# Light Transmittance by Organic Eyeglass Lenses According to their Class

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*The research concerns the transmission of electromagnetic waves with a wavelength corresponding to the visible part of the spectrum and part of the ultraviolet and infrared radiation range. Light transmittance through ocular lenses was tested using a UV-Vis spectrophotometer for the wavelength range 250-850 nm. Obtained results encourage reflection on the quality of the spectacle lenses produced. The obtained results do not confirm the assurances of producers about the increase in light transmittance in the range of wavelengths corresponding to the highest sensitivity of the human eye. In addition, lenses having UV protection coatings do not perform their function in a proper way. Eyeglass lenses of various classes were tested, equipped with various refining coatings. The effect of the number of coatings on the transmission of light through the lenses was not observed. Conducting and publishing studies such as those presented in this work may have a significant impact on the improvement of the quality of manufactured eyeglass lenses.*

*Keywords: Engineering Polymers, Thin Coatings, UV-Vis*

The optical market is growing at a very fast pace. The sale of contact lenses and glasses increases year by year. There is no shortage of facilities offering a free eye test and selection of eyeglass correction. The fact that more and more people wear sunglasses is largely caused by two factors. The first factor is the growing awareness of the society. People who have even relatively small refractive errors go to the optometrists in order to choose glasses that eliminate the burdensome effects of myopia or far-sightedness. The reason why many people did not opt for glasses was gone, namely their attractive appearance. Nowadays, wearing glasses is simply fashionable. The second factor, undoubtedly more scientific and investigative, is the significant deterioration of the vision of the majority of the population. This is the effect of widespread use of smartphone and tablet screens and the use of computers at work and at home. These factors together with the growing consumer requirements have a big impact on the development of eyeglass lens technology.

Spectacle lenses are used primarily to correct eye defects of eyeglass users. However, apart from the correction itself, several factors are important. The quality of the lens determines the resistance to abrasion - it determines the durability of the product and its longest possible use. Another important factor is the transmission of light. A good lens should transmit the maximum amount of light in the visible range and completely cut off radiation from the ultraviolet range, which is extremely harmful to the optical system of the eye. The cornea of the human eye absorbs almost completely electromagnetic radiation with a wavelength less than 280 nm. Waves with a length of 300 to 370 nm are mostly retained by the lens of the eye. In contrast, radiation from the 380 - 400 nm range reaches the retina [1,2]. It should be mentioned that electromagnetic radiation in the ultraviolet range is extremely harmful to the optical system of the eye. The greatest risk associated with exposure to this type of radiation is the development of macular degeneration (AMD) leading to loss of vision. From the point of view of light transmission, the level of light transmission in the field of photopic (day) and scotopic (night) vision is also important. The maximum daily view sensitivity corresponds to a wavelength of 555 nm and for night vision it is 507 nm. Spectacle lenses should theoretically exhibit maximum light transmissions in these ranges [3,4].

The first eyeglass lenses were made of mineral materials. Undoubtedly their advantage was and still is high abrasion resistance. Mineral materials such as quartz have a hardness of 7 on the Mohs scale. Lenses made of mineral materials, however, are not without flaws. The main shortcomings of this kind of lenses are the susceptibility to cracking and a relatively large mass causing cumbersome use. The answer to problems arising from the use of mineral lenses are organic lenses. They are characterized by much lower mass or greater resistance to cracking. A popular material used for the production of organic lenses is the allyl invuclide carbonate designated CR-39. This material is characterized by a refractive index of 1.498 and an Abbe number of 53.6 [5]. This material has a hardness grade of 2 on the Mosh scale. This means significantly less abrasion resistance compared to mineral lenses and determines the need for refining the lenses with hardening layers. The production of lenses from this material consists in the casting of diallyl ethylene glycol dicarbonate together with the UV absorber and dibenzoyl peroxide into glass molds. The next step is the polymerization of the material carried out for 20 h at 95 ° C. The production of this material is relatively inexpensive, which is its additional advantage. Currently, many spectacle lenses are available on the market, both mineral and organic. These second lenses are especially recommended for children and athletes due to the much higher resistance to damage compared to mineral lenses.

