CLINICAL

Spectral Transmittance of Selected Tinted Ophthalmic Lenses

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Abstract

Spectral transmittance data over the waveband 200 to 2500 nm are presented for a selection of tinted ophthalmic lenses. Criteria for the prescription of tinted lenses are briefly discussed.

Abrégé

Ce travail présente la transmission spectrale d'un échantillonage de lentilles ophtalmiques pour les ondes entre 200NM et 2,500NM. On discute brièvement des critères à employer dans la préparation d'une ordonnance pour lentilles teintés.

Introduction

The prescription and provision of tinted ophthalmic lenses has been, and continues to be, an important aspect of optometric practice. Whether the tinted lens is for cosmetic, sunglass, occupational, environmental or therapeutic purposes, it is important for the practitioner to be familiar not only with the range of tints available but also the manufacturing processes and the absorptive properties of the tinted lenses, so that the most appropriate choice may be made.

Previously published spectral transmittance data for tinted spectacle lenses[1-5] have been limited to the near ultraviolet (300 to 400 nm) and visible light (400 to 780 nm). The effects of ultra-violet radiation on the anterior segment[6-8] and the retina[9-11] have been well documented, and there can be no doubt that high levels of near-infrared radiation (780 to 2500 nm(can also damage ocular tissues.[12-13] Our data include spectral transmittance measurements in the far ultra-violet (200 to 300 nm) and the near infrared (to 2500 nm) which have not been reported earlier.

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There are three general approaches to tinting ophthalmic lenses. The solid or through-and-through tint is produced by adding metallic oxides to the constituents of the glass prior to fusion of the mixture. Such coloured glasses have the advantage of long-term stability of the tint with good reproducibility between production lots. However, such glasses used in high-power single vision lenses, or in any fused multifocal lens design, will produce lenses with non-uniform density of tint, being denser in thicker areas.

White (i.e. colourless) glass may be vacuum coated with a thin film of colorant. Such tints are relatively stable over long periods of time and uniform over the entire lens. They may, over a long period of time, be worn away, or scratched, during the course of normal use. They can generally be removed and replaced as desired.

Plastic lenses are generally tinted by immersion in hot aqueous dye solutions for a period of time which increases with the density of tint desired. The dye is absorbed and adsorbed by the surface layers of the lens. Uniform colour is achieved over the entire lens. Certain dyes are less chemically stable than others, however; consequently, tinted plastic lenses may show changes with time. (This is especially true of grey plastic lenses, which over a period of years, take on a reddish hue, as the green dye constituent breaks down). Dyed lenses may be bleached and redyed as desired.

For convenience of classification, we have included photochromic lenses among the solid tints, as well as the ultraviolet-absorbing materials UV400 and Lite Gard UV. Although the latter are plastic lenses, the active constituent (UV inhibitor) is mixed with the CR-39 components prior to polymerisation of the resin, in a manner analogous to the addition of the photochromic silver halide, or the solid tint metal oxide, to a glass mix prior to fusion.

Materials and Methods

The lenses used in this study were randomly selected from the stock of local suppliers, or taken from the collection of sample tinted lenses used in the Optometry Clinic of the University of Waterloo School of Optometry. A few lenses which are not readily available were kindly lent by Dr. S.D. Riome from his personal collection. All lenses used in this study were plano power, 2 mm thick uncut finished lenses. Table 1 describes the tinted lenses used, according to colour, density (light, medium or dark), and method of tinting (solid, coat, dye).

The measurements of spectral transmittance were made with a Zeiss (Oberkochen) DMR-21 dual-beam recording spectrophotometer. The instrument was electronically balanced to 0% and 100% levels prior to each spectral scan, and a chart record made of transmittance values over the entire waveband. The record tracings were then redrawn to consolidate the data according to tint classification.

Results and Analysis

Spectral transmittance curves over the waveband 200 to 2500 nm for the tinted lenses listed in Table 1 are shown in Figures 1 to 13. The photochromic

