Original Article / Araştırma Makalesi

INVESTIGATION OF SPECTRAL AND OPTICAL PROPERTIES OF SOME ORGANIC EYEGLASS LENSES

Bazı Organik Gözlük Camlarının Spektral ve Optik Özelliklerinin İncelenmesi

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ABSTRACT

In this study, the spectral and optical properties of organic spectacle lenses used as visual aids were analyzed using Jasco V-730 UV/VIS spectrophotometer device in the ultraviolet and visible light wavelength ranges. The results obtained showed that the light transmittance in the wavelength (550nm) range to which the human eye is most sensitive in the lens samples examined was over 80% and that Polycarbonate (A_3) lenses had a maximum value of 97.87%. The largest cut-off edge wavelength value was found to be 390nm for the A_3 lens. At 550 nm for all lenses, the absorption spectrum was below 0.07. In terms of visual quality, it is expected that the visible light transmittance is high and the ultraviolet light transmission is minimal. Our eyes are exposed to ultraviolet rays almost every day, and these rays cause damage to the ocular tissues. The degree of damage caused by the amount of ultraviolet light absorption increases. Among the organic lenses with ultraviolet protection coating, the protection of the A_3 lens was relatively higher. Furthermore, optical band gap energies were found to range from 3.145 – 4.155 eV and 2.994 – 3.936 eV for direct and indirect transitions, respectively. The highest optical band gap values were found to be those of the B_1 and C_1 organic lenses, respectively.

Keywords: CR-39 lens, Eye health, Polycarbonate lens, UV radiation.

ÖZ

Bu araştırmada, görme gereci olarak kullanılan organik gözlük lenslerinin spektral ve optik özellikleri ultraviyole ve görünür ışık dalga boyu aralıklarında Jasco V-730 UV/VIS spektrofotometre cihazı kullanılarak analiz edildi. Elde edilen sonuçlar incelenen lens örneklerinde insan gözünün en duyarlı olduğu dalga boyu (550nm) aralığında ışık geçirgenliğinin %80'nin üzerinde olduğunu ve maksimum değere %97.87 olarak Polikarbonat (A_3) lenslerinin sahip olduğunu gösterdi. En büyük kesme kenarı dalga boyu değeri A_3 lensi için 390 nm olarak elde edildi. 550 nm'de soğurma spektrumlarının ise 0.07'nin altında olduğu bulundu. Görme kalitesi açısından görünür ışık geçirgenliğinin yüksek olması, ultraviyole ışık geçirgenliğinin minimum olması beklenir. Gözlerimiz neredeyse her gün ultraviyole ışınlarına maruz kalmakta ve bu ışınlar oküler dokularda hasarlara neden olmaktadır. Ultraviyole ışık emilim miktarı ile oluşan hasarların derecesi artmaktadır. İncelenen ultraviyole koruma kaplamalı organik lensler içerisinde A_3 lensinin koruyuculuğunun nispeten daha fazla olduğu görüldü. Ayrıca, optik bant aralığı enerjilerinin doğrudan ve dolaylı geçişler için sırasıyla 3.145-4.155 eV ve 2.994-3.936 eV aralıklarında değiştiği bulunmuştur. En yüksek optik bant aralığı değerlerine sırasıyla B_1 ve C_1 organik lenslerinin sahip olduğu görüldü.

Anahtar kelimeler: CR-39 lens, Göz sağlığı, Polikarbonat lens, UV radyasyon.

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INTRODUCTION

According to 2020 Health Statistics Yearbook (MoH of Turkey, 2022) data, it is stated that from 2016 to 2019, the use of glasses or lenses in individuals aged fifteen and over increased by 2.6%, while the number of individuals total visual impairment (blind) an increase of 0.3%. The increase in the need for glasses has led to an increase in the range of lenses by manufacturers who are in search of optical quality. Spectacle lenses are basically divided into organic and mineral. Organic eyeglass lenses are widely used in the optical industry with their chemical structure and composition, processing and coatings, and have a lighter structure than mineral eyewear lenses (Bilici, Bilici, Külahcı, 2022; Alonso, Gómez & Quiroga, 2019; Ralph, Dain & Cheng, 2015). Therefore, organic glasses are largely preferred as a visual aid. Another name of organic glasses is plastic glasses. In the optical industry, organic glasses such as CR-39, PC (Polycarbonate), High index and Trivex are widely manufactured. These lenses are expected by the user to be good at important parameters such as light transmission, ultraviolet light protection, durability of the lens and abrasion resistance, as well as correcting the user's eye defects. The visible light waves to which the human eye is sensitive are between (400-700nm) (Oliva & Taylor, 2005). In a good lens, light transmission is expected to be very high in this range. Vision depends on photoreceptive cells adapted to lighting conditions and can be classified as photopic and scotopic. The maximum vision through the cones corresponds to a wavelength of 550 nm. For night vision, it is 507 nm. Spectacle lenses must show maximum light transmittance at these wavelengths (Li, 2017; Jez et al., 2019).

