation of key:*

| | |
|---|---|
| *oberes Augenlid* | *Upper eyelid* |
| *Regenbogenhaut* | *Iris* |
| *Pupille* | *Pupil* |
| *Hornhaut* | *Cornea* |
| *Bindehaut* | *Conjunctiva* |
| *unteres Augenlid* | *Lower eyelid* |
| *Glaskörper* | *Vitreous body* |
| *Linse* | *Lens* |
| *Ringmuskel* | *Ciliary body* |

| | |
|---|---|
| *blinder Fleck* | *Blindspot* |
| *Lederhaut* | *Sclera* |
| *Aderhaut* | *Choroid* |
| *Netzhaut* | *Retina* |
| *gelber Fleck* | *Fovea* |
| *zum Gehirn* | *To the brain* |
| *Sehnerv* | *Optic nerve* |
| *Augenmuskel* | *Muscle (rectus muscle)* |

## 2 Depth of penetration for optical rays into the eye

Optical radiation can have the greatest effect on the parts of the eye that absorb them. How deep the rays can penetrate into the eye depends on their wavelength. The depth of penetration is roughly described in this table:

| Type of radiation | Penetrates eye to (depth) |
|---|---|
| UVC and UVB (partly) | Cornea / conjunctiva |
| UVB (partly) and UVA | Lens |
| Visible (light) rays | Retina |
| IRA (partly) | Retina, vitreous body |
| IRA (partly) | Lens |
| IRB and IRC | Cornea / conjunctiva |

Yet the dividing lines are not quite so distinct. A more accurate distinction is made by considering how easily the different wavelengths pass through the components of the eye [2]. The eye's translucence also depends on a person's age. In early life, the frontal part of the eye is more translucent than it is in old age. Figure 2 shows the depth of penetration into the eye of different wavelengths.

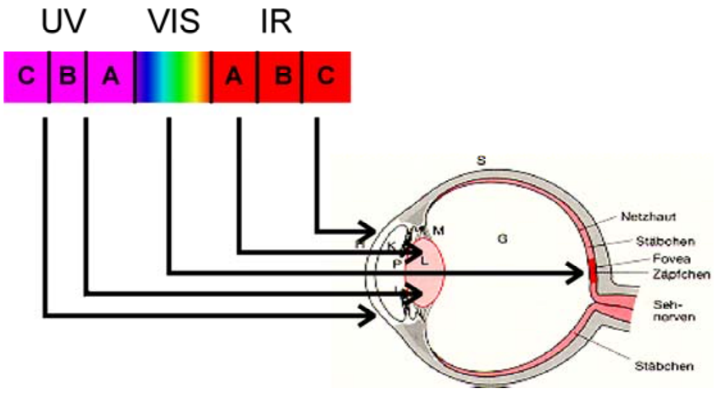


Figure 2: Depth of penetration into the eye of different wavelengths of optical radiation

*Translation of key:*

| | |
|---|---|
| *Netzhaut* | *Retina* |
| *Stäbchen* | *Rods* |
| *Fovea* | *Fovea* |
| *Zäpfchen* | *Cones* |

| | |
|---|---|
| *Sehnerv* | *Optic nerve* |
| *Stäbchen* | *Rods* |

## 3 Positive effects of radiation on the eye

The main function of the eye is the sense of sight. Most people consider vision to be the most important of their senses. It is light, the visible portion of the optical radiation spectrum, that allows us to perceive our surroundings, remember them, and maintain our orientation.

The role of light in our sense of well-being should also not be underestimated. The effects of visual light on the skin and the eyes, as well as the effects of infrared radiation on the skin, have both physiological and psychological benefits. Humans need a certain minimum of light. Nevertheless, these benefits are only found within a certain intensity of radiation. If the intensity is too small or too high, the effects are either negligible or potentially harmful.