TABLE I
TINTED LENSES USED IN THIS STUDY

Colour	Name	Density*	Material	Method*	Figure	
White		N/A	Spectacle crown glass	N/A	1	
		N/A	CR-39	N/A	1	
Yellow	Hazemaster	L	glass	solid	2	
	Kalichrome	M	glass	solid	2	
	UV400	L	plastic	solid	2	Note 1
Green	Calobar D	D	glass	solid	3	Note 2
	G-15	D	glass	solid	3	
	Omnigard Green 3	D	polycarbonate	dye	3	
	K&W Green 50	M	plastic	dye	4	
	K&W Green 50	M	plastic	coat	4	
	Vision Ease Green 1	L	glass	solid	4	
	Vision Ease Green 2	M	glass	solid	4	
Grey	K&W Grey 60	M	glass	coat	5	
	K&W Grey 50	M	plastic	dye	5	
	Trucolor	D	glass	solid	6	Note 3
	Grey 3	D	polycarbonate	dye	6	
Brown	Custom Opt Tan 1	L	glass	solid	7	
	Custom Opt Tan 2	M	glass	solid	7	
	Custom Opt Tan 3	D	glass	solid	7	
	Vision Ease Tan 3	M	glass	solid	8	
	K&W Brown 50	M	glass	coat	8	
	K&W Brown 50	M	plastic	dye	8	
Pink	Cruxite AX	L	glass	solid	9	Note 4
	Cobum Pink 1	L	glass	solid	9	Note 5
	K&W Pink 2	L	glass	coat	10	
	K&W Pink 2	L	plastic	coat	10	
Blue	K&W Blue 30%	M	plastic	dye	11	
	Hoya Neo	L	glass	solid	11	
	Crookes A	L	glass	solid	12	
Special purpose	Hoya UI	L	glass	solid	12	
	Hoya UV	L	glass	solid	12	
Photo-chromic	Photobrown Extra		glass	solid	13	
	Photosun Extra		glass	solid	13	

* - described in text

Notes

1. Same as Lite Gard UV.
2. The Calobar D curve was the same as those of Toneray and Custom Optical Green 3, both solid glass tints.
3. This curve was the same as those of C-15, Custom Optical Grey 3 and Vision Ease Grey 3, all solid glass tints.
4. Same as Imperial Pink 2, a solid glass tint.
5. Same as Tonelite 1, a solid glass tint.

lenses were measured after storage in the dark overnight ("faded") and after exposure to full afternoon sunlight for 5 minutes ("dark").

The white lenses show neutral density (i.e. constant spectral transmittance) over the entire visible spectrum, with glass at 92% transmittance and optical plastic at 96%. The shortwavelength cutoff for the glass lens was 290 nm, compared with 360 nm for optical plastic. The greatest difference between glass and plastic lenses is in their infrared absorption. Whereas glass is relatively transparent to the infrared waveband studied, optical plastic shows 5 strong absorption bands between 1100 and 2250 nm which arise presumably from molecular bonds. There is very strong absorption of infrared radiation between 2250 and 2500 nm by the plastic.

Yellow glass lenses were originally developed as "shooting glasses" for improving contrast in a hazy visual environment. Both the Hazemaster and Kalichrome tints show a sharp shortwave cut off at 440 nm and neutral absorption at longer wavelengths. The UV 400 and Lite Gard UV are of CR-39 resin to which is added an ultraviolet-absorbing material prior to polymerisation. The straw colour of these lenses is similar to a glass solid tint, and the lenses may be tinted in the usual dye method. Both lenses show a sharp cut off between 390 and 400 nm, and neutral density across the visible spectrum. The characteristic infrared absorption features of CR-39 resin are evident.

Green lenses are generally used for sunglass applications, and may be light (transmittance about 70%), medium (50%) or dark (under 20%). All green tints produced transmittance curves with maximum transmittance near 520 nm, but showed remarkable differences in absorption in the ultraviolet and infrared. All tints transmitted long-wave-length ultraviolet (320 to 400 nm), with the polycarbonate Omnigard Green 3 having the longest cut off wavelength (approximately 385 nm). The glass solid tints transmitted less infrared; the best performance between 800 and 2500 nm was by the Calobar D, Toneray and Custom Optical Green 3 tints. The plastic lenses showed high infrared transmittance, comparable in the case of the K & W Green 50 to white CR-30. Inspection of all figures shows that indeed all tinted CR-39 lenses showed no substantial difference in infrared transmittance from that of white CR-39.

Grey lenses are used primarily as sunglasses; such lenses are favoured over green sunglass tints, as colour perception is not distorted. In general we found that glass lenses performed better in the infrared, while the plastic lenses were better absorbers of ultraviolet. All lenses transmitted long wavelength ultraviolet; the coated glass sample also transmitted a significant amount of ultraviolet radiation between 290 and 320 nm. The best overall performance was by the Tru Color, C-15, Custom Optical Grey 3 and Vision Ease Grey 3 tints, all of them solid glass.