Ultraviolet (UV) light is defined as an electromagnetic radiation whose wavelengths vary in the range of 100-400nm. The UV radiation spectrum is divided into three bands according to the wavelength; UV-A (315-380nm), UV-B (280-315nm), UV-C (100-280nm) (McKenzie et al., 2003; Oliva &Taylor 2005). UV light has more of an effect on biological damage because it has more energy than visible light (Rosen 1986). The cornea of the human eye almost completely absorbs electromagnetic radiation, the wavelength of which is less than 280 nm. Waves between 300 and 370 nm long are mostly captured by the lens of the eye. In turn, radiation from the 380-400 nm range reaches the retina (Kinsey, 1948; Werner , 1982; Weale, 1988). Long-term exposure to UV radiation causes photokeratitis in human eyes, such as pterygium, cataracts, climatic droplet keratopathy and chionablepsia (Coroneo, 2011; Hampel et al., 2022; Hockwin et al., 1999; Kim & Koh, 2011; McCarty et al., 1996; Sasaki et al., 2011; Yam & Kwok, 2014). As the lens ages, it begins to turn yellow and becomes opaque, absorbing more UV light. However, in children under the age of 10, the crystal lens conducts 75% of UV, which makes it particularly important to protect children's eyes from UV. In adults over the age of 25, UV transmission through the lens decreases to 10% (Cooper & Robson, 1966; Fishman, 1986; Hardy, Frederick, Kay & Werner, 2005; Lerman, 1987; Roberts, 2011; Werner, 1991). All of these effects have been an important topic in the medical literature (Coroneo, 2011) and have also increased the importance of UV protection in spectacle lenses. For this reason, it is very important to raise awareness of spectacle wearers about glasses lenses. It is not possible for users to analyze with their own means. In this study, absorption and transmittance measurements of CR-39 and PC organic glasses were taken using UV/VIS spectrophotometer. Data on the permeability and absorbance spectra were plotted using OriginPro-8 software. The cut-off edge wavelength was calculated for each organic lens measured. In addition, the energy band gap was calculated by examining the absorption coefficient and the change of the absorption coefficient with the wavelength of the incoming light. Finally, the Urbach energy value was calculated by getting benefit from absorbing spectrums again.

MATERIAL AND METHOD

Many types of organic lenses, which are widely used in the optical industry with their chemical structure, composition, lightweight structure, processing and coatings, are available on the market. CR-39 and PC organic lenses used in this study belong to different companies and the necessary information for the lenses is given in Table 1 (Alonso, Gómez & Quiroga, 2019; Bilici, Bilici & Külahcı, 2022; Musikant, 1985; Ralph, Dain & Cheng, 2015). In Table 1, the letters A, B, and C represent three different firms, while those with a refractive index of 1.49 and 1.59 refer to CR-39 and PC organic lenses, respectively. The Jasco V-730 UV/VIS Dual Beam Spectrophotometer instrument at Şırnak University Technology and Research Central Laboratory was used for absorption and permeability measurements including the visible region of organic lenses made of uncoated, coated or different coatings that the user may prefer. Spectroscopic studies are based on the phenomenon of absorption or emission of an electromagnetic wave by matter as a result of its interaction with matter. When UV or an electromagnetic wave in the visible region passing through the material is examined by UV/VIS spectroscopy, the wavelength corresponding to the rays absorbed by the material will be different for each atom and molecule, so obtained values provide important information about the structure of the material being examined (Grinter & Threlfall, 1992). In the UV energy band gap, information about the molecular bond structures and shapes of the material is obtained, while in the visible region energy band gap, information about electronic transitions in the material is obtained (Zhong-Zhang, 2009). In this study, in addition to the permeability and absorbance spectra of organic lenses used in vision instruments with UV/VIS spectroscopy, optical parameters such as % transmittance value, wavelength cut-off value, absorption coefficient and optical band gap energy of the lenses were obtained. Thus, the optical differences of coated and uncoated organic lenses, which are offered for sale in the optical sector with different names, were analyzed. For all the results obtained, the relevant graphs were drawn using the OriginPro-8 software.