## 4 Damage to the eye from optical radiation

Higher intensity optical radiation can cause damage to the eye. Just where the damage is caused depends on the depth of penetration of the rays, which in turn depends on the wavelength. Direct damage occurs in places where the radiation is absorbed. Indirect damage, on the other hand, can also occur in other places, such as in the lens due to the warming of adjacent components. The type and degree of damage is also related to the duration and cumulative exposure to visible radiation, as well as to the intensity of the rays. The main types of damage to the eyes from optical radiation are described below.

### 4.1 Inflammation of the cornea and photo conjunctivitis

UV radiation of a higher intensity can damage the front-most parts of the eye in a manner of hours or even mere minutes. It can result in inflammation of the cornea (photo keratitis) and of the conjunctiva (photo conjunctivitis). These problems can also be caused by photochemical reactions in the epithelial cells. Here, the outermost cell layer of the cornea and conjunctiva are destroyed. The damage can be felt as a sharp pain in the eyes six to eight hours after the exposure. The person suffering from one of these conditions has the feeling of having sand in the eyes. Because new cornea and conjunctiva cells constantly re-grow, the damage is reversible. The eyes heal completely in one to two days after contracting the condition. The spectral effects of photo-conjunctivitis are shown in Figure 3.

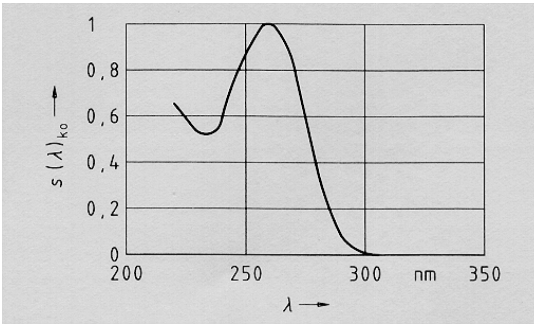


Figure 3:
Action spectrum of photo conjunctivitis as set out in DIN 5031-10

Damage can above all occur in places where the eyes are subjected to high intensity UV radiation. This is common in electric-arc welding (Figure 4) when seen without appropriate eye protection, or in spending time in snowy alpine zones under clear skies. The condition contracted from welding is known as "flash blinding" and from mountaineering as "snow blindness". These are relatively common.

Figure 4: UV exposure from welding

## 4.2 Cataracts from UV radiation

One long-term effect of UV radiation is a certain clouding of the lens (cataracts). Certain proteins, so-called crystalline, are altered in the lens cells by photochemical reactions. In connection with other factors, such as diabetes, this can cause a pigmentation of the cells and a clouding of the lens (Figure 5). This process progresses over time until vision is sharply impaired or even blindness occurs. Since lens tissue – in contrast to other tissues in the body – does not grow new cells, the damage is irreversible. Yet modern surgical technology does allow the clouded lenses to be replaced by artificial lenses. UVA and UVB radiation can cause damage [3]. The exact action spectrum leading to cataracts over the long term has not yet been identified. The action spectrum has been identified in animal tests only for short-term effects.

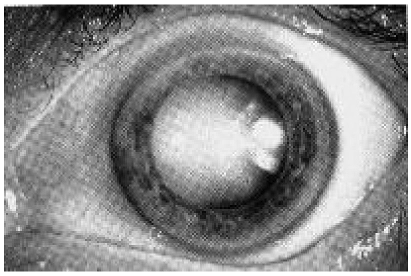

Figure 5: Lens with cataract

The intensity of the radiation that causes this disease is well below the intensity that can cause an acute inflammation of the cornea or conjunctiva. Most important is the cumulative length of the exposure, mostly extending over several decades. The disease can also be caused by artificial UV radiation sources. One example is of a doctor's assistant who administered sunray lamp radiation to small children while not protecting her own eyes [5]. But plain sunlight can also cause cataracts. This often affects people who work a lot outdoors, such as farmers or seamen. The disease can affect practically anyone. The common form occurs in people nearing the end of their seventies [1]. The rate of cataract disease in the population increases with the age. In general, cataracts are a very common disease.