Brown lenses (tan and brown tints) are used for cosmetic and/or sunglass purposes. All showed an increase in transmittance with wavelength up to 700 nm. In the infrared substantial differences were found; these were presumed to be due to the different methods of tinting (and different colorants used in the solid glass tints). Best overall performance was by the Custom Optical Tan 3; worst was the K & W Brown 50 glass coating which transmitted ultraviolet as short as 290 nm.

Pink lenses have traditionally been used to provide relief of asthenopia due to fluorescent lamps and other blue-rich or ultraviolet-rich light sources. It has been speculated[14] that relief is due to attenuation of short-wavelength radiation entering the eye. None of the lenses studied showed a significant reduction in the ultra-violet radiation reaching the eye; indeed the difference between transmittance at 400 and 700 nm amounted to only 10% in all cases. We found no physical explanation in these data for the reported relief of asthenopia.

Blue lenses transmit high levels of ultraviolet and infrared radiation. The Hoya Neo lens is a multiple-antireflection-coated version of the Crookes A solid tint.

Hoya UV is advertised as a general purpose lens which protects the eye from ultraviolet radiation due to the sun and fluorescent lamps. Although this solid glass tint does absorb all ultraviolet radiation below 320nm, it is almost as transparent to the longwavelength ultraviolet (320 to 400 nm) as white crown glass.

Hoya UI, another solid glass tint, is advertised as providing protection from ultraviolet and infrared radiation. This material has its ultraviolet absorption cut-off at a longer wavelength than that of white crown glass, and has greater infrared absorption. However, its performance in the longwavelength ultraviolet is similar to that of Hoya UV. Neither the Hoya UV nor the Hoya UI provides significantly greater protection from longwave ultraviolet than white crown glass.

The photochromic lenses studied are adequate when fully darkened for sunglass use. While they are effective absorbers of ultraviolet radiation at wavelengths less than 320 nm, they transmit significant amounts of longwavelength ultraviolet (320 to 400 nm) and levels of infrared comparable to levels transmitted by white glass, even when fully darkened.

Discussion

Given the number of colorants and tinting methods available to optical laboratories and lens manufacturers, it is not surprising that a given

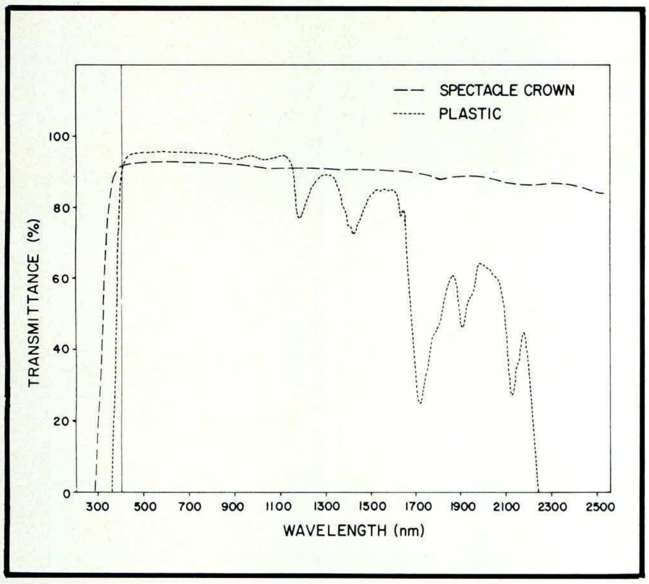

Figure 1: Transmittance curves of untinted spectacle crown glass and plastic lenses. All lenses in this study were plano power, 2 mm thick. Note the infrared absorption common to all plastic lenses. Glass transmits much more of the ultraviolet (wavelengths below 400 nm). In all figures the vertical line denotes 400 nm, the long-wavelength limit of UV-A.

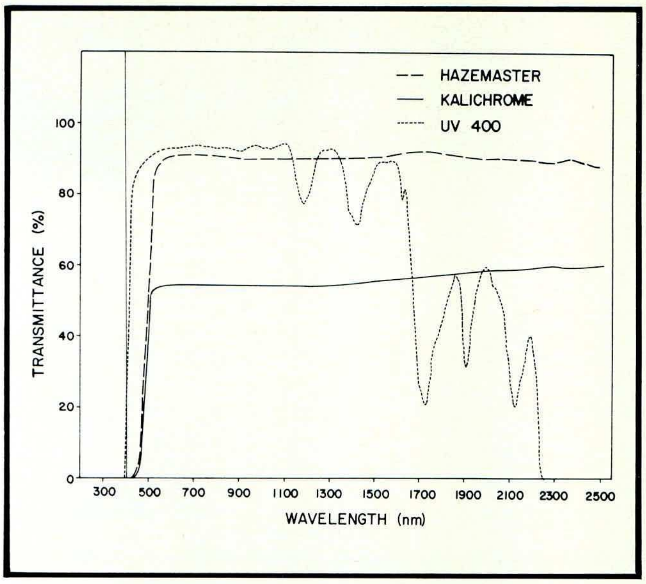

Figure 2: Transmittance curves of yellow lenses. LiteGard UV and UV400 have almost identical curves.