Table 1. Some Parameters for Organic Lenses Used in the Study

Samples	Refractive Index	Diameter (mm)	Coating Type	Thickness (mm)	Power
A_1	1.49	70	None	1.60	Monofocal
A_2	1.49	70	UV protective	3.25	Multifocal
A_3	1.59	70	UV protective	1.00	Monofocal
B_1	1.49	65	None	1.10	Monofocal
C_1	1.49	65	None	1.50	Monofocal
C_2	1.49	65	None	2.75	Multifocal

UV/VIS spectroscopy is an analytical technique that measures the absorbance or transmittance of UV or visible light from a sample. UV//VIS spectroscopy measurements provide important information such as the potential content and optical structure of the sample being examined. UV/VIS spectroscopy is based mainly on electronic transitions of molecules (Fellipy, Anderson, Claure, Serge & Gregory, 2018; Mergen, Arda & Evingür, 2020). The relationship between absorption and permeability is explained by Beer Lambert's law given in equation 1 (Hassan, 2020; Jianjun et all., 2020).

$$I = I_0 \exp(-\alpha l) \tag{1}$$

Here, α refers to the absorption coefficient, *l* refers to the thickness of the sample, I_0 refers to the intensity of the light before the passage into the sample and *I* is after. The absorption coefficient is given in equation 2 (Dhanaraj, Das and Keller, 2020; Grinter & Threlfall, 1992).

$$\alpha = 2.303A/l \tag{2}$$

Here, A is absorbance value. The energy band gap for electronic transfer using absorption and permeability spectra was estimated using equation 3 (Tauc, 2012). The optical band gap is measured using the difference of the energy level between the valence and conductivity band.

$$\alpha h\nu = a\left(h\nu - E_g\right)^m \tag{3}$$

Here, hν refers to the incoming photon energy, E_g refers to the optical energy range between the valence band and the conduction band, a refers to the constant based on the properties of valence and conductive band. In this equation, the m value for direct permission and indirect permission transitions is taken as 1/2 and 2 respectively (Hassan, 2020).

Absorption edge can be determined from the exponential dependence of the absorption coefficient and is determined as given in equation 4 (Urbach, 1953; Shahmoradi & Souri, 2019). The inversion of the slope of the *lnα-hv* graph given in Figure 5 was obtained to obtain Urbach energy values for each sample.

$$(\alpha h\nu) = \alpha_0 \exp(h\nu / E_u) \quad (4)$$

RESULTS AND DISCUSSION

Many kinds of organic spectacle lenses offered to the user by optical institutions are available on the market. In this study, absorption and permeability measurements were made using UV/VIS Dual Beam Spectrophotometer device to investigate the optical properties of organic glasses that meet the different needs of three different companies (A, B and C) and whose properties are given in Table 1. While making the measurements, the wavelength was taken in the range of 200-800 nm. Using UV/VIS absorbance spectra, the optical band gap (E_g) value, which is an important parameter to determine changes in band structure, was calculated for each sample. E_g is one of the important optical parameters for estimating the performance of optical materials and their potential use in the optical field. In addition, the Urbach energy values of the sample were calculated. OriginPro 8 software was used to draw the graphs of the results obtained.