The quality of the lenses made depends, however, first and foremost on the further stages of the production of spectacle lenses. The amount and type of layers applied to the lenses are important here [6-12]. The individual layers have different tasks to fulfill. And so anti-reflective layers

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are responsible for eliminating light reflections. This phenomenon on the lenses distracts the user of the glasses. Antireflective coatings have a positive effect on the transparency of the lens. Research shows that the use of antireflex may increase the coefficient of light transmittance by about 8% [13,14]. The hydrophobic layers, as the name suggests, are designed to prevent adhesion of water to the surface of the lens. The next type of layers are oleophobic coatings, which in turn are responsible for not adhering fat to the surface of the lens. In addition, lenses made of organic materials are subjected to various curing processes due to their low hardness compared to mineral lenses. Lenses from higher shelves have additional hardening. The effect on the quality and strength of the lenses is not only the quantity and type of coatings applied, but also the way they are applied [15].

Coatings are directed to the lenses with several methods. Methods of vapor deposition from the gas phase have been known for a long time. Thin layers are applied under high vacuum conditions [4]. The number of coatings applied has a significant impact on the transmission of light. Multilayer coatings in theory approximate the light transmission to about 99%. There is physical and chemical vapor deposition. The first method consists in the adhesive combination of the coating resulting from the crystallization of metal vapors with the surface of the lens. The vapor deposition is usually carried out by means of an electron gun and an ionic gun (improves the adhesion of the coating). The chemical method is less frequently used, inter alia, for a long duration of treatment.

Hardening coatings are also applied in various ways. Originally, the coating was produced under high vacuum conditions, the material applied was SiO2. In addition, binding agents are used to improve the adhesion of the layer. Increasing the use of refining coatings by the dipping of the lenses in the applied material is increasingly the method. The first stage of the method is cleaning the lenses. The prepared material is immersed in a suitable varnish (polysiloxane thermosetting varnish). Immersion speed and viscosity varnish determine the thickness of the coating. An important factor here is maintaining absolute cleanliness and ambient temperature at a constant level (around 18 ° C). The next step is curing the applied coatings in 3 - 4 h in a special furnace. The resulting curing coatings provide the organic lens with a much better abrasion resistance, in some cases a resistance comparable to those made of mineral materials is achieved [16,17].

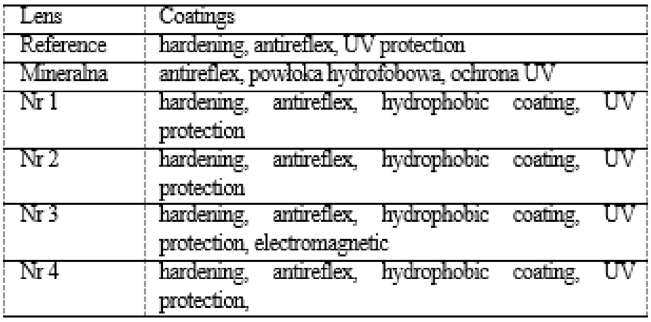
## Experimental part

Six organic lenses made of the CR-39 material popular in the ophthalmic industry and one mineral lens were used for the research. The lenses selected for the tests were equipped with various types of refining coatings. The quantity and type of coatings determine the properties and assumption of high quality of the lens. Data for examination of copies is given in table 1.

The first lens established by the reference lens comes from the so-called economic line. It contains an anti-reflective coating and protection against ultraviolet. The products of this group are characterized by nanocomposite curing and are additionally coated with a multilayer anti-reflective coating. It is a lens with zero optical power. As anyone know, the thickness of the material affects the level of radiation transmission. As the thickness of the coating increases, the radiation absorbance increases, so lenses with optical power should be less able to transmit radiation. The second lens is also treated as a reference lens. It is a mineral lens with a refractive index of 1.56. It has an optical power of + 4.0 D. The next lenses are made of CR-39 material and have the same optical power equal to + 4.0 D The number 1 lens, in addition to standard curing and anti-reflective coatings, is equipped with a hydrophobic coating. The lens No. 2 contains the previously mentioned layers but comes from a different manufacturer. The number 3 lens is colored in gray (80%). It is obvious that the transmission of visible light is lower but it is nevertheless interesting to check the amount of light transmitted and the quality of the UV cut-off. In addition to the previously mentioned layers, the No. 3 lens has an additional electromagnetic coating. Lens No. 4 has the same refining layers as lenses No. 1 and No. 2. The subsequent layers applied affect the quality of the product, which is also reflected in the price range in which the products are located.