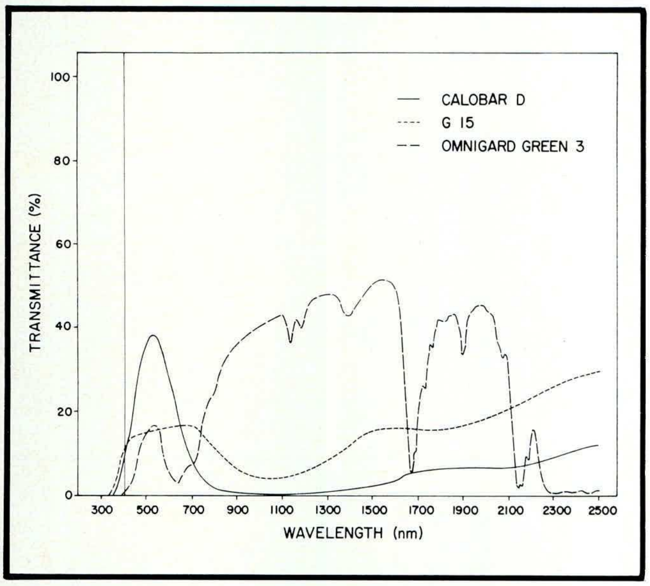

Figure 3: Transmittance curves of green lenses. Calobar D, Toneray and Custom Optical Green 3 have identical curves. Note the high infrared transmittance of the polycarbonate Omnigard Green 3 compared to that of the glass lenses.

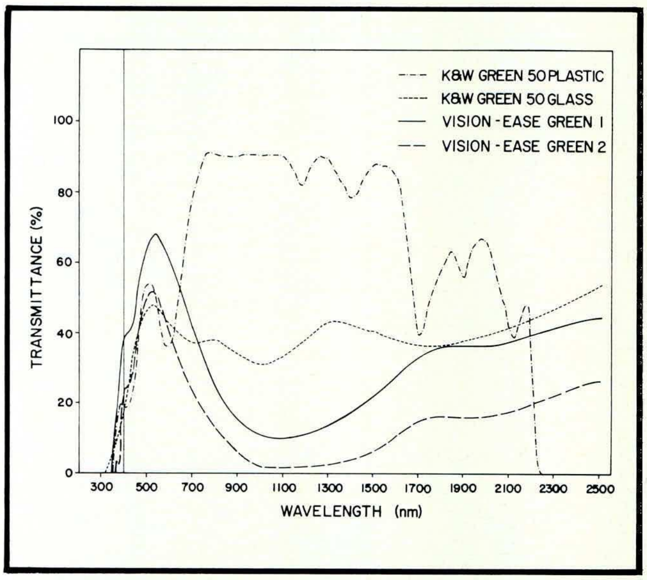

Figure 4: Transmittance curves of green lenses. All show transmittance peaks near 520 nm. There are significant differences in both ultraviolet and infrared transmittances. Note also the difference between the infrared curves of the plastic lens in this figure, and the Omnigard Green 3 of figure 3.

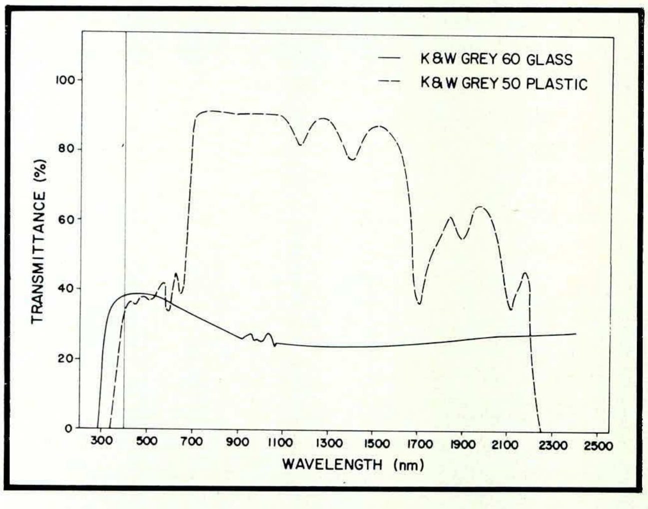

Figure 5: Transmittance curves of grey lenses, showing the difference between a glass coating and plastic dye. Note that infrared transmittance of the plastic lens is unaffected by the dye.