## 4.3 Retinal burn

Since visible radiation permeates through to the retina and is absorbed by it and the lower tissue layers, it can also cause damage here. Very intense radiation can cause retinal burn (thermal retinal damage) by quickly warming the tissue in a very short time (in s, ms, or $\mu$s). This can be induced by looking at the sun without eye protection, as frequently occurs when people try to observe a solar eclipse. Yet the radiation from artificial light radiation sources may also cause damage. This is particularly true for laser rays, which often have a very high, concentrated intensity. The process of radiation absorption, heat conductivity, local retinal warming, and the resulting burn is rather complex. Whether or not burning occurs thus does not depend only on the intensity and duration of the radiation exposure, but also on the surface area of the retina that is affected. It is often the radiance of an optical radiation source, rather than the irradiance, that needs to be considered when evaluating the potential hazards. The maximal effects occur at wavelengths of around 435 to 440nm. The action spectrum R(λ) published by the International Commission on Non-Ionising Radiation Protection (ICNIRP) includes parts of the spectrum in the IR and visible ranges [6].

Retinal burn is irreversible. Yet point burns on the retina are often not perceived as long as they do not occur to the area of sharpest vision, the fovea. Larger burns, or burns where the optic nerve enters the retina (the "blind spot") can often lead to blindness. Retinal burns frequently occur as a result of isolated accidents.

## 4.4 Blue-light hazards (photoretinitis)

Along with thermal damage, photochemical damage to the retina – the so-called "blue-light hazard" – or even photoretinitis can occur. This condition is often overlapped by thermal damage to the retina. The photochemical changes to the cells of the retina and lower tissues can arise due to exposure to a medium-strength to intense-strength visible radiation for more than 10 seconds (in part, also as the result of chronic exposure) [2]. The damage is normally noticeable with a delay of 4 to 48 hours after exposure. Because this damage is caused by photochemical reactions, it is quite dependent on wavelength. The highest potential for causing damage is radiation with a wavelength of 440nm (see Figure 6). The damage is irreversible and can lead to blindness. As there is little available in the scientific literature on photochemical retinal damage, it is to be assumed that this condition is either quite rare or that it is seldom distinguished from thermal retinal damage.

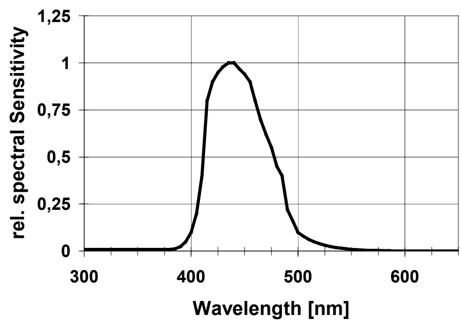


Figure 6: ICNIRP Weighting function B(λ) for photoretinitis

## 4.5 Blinding

Blinding can also arise as the effect of intensive visible light radiation on the eye. A blinding light or glare is not necessarily directly connected with damage to the eye. Yet because this blinding can impair vision and the perception of objects, it may lead to indirect hazards, such as when driving.

## 4.6 Cataracts from IR radiation

The impact of many years' worth of IR radiation can result in a clouding of the lens (cataracts). This disease can also be described as "glass blower's cataracts" or "fire cataracts". The period of exposure is between 10 and 30 years. This condition is also irreversible, and can lead to total blindness. As mentioned above, a clouded lens can be replaced by an artificial lens in surgery today.

The harmful wavelengths here lie in the range of between 780 and 1400nm; several sources also mention a range of 780 to 3000nm. The damage mechanism has not yet been entirely explained. The clouding of the lens due to the direct effects of radiation both on the lens and the adjacent tissue as well as a resulting heat development are currently in discussion as factors. Medicinally, cataracts that develop on the lens due to IR radiation have been found to share some characteristic features. The clouding begins in the rear pole of the lens. In part, a so-called fire lamella appears. Because of its characteristic pattern, it is often possible to trace these cataracts to the effects of IR radiation in many cases of occupational disease while ruling out other causes, such as age-related cataracts.