**Table 1**

LENSES USED FOR THE STUDIES



| Lens | Coatings |
|---|---|
| Reference | hardening, antireflex, UV protection |
| Mineralna | antireflex, powloka hydrofobowa, ochrona UV |
| Nr 1 | hardening, antireflex, hydrophobic coating, UV protection |
| Nr 2 | hardening, antireflex, hydrophobic coating, UV protection |
| Nr 3 | hardening, antireflex, hydrophobic coating, UV protection, electromagnetic |
| Nr 4 | hardening, antireflex, hydrophobic coating, UV protection, |

By definition, lenses having a greater number of refining coatings should have a higher quality. The transmission of light is considered to be the main factor that characterizes the lens's ability to perform its task. Therefore, the damaged lenses were tested using a UV-VIS spectrometer. This device is used, inter alia, to study the structure of molecules. The information obtained enables quantitative and qualitative chemical analysis. Depending on the needs, the transmission of light through a given material or the absorption of radiation can be taken into account. For the purposes of this study, the absorption and transmission of light radiation is taken into account. Light transmission experiments were carried out not only in the visible light range but also in infrared and ultraviolet light. The range of the studied waves was set at 250 - 850 nm. The range of the tested wavelengths was selected in order to examine the transmission of the visible part of electromagnetic radiation and the UV radiation cut-off. Particular attention has been paid to the transmission level in the wavelength range corresponding to scotopic and photopic vision.

## Results and discussions

Figure 1 presents a graph of electromagnetic radiation transmission through selected spectacle lenses in the wavelength range from 250 to 850 nm. Measured curves significantly differ from the assurances of producers with almost total transmission in the visible spectrum. A lens with no optical power (reference lens) ensures high light transmission due to the smallest thickness. Lenses marked with: No. 1, No. 2, No. 4 and mineral lens are characterized by a similar level of light transmission in the visible range. As expected, the smallest transmission is shown by the lens No. 3 (colored lens). The tested lenses practically do not allow electromagnetic radiation with a wavelength below 350 nm. Almost all the curves shown in figure 1 are characterized by a fairly similar course. In the wavelength range from about 320 - 400 nm, there is a very large increase in light transmission through the tested lenses. Next, the electromagnetic wave transmission after reaching the level of about 80% slowly increases with the length of the electromagnetic wave. The light transmission curve for a colored lens (fig. 1d) deviates from the other measurements. The lens achieves a low transmission level in the visible light range. on the curve, a significant increase in electromagnetic wave transmission is observed for wavelengths exceeding 650 nm. Figure 2 presents light transmission curves in the range 500 - 560 nm.