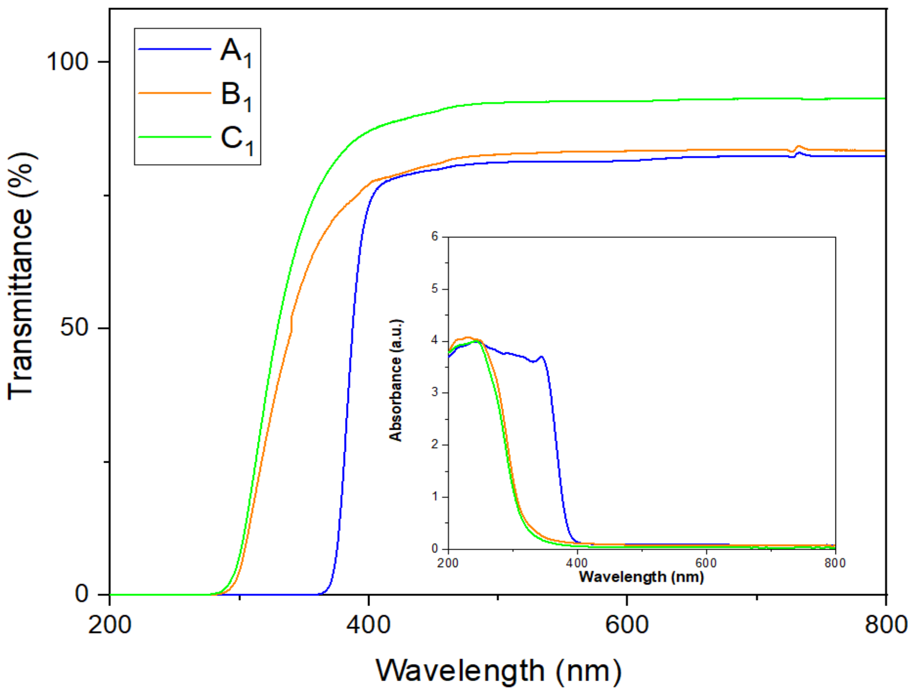

Figure 1. Transmittance and Absorbance Spectra of Monofocal Uncoated (A_1, B_1, C_1) Organic Lens Samples

When Figure 1 is examined, A_1, B_1 and C_1 organic lenses show very small permeability in the UVB range, while the maximum transmittance values in the UVA range are 22.63, 82.40 and 72.69, respectively. It is important that lenses in the UVB range do not have almost transmittance. In Figure 1, the permeability values increased after an average of 390 nm. The maximum transmittance of organic lenses A_1, B_1 and C_1 is 85.13, 86.21 and 93.35, respectively. At 550 nm, the C_1(92.71) lens had the highest permeability, followed by the B_1(83.22) and A_1(81.34) organic lenses. The high permeability values in the visible region range confirm the results. In addition, when the absorbance graph is examined in Figure 1, the absorption amounts fall below 0.07% when the visible region is reached. A strong increase in absorption can be interpreted as the transition of electrons in the polymer from the valence band to the conduction band. When the graph drawn for multifocal lenses in Figure 2 is examined, the maximum transmittance values for A_2 and C_2 lenses are 93.46 and 87.01, respectively. The permeability values at 550 nm were 92.93 for the A_2 lens and 80.39 for the C_2 lens. In addition, A_2 and C_2 lenses appear to show a high degree of absorption in the UVB region. The multifocal nature of the lenses can be considered as the reason for the fluctuations in the UV region range. The results showed that there was no improvement in the absorbance value of the C_2 lens compared to the A_2 lens, even though it was UV coated.