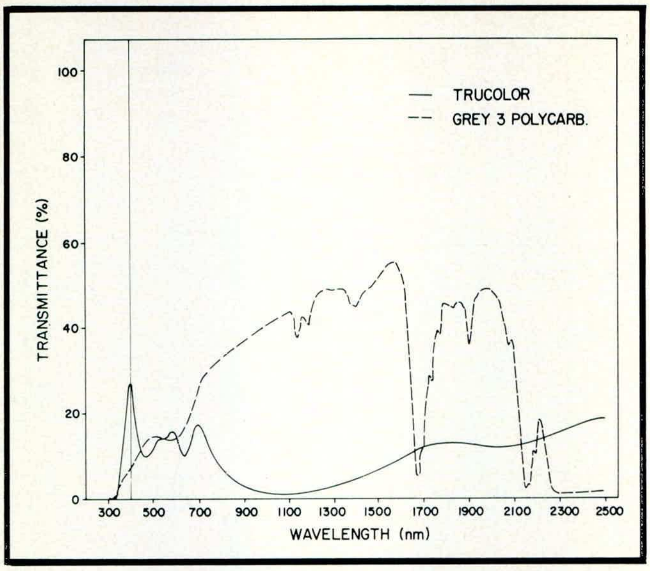

Figure 6: **Transmittance curves of solid grey glass and grey polycarbonate.**

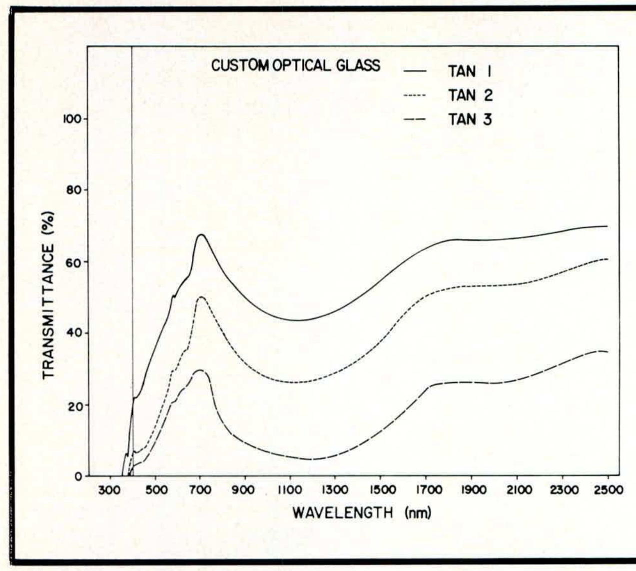

Figure 7: **Transmittance curves of three density levels of solid brown glass. The low transmittance at short wavelengths may lead to reduced hue discrimination in the blue and green regions.**

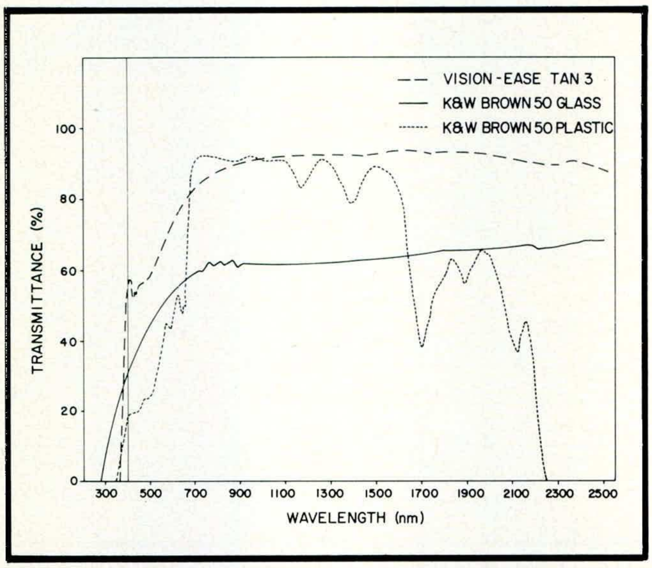

Figure 8: **Transmittance curves comparing solid glass, coated glass, and dyes plastic brown tints.**