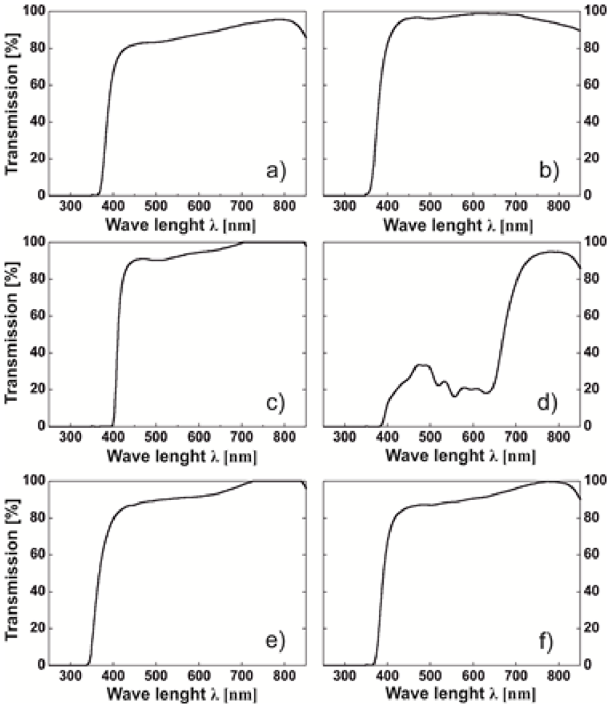


Fig.1. Electromagnetic wave transmission through spectacle lenses in the wavelength range from 250 - 850 nm: a) lens nbr 1, b) lens 0D, c) lens nbr 2, d) colored lens, e) mineral lens, f) lens nbr 3

According to manufacturers, eyeglass lenses should ensure maximum transmission of light in the range of the highest sensitivity of the human eye to daytime vision. However, the curves shown in figure 2 do not confirm these assumptions. No maxima can be observed on curves that can indicate an increase in transmission for 507 or 555 nm wavelengths. The light transmission curves of the tested lenses are characterized by a similar course, only the colored lens deviates from the norm (figure 2 d). In this case, the local maximum transmission through the lens is observed for an electromagnetic wavelength of about 535 nm.

From the curves shown in figure 2, the light transmission values of the tested eyeglass lenses for electromagnetic waves corresponding to the maximum sensitivity of the human eye to day and night vision were read. The determined values are shown in table 2. The best light transmission for wavelength 507 and 555 nm is characterized by a lens with no optical power which can be considered as the expected result. This is of course influenced by the smallest thickness of the lens without optical power. Apart from the obvious weak result of the colored lens (No. 3), a fairly low transmission was obtained for the lens No. 1. The values of electromagnetic wave transmission with lengths 507 and 555nm oscillating around 90% should be considered low.

**Table 2**

LIGHT TRANSMISSION LEVEL FOR SCOTOPIC AND PHOTOPIC VISION OF THE HUMAN EYE

| Lens | transmission for scotopic vision (507) | transmission for photopic vision (555 nm) |
|---|---|---|
| Reference | 96.1 | 97.5 |
| Mineral | 89.8 | 90.9 |
| Nr 1 | 83.4 | 85.5 |
| Nr 2 | 90.3 | 92.5 |
| Nr 3 | 26.5 | 16.3 |
| Nr 4 | 87.1 | 88.7 |

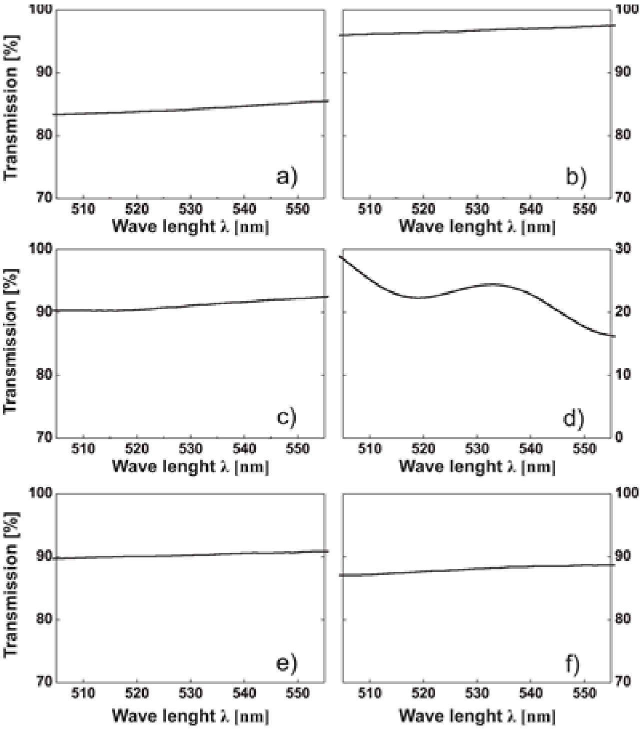


Fig. 2. Electromagnetic wave transmission through spectacle lenses in the wavelength range from 500 - 560 nm: a) lens nbr 1, b) lens 0D, c) lens nbr 2, d) colored lens, e) mineral lens, f) lens nbr 3

Interpreting the measured values, it can be said that the user of the tested eyeglass lenses receives 10% less light in the visible range compared to the unaided eye. It is worth mentioning that the results achieved are significantly lower than those reported by the producers. However, it can be concluded that the light transmission values in this range are acceptable. Figure 3 shows the measured light transmission curves for spectacle lenses for the 315 - 415 nm range.