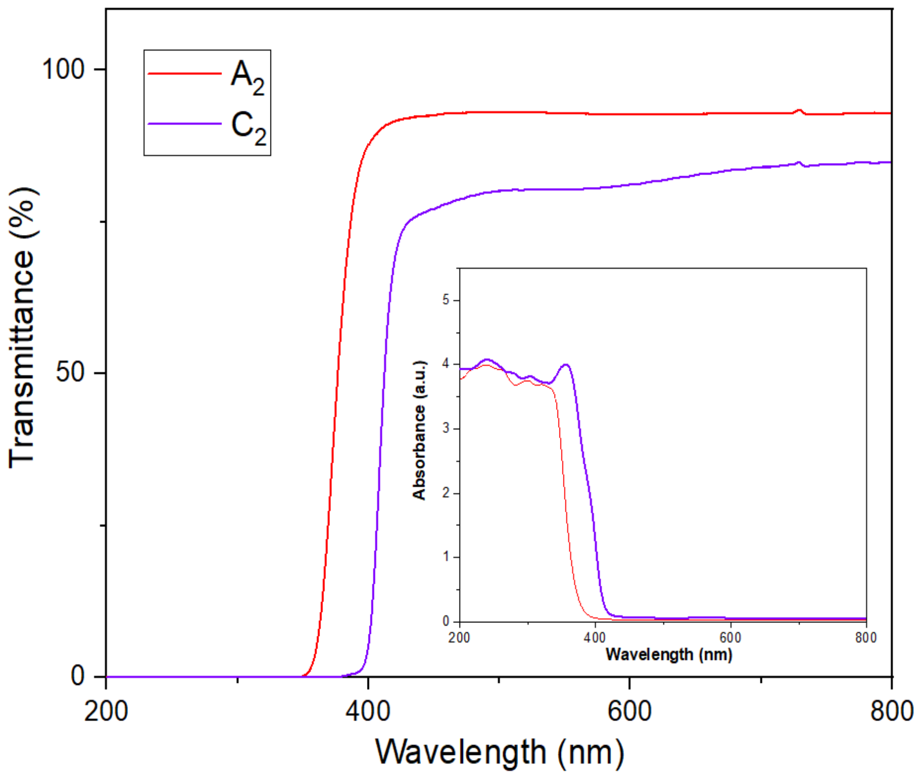

Figure 2. Transmittance and Absorbance Spectra of Multifocal (A_2, C_2) Organic Lens Samples

As the wavelength of light increases, that is, as its energy decreases, the damage it causes to the eye decreases. While the human eye cornea does not transmit all of the rays in the UVB range, it cannot prevent a very small part of the UVA from reaching the retina. Figure 3 shows a graph of transmittance and absorption for lenses with UV protection coating. The maximum transmittances for A_2 and A_3 lenses were obtained as 93.47 and 98.74, respectively. The A_3 lens is seen to have higher permeability. The A_3 sample belongs to a PC lens and is highly transparent to visible light (Pop, Popescu, Danila & Batin, 2011). It is clear that UV light absorption will affect the optical and mechanical properties of lens materials. In the industrial implementation, UV protection or anti-scratch coating is applied to the lenses if the material does not provide the expected performance in terms of optics (Pop, Popescu, Danila & Batin, 2011). Both lenses were not exposed to light at all in the UVB region, while the maximum absorbance in the UVA region was 4.04 for the A_3 lens and 4.59 for the A_3 lens. The PC lens was found to provide relatively more UV protection.

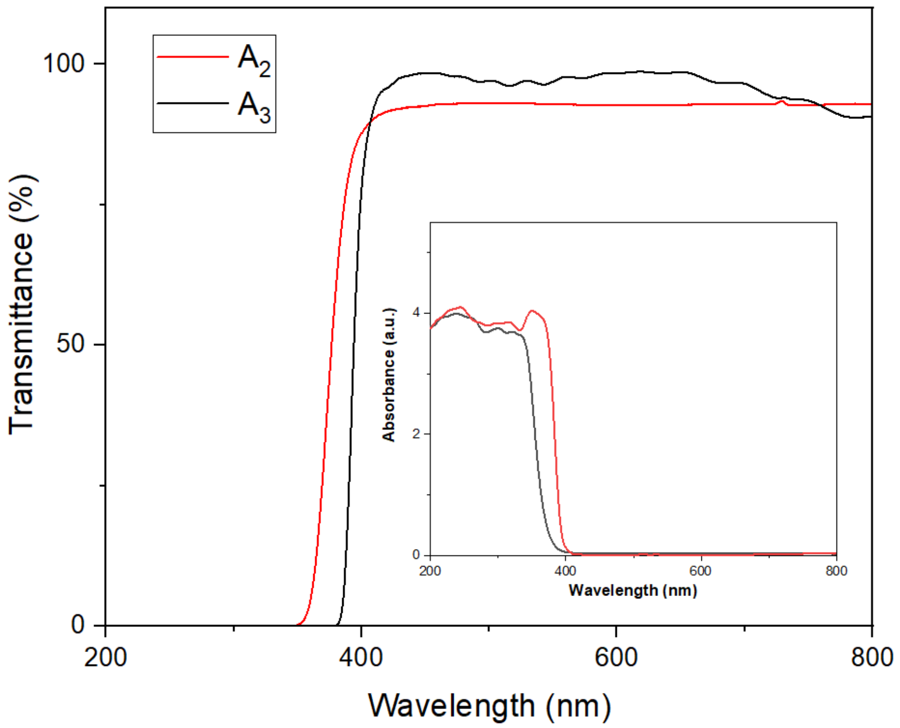

Figure 3. Transmittance and Absorbance Spectra of UV Protective Coated ($A_{2,}$ A_3) Organic Lens Samples