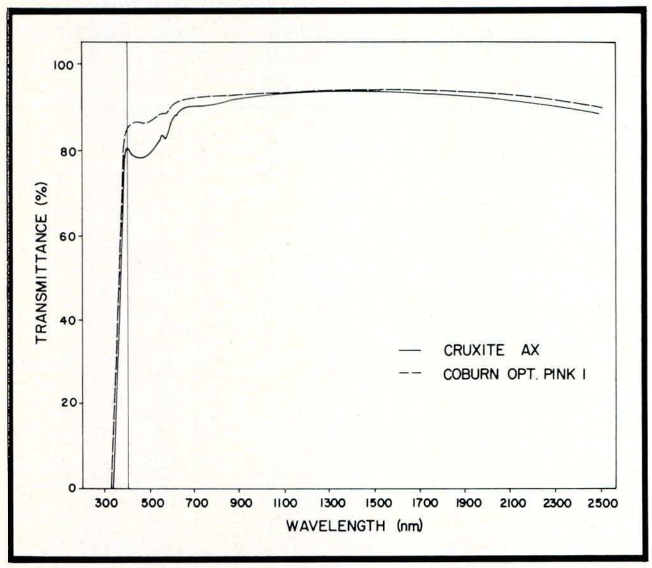

Figure 9: **Transmittance curves of fleshtone and pink solid tinted glass.**

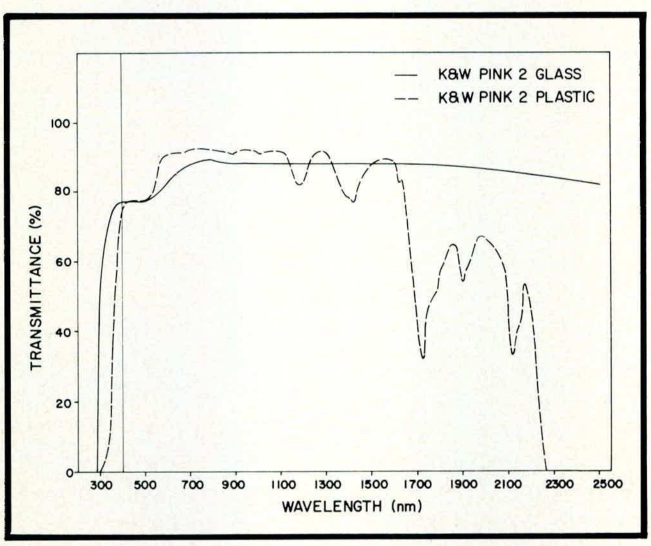

Figure 10: **Transmittance curves of pink lenses tinted by vacuum coating and dye. These are very different from the curves of Figure 9.**

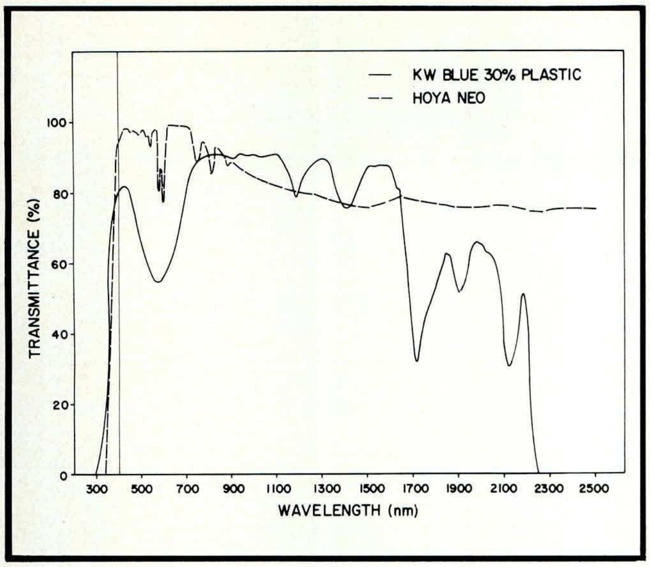

Figure 11: Transmittance curves of blue lenses. Note the reduced transmittance near 600 nm.