All studied lenses have protection against ultraviolet radiation (UV protection). However, the investigation results show that ultraviolet radiation is not fully absorbed by the protective coatings of the lenses. Lenses: mineral, without optical power and No. 1 and No. 4 show a high level of radiation transmission for the wavelength corresponding to ultraviolet. A satisfactory result is achieved by the No. 3 lens having an electromagnetic coating. At 400 nm, transmission level is 12.2% and for wave length 385 nm below 0.5%. The best in this combination turned out to be the No. 2 lens, which at the wavelength of 400 nm achieves transmissions at the level of 1.8%. The worst drops in the combination are mineral lenses and without optical power. For a wavelength equal to 400 nm, the radiation transmission for them is respectively: 79.4% and 82.3%.

## Conclusions

The problem of light transmission through eyeglass lenses was considered in the work due to their class. Class means the quantity and quality of refining coatings.

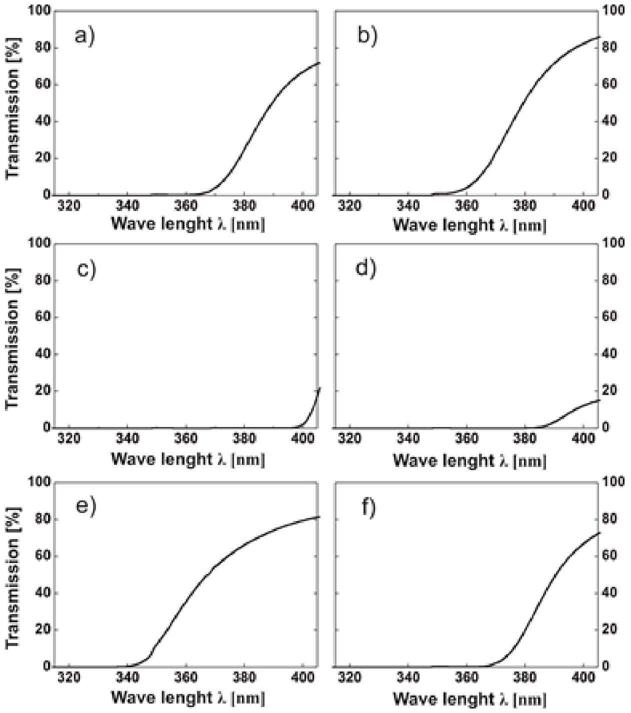


Fig. 3. Electromagnetic wave transmission through spectacle lenses in the wavelength range from 315-415 nm:
a) lens nbr 1, b) lens 0D, c) lens nbr 2, d) colored lens, e) mineral lens, f) lens nbr 3

Research has shown that the coatings of various manufacturers similarly affect the level of light transmission in the visible range. In the comparison in terms of the level of visible light transmission, the lens with optical power best flew out, which is the expected result due to the smallest thickness of the lens. The materials do not show the light transmission announced by the producers at almost 100%, but the transmission results exceeding in some cases 90% can be considered satisfactory. The reason for reflection are the levels of transmission of radiation in the ultraviolet range. All lenses have radiation protection coatings of this wavelength. Unfortunately, only two of the six tested lenses meet the promise of total protection against UV radiation. The remaining lenses transmit a significant portion of the radiation in the UVA range. Although this radiation is less harmful than UVB and UVC, it can cause damage to collagen fibers and lead to cataracts. The results of the conducted research pay a closer look at the eyeglass lenses offered on the market. Almost all currently available lenses are equipped with a protective coating over UV radiation, but the quality of these coatings leaves many doubts in many cases.

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