Figure 7: Glass blower at a melting furnace

Typical occupations where these "fire" cataracts arise are traditional glass-blowing at melting furnaces (Figure 7) and working with liquid metals in smelting ovens. The intensity of the heat radiation in smelting works is, however, normally so great that working here would cause pain and burns to the skin without the use of protective gears. These workers thus typically wear both eye and skin protection. The number of cases of IR-induced cataracts is generally very low today.

## 5 Exposure limit values and regulations

In comparison to other hazardous agents, such as ionising radiation, the intensity of optical radiation in our environment (from the sun) is so high that it can easily cause damage. In establishing the limit values, it is thus not possible to take large safety factors into account, as would otherwise be the case. The most commonly used limit values today are based on recommendations that were published by the ICNIRP [6, 7, 8, 9, 10, 11]. The ICNIRP recommendations include the limit values both for incoherent optical radiation and for laser radiation. These reflect the wavelength of the radiation, the potential type of damage, and the overall period of exposure. Physical variables that are reported in the limit values include those such as radiation strength, radiation type, and ray density. In part, these variables are weighted using a spectral weighting equation that is suited to the respective effect function.

So far only workplaces in health services [12] are subject to binding legal regulations with limit values for exposure to incoherent optic radiation. The accident prevention guidelines BGV B9 "*Optische Strahlung*" ["optical radiation", 13] is currently being prepared that will cover all workplaces where optical radiation can effect people. These accident prevention guidelines requires that the exposure to optical radiation be identified and evaluated. For the evaluation, the regulation includes exposure limit values that are derived from the ICNIRP recommendations. In addition, an annual UV radiation limit value is laid out for protection against skin cancer. If the exposure limit values at the workplace are exceeded, then suitable protective measures must be applied in order to reduce exposure to a safe level.

Limit values for exposure to laser radiation are recommended in the European standard DIN EN 60825-1 [14] for one, whereas they are made legally binding in the accident prevention guidelines BGV B2 [15]. BGV B2 contains additional definitions for establishing the hazards and for applying protective measures. Because the definitions for the classification of laser devices differ between DIN EN 60825-1 and BGV B2 ever since the introduction of the new laser classes into the standards, the BGs are currently drafting an information sheet BGI 832. This is meant to help users harmonise the protective measures required by the new classification with the legally binding requirements of BGV B2.

## 6 Determining exposure

The eye's exposure to incoherent optical radiation can be determined by using the procedures laid out in the European standard E DIN EN 14255-1 [16] for UV radiation and prEN 14255-2 [17] for visible and IR radiation. At first it must be determined whether the available data permits a general estimation of radiation exposure. If this is not possible, exposure measurements must follow. The details on this are defined in the standards.

Details on establishing exposure to laser radiation can be found in the series of standards DIN EN 60825 (see [18] in the references).

## 7 Protective measures

The best protection against damage to the eye resulting from optical radiation has already been developed during the natural process of evolution. The eye is embedded in the eye socket, which essentially shades it by blocking out solar radiation from above. Looking directly into the sun is normally avoided because of the blinding pain. Yet the distributed radiation in the sky's periphery and the reflected light from the ground can get into the eyes. The eyes should thus be protected whenever the sun is particularly intense. Sunglasses of the DIN EN 1836 [19] standard are appropriate. The frames should be designed in a manner that also provides protection against peripheral radiation.

The use of suitable protective eyewear is also recommended in the presence of artificial radiation sources. This includes activities such as welding and the use of laser devices, but also the use of UV and IR radiation sources. The filtering eyewear must be selected on the basis of the required minimum need to see, the radiation intensity, and the wavelength. Here, the details of the respective norms and standards can be of help. They are summarised in [18].

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