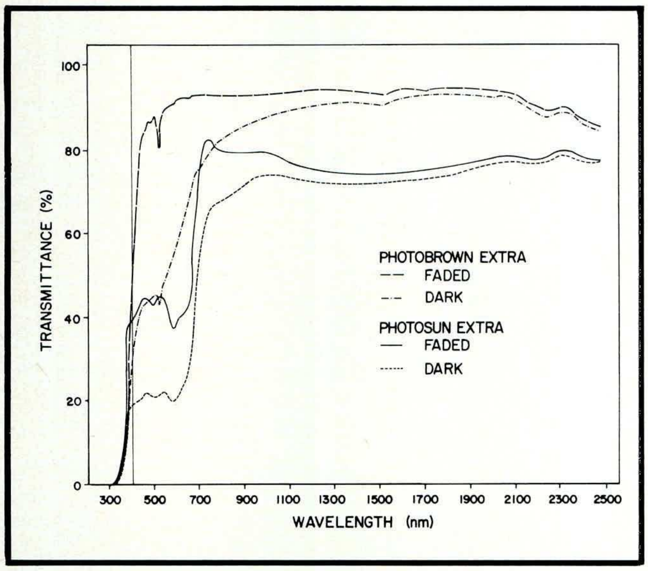

Figure 13: Transmittance curves of cosmetic and sunglass photochromic lenses in faded and darkened states. Note that the photochromic action has little effect in the ultraviolet and infrared regions.

popular tint will be produced in both glass and plastic lenses. Our data demonstrate that although the visual impression of such lenses may be the same, the actual spectral transmittance characteristics may differ considerably. An example would be the differences seen between the curves for Trucolor and the Grey 3 polycarbonate lenses in Figure 6, two lenses which visually appear similar in colour and absorption. Both the practitioner and patient should remember that, "What you see is not necessarily what you get — unless you specify the tint exactly!"

Earlier workers[1-3] have stressed the need to protect the eyes from near infrared radiation. In the past five years, it has become apparent that the effects of ultraviolet radiation are much more

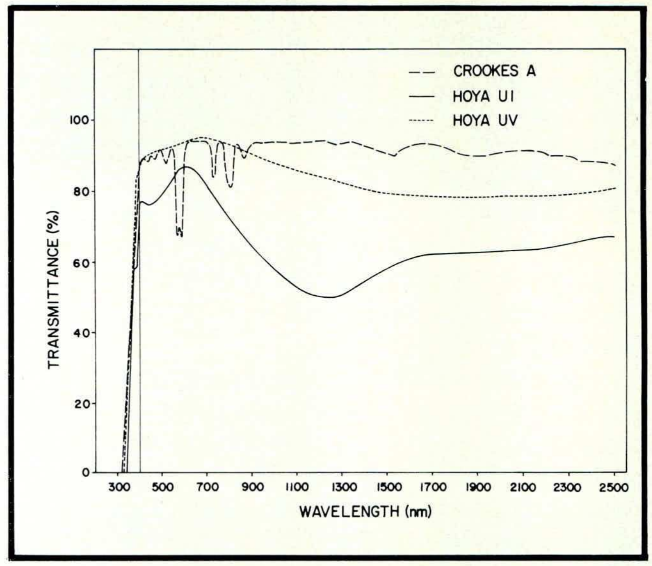

Figure 12: Transmittance curves of special purpose glass lenses. The curves of Crookes A and Hoya Neo glass are quite similar.

important a consideration. Radiation between 290 and 320 nm (UV-B) is known to be cataractogenic and also causes photokeratitis and photokeratoconjunctivitis upon acute or chronic high levels of exposure.[6-8] Ham et al[9-11] have demonstrated the great sensitivity of the retina to photic damage due to UV-A (320 to 400 nm) and blue (441 nm) light. It has also been speculated that chronic exposure to high levels of ultraviolet radiation may lead to development of pterygia and pingueculae.[6]

None of the solid or coated glass tints was a satisfactory absorber of UV-A, except for Hazemaster, Kalichrome and Custom Optical Tan 3 tints. Of the plastic lenses, only UV400, LiteGard UV and Omnigard Green 3 were satisfactory. No lenses transmitted ultraviolet wavelengths below 290 nm, while UV-B was totally absorbed by all tints except the coated glass tints, and the K & W pink 2 and blue 30% plastic tints.

Tinted plastic (CR-39) lenses did not show significantly different infrared transmittances compared to white CR-39. Glass tinted lenses showed very wide variations in infrared transmittance.

Each type of tinting process has advantages and disadvantages.

Solid tints are permanent and generally do not vary significantly between production lots. They do have significant disadvantages however. Lenses of high vertex power show changes of tint density across the lens according to Bouguer's law (Thicker lens substance has greater tint density), as do fused multifocals with solid tinted carriers. They are also generally available only in restricted power ranges.

Coatings are uniform across the lens and can be removed and replaced as desired, or as they wear off. However, they vary between laboratories and may change with time. The ultraviolet absorption of such coatings is relatively poor.