The wavelength at which a lens stops absorbing light and begins to transmit light is called a cut-off value. The cut-off edge wavelength values in A_1, A_2, A_3, B_1, C_1 and C_2 lenses were approximately 377, 380, 390, 340, 381 and 354nm respectively. Lenses with a higher cutting value have better UV protection.

In addition to the permeability and absorption spectra of the examined lenses, optical band gap (E_g) and Urbach energy (E_u) values were calculated and the relevant graphs were given in Figures 4 and 5. The optical band gap or forbidden energy band gap refers to the distinction between valence and transmission band. UV/VIS absorbance spectra were used to directly determine the E_g. The Tauc method is widely used to determine E_g (Kilic, G., Ilika, E., Issa, S. A. M. & Tekind, H. O., 2021). The graphic obtained for the permitted direct transitions of all lenses used in the study is given in Figure 4 (a) and the indirect transitions are given in Figure 4 (b). In Figure 4 (a) and (b), E_g values were determined from the values where the linear lines drawn from the absorption edges of the Tauc graphs intersected the energy axis. The Urbach energy was calculated by taking the inverse of the slope of the line obtained from the linear region of the absorption edge. The variation of the E_g and E_u values obtained for each sample lens is given in Table 2. Indirect band gap values for all sample lenses were found to be lower than permissible band gap values. Traditionally, there is an inverse relationship between Urbach's energy and optical band gap for each material examined, which means that a sample with a narrower band gap must have a wider band tail (Dhanaraj, Das and Keller, 2020). In addition, the fact that the B_1 and C_1 samples in Figure 4 have the highest E_g values is an indication that these samples have lower electrical properties than the others.

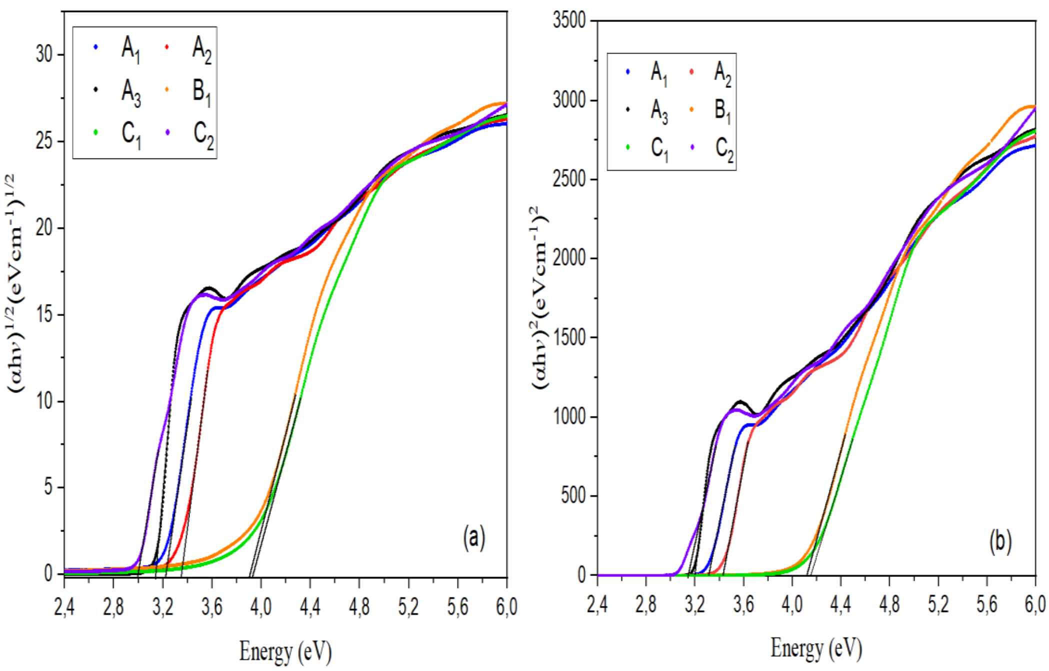

Figure 4. Tauc's Plot for (a) Indirect and (b) Direct Band Gap Energies of all Organic Lens Samples.

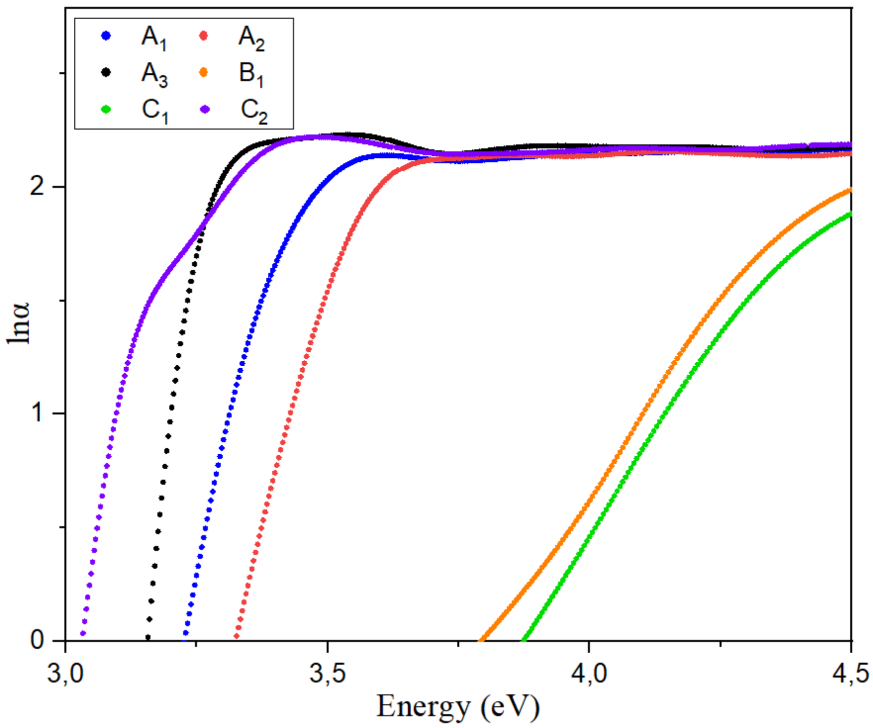

Figure 5. Urbach Energy Values of all Organic Lens Samples (A_1, A_2, A_3, B_1, C_1, C_2)

Table 2. Optical Band Energy Gap (E_g) and Urbach Tail Values (E_u) of all Organic Lens Samples

Samples	E_g (eV)		E_u (eV)
	Direct	İndirect	
A_1	3.31683	3.21988	0.09653
A_2	3.43167	3.35121	0.11211
A_3	3.20565	3.14418	0.05227
B_1	4.11793	3.90022	0.27100
C_1	4.15529	3.93579	0.27248
C_2	3.14458	2.99370	0.07310

CONCLUSION

Optical transmittance and absorption measurements of CR-39 and PC lenses produced by different manufacturers at room temperature and in the 1nm band gap range were made with UV/VIS spectrometer. The effect of the obtained optical parameters on the lens type was investigated. While the greatest effect was due to the lens material, the thickness and diopter strength of the lens caused little change. The optical transmittance of the organic lenses examined was found to be over 80%. The maximum transmittance value corresponding to the wavelength to which the eye was most sensitive (~550 nm) was 92.93% of the A_2 lens. When the absorbance values in the UV range were examined, the A_3 (PC) lens provided relatively more UV protection and the cut-off edge wavelength value (390 nm) was relatively larger. This is especially important for children where the UV transmittance of the crystal lens is higher and for the aphakia eyes that do not have UV absorbing lenses. For the organic lenses examined, indirect band gap values were in the range of 2.99370 - 3.9357 eV and direct band gap values were in the range of 3.14458 - 4.15529 eV. The highest E_g values had by the B_1 and C_1 sample lenses, respectively. E_u values were seen to range from 0.05227 to 0.27248 eV. Traditionally, there is an inverse relationship between E_u and E_g for each material examined.

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