Plastic dye tints are also uniform, and can be removed, changed, or replaced as often as desired. However these dyes offer no additional protection from UV-A, and do not generally affect absorption of the infrared; this is clearly demonstrated by our data. There is no reason, however, why lens manufacturers could not routinely include an ultraviolet inhibitor in the resin mix prior to polymerisation, as is done with UV400 and Lite Gard UV, in order to give protection against all ultraviolet radiation.

Polycarbonate lenses present some problems if a tint is desired, but when combined with other protective filters (e.g. welding filters), provide good protection from both mechanical and radiation hazards. These lenses can be tinted by a special vacuum-coating process.[15]

The recently developed Corlon™ lens by Corning Glass Works (marketed as C-Lite™) is a thin glass lens with a polyurethane film bonded to the ocular surface. The glass carrier may be any glass lens; stock lenses are white or photochromic, and custom bonding to any glass lens is available. Additional tint including gradients can be obtained with special water-based dyes, as the usual plastic dyes are not compatible with polyurethane.[16]

Because of the vast number of tinted lenses available to practitioners, and the rate at which different tinting processes or formulae are being introduced, these transmittance data should be considered only as a general guideline to the transmittance characteristics of tinted ophthalmic lenses. A detailed knowledge of the spectral transmittance of a given tinted spectacle lens would require spectrophotometric measurements at all wavelengths for that lens.

Commercial over-the-counter plano sunglasses also present problems for the ophthalmic practitioner. Measurements on selected sunglasses are in preparation.[17]

Acknowledgements

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References

1. Kors K, Peter HB (1972) Absorption characteristics of selected commercially available ophthalmic lenses. *Am. J. Optom. Arch. Am. Acad. Optom.* 49(9): 727-735.
2. Garner LF (1973) The transmission properties of some commercial ophthalmic tinted lenses. *Aust. J. Optom.* 56(7): 254-261.
3. Garner LF (1974) A guide to the selection of ophthalmic tinted lenses. *Aust. J. Optom.* 57: 346-350.
4. Borgwardt B, Fisherman GA, Vander Meulen D (1981) Spectral transmission characteristics of tinted lenses. *Arch. Ophthalmol.* 99(2): 293-297.
5. Dain SJ, Nasser G, Ramshaw P, Russel GK, Vercoe GJ (1981) Technical Note: Guide to the transmittance properties of some ophthalmic lenses. *Aust. J. Optom.* 65(4): 165-168.
6. Pitts DG, Cullen AP, Hacker PD (1977) Ocular effects of ultraviolet radiation from 295 to 365nm. *Invest. Ophthalmol.* 16(10): 932-939.
7. Koliopoulos JX, Margaritas LH (1979) Response of the cornea to far ultraviolet light: An ultrastructural study. *Am. J. Ophthalmol.* 11: 765-769.
8. Cullen AP (1980) Ultraviolet induced lysosome activity in corneal epithelium. *Albrecht von Graefes Arch. Klin. Exp. Ophthalmol.* 214: 107-118.
9. Ham WT Jr, Mueller HA, Ruffolo JJ Jr. Clarke AM (1979) Sensitivity of the retina to radiation damage as a function of wavelength. *Photochem. Photobiol.* 29: 735-743.
10. Ham WT Jr, Mueller HA, Ruffolo JJ Jr, Guerry D III (1980) Solar retinopathy as a function of wavelength: its significance for protective eyewear. in Williams TP, Baker BN (Eds) *The Effects of Constant Light on Visual Processes.* New York, Plenum Press, pp. 319-346.
11. Ham WT Jr, Mueller HA, Ruffolo JJ Jr, Guerry D III, Guerry RK. (1982) Action spectrum for retinal injury from near-ultraviolet radiation in the aphakic monkey. *Am. J. Ophthalmol.* 93-299-306.
12. Turner HS (1970) The interaction of infrared radiation with the eye: A review of the literature. Report from The Aviation Medicine Research Laboratory, Ohio State University.
13. Pitts DG, Cullen AP, Dayhaw-Barker P (1980) Determination of ocular threshold levels for infrared radiation cataractogenesis. DHHS (NIOSH) Publication No. 80-121.
14. Borish IM (1970) *Clinical Refraction*, 3rd Ed. Chicago, Professional Press, pp. 1118-1119, 1123.
15. Anonymous (1982) Product News: Lenses for your active patients. *Rev. Optom.* 119 (1): 71-72.
16. Anonymous (1983) Ophthalmic lenses for special uses. *Rev. Optom.* 120(5): 89-98.
17. Chou BR, Cullen AP (1983) Spectral transmittance of selected over-the-counter sunglass tints. in preparation.

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