Photochromic and polarising tints

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Competencies covered:	Optical appliances
Target group:	Dispensing opticians, optometrists

This article will discuss the properties of both photochromic and polarising lenses used as sunglasses. Their development from the first commercially available ophthalmic products, how they work, and the protection given from harmful radiation. Some current available options are considered as well as those combining both photochromic and polarising properties.

A tinted lens is defined as having a noticeable colour in transmission. There may be different reasons for requiring this, cosmetic as well as intentionally modifying the incident radiation profile or attenuation of unwanted or even harmful radiations. A filter in this context is a device which changes the intensity and may also change the spectral distribution of the radiation passing through it, and sunglasses are spectacles (or attachments) incorporating a filter for attenuating natural solar radiation[1]. For the purposes of this article, the discussion will be centred on photochromic and polarising lenses used as sunglasses.

From **figure 1**, it can be seen that the visible range of solar radiation within the electromagnetic spectrum is from 380 to 780nm. This effectively is light which gives rise to the sensation of vision. Bright light outdoors can be uncomfortable but not necessarily harmful. Wavelengths shorter than 380nm are ultra-violet (UV) and longer than 780nm are infrared (IR). Both these bands are potentially harmful to the eye although the latter will be accompanied by the sensation of heat, and therefore giving rise to the awareness of this hazard.

UV radiation is divided into three bands, UVC 200-280nm is filtered out by the earth's ozone layer although this natural protection can vary in thickness depending on latitude and altitude. UVB 280-315 can cause sunburn and therefore affects the front of the eye, potentially causing eyelid, corneal and conjunctival damage. Exposure to this hazard is also increased by reflection from surfaces such as snow, sand and water. UVA 315-380nm can penetrate deeper in the eye and even low amounts can cause damage as the effect is cumulative over time. As the crystalline lens absorbs these wavelengths, 70% of eyes will have some form of cataract by our 70's, up to 80% of a person's exposure to harmful UV happens before the age of 18[2]. UVA and short wavelength light (high energy or blue light hazard) have been shown to have an impact on the retina inducing receptor and epithelial damage. This becomes a factor in aphakic and clear intraocular lens pseudophakic eyes, thus increasing the risk of age related macular changes. CE regulations require tinted lenses to obstruct all radiations below 360nm and at least 90% below 380nm, so some commercially available tinted lenses do require a UV filter to achieve

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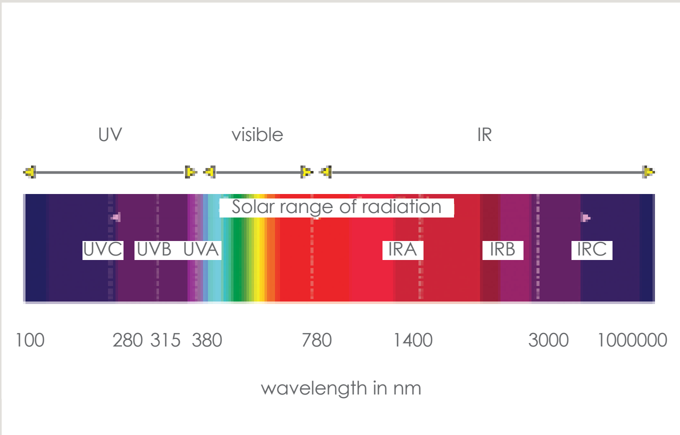

Figure 1: Optical range of radiation

Class	Category	Usage	Trans %	Driving
0	Clear or very light tint	Indoor or overcast	80 - 100	No limitations
1	Light tint	Low sunlight	44 - 79	Not suitable at night
2	Medium tint	Medium sunlight	19 - 43	Not suitable at night
3	Dark tint	Bright sunlight	9 - 18	Not suitable at night
4	Very dark tint	Very bright sun	3 - 8	Not suitable for any driving

Figure 2: CE regulations for tinted lenses[3]

this requirement. A UV filter however will not appear to have any colour since it attenuates below the visible light spectrum.

The purpose of sunglasses can be considered to provide protection from harmful radiation and comfort to the eyes under all conditions of illumination. Assuming constant bright sunlight immediate protection and visual comfort may be obtained by a fixed tint filter. **Figure 2** shows the CE regulations for tinted lenses[3] divided into 5 classes depending on the luminous transmission factor (LTF) although each class also has a requirement regarding the amount of UV light transmission. It can be seen that anything below 80% LTF should not be used if night driving and if below 8% LTF ie class 4, should not be used for any driving (there are also requirements for recognition of signal colours regarding driving).

Photochromic lenses

A fixed tint may be too dark or too light if illumination levels vary therefore a variable tint, where the modification of the light attenuation characteristics under the influence of solar radiation may be more versatile. A photochromic lens can be defined as - a lens made all or partially from material which reversibly changes its transmission characteristics dependant upon the radiation itself (to include lenses that have photochromic properties)[4].

The technology originated from photographic film processing. The sensitive surface of ordinary photographic film is a layer of gelatine carrying minute suspended silver halide crystals. A silver halide (AgX) is one of the compounds formed between silver and one of the halogens (silver bromide AgBr, chloride AgCl, iodide AgI). Exposure to light in a camera produces an invisible change yielding a latent image reduced to metallic silver by certain developing agents. This is a permanent change, although the silver may oxidise over a longer period of time, thus degrading the quality of the image.
Photochromic glass contains silver halide crystals dispersed in the glass melt. Exposure to a small band in the optical range (short-wave light and UVA radiation) decomposes the crystals, forming a small silver particle (100nm in size). The silver will absorb the light to produce a tint in the lens. The greater the intensity of the source the darker the lens will become until saturation point is reached. The crystals remain decomposed in the presence of the exciting radiation. The halogen cannot escape from the glass, so it recombines with the silver when the source is removed, hence the lenses will return to its unreactive appearance. The crystals are between 800 and 1500nm in size suspended in the glass, with the addition of copper added to the melt to increase the speed of the reaction. Absorption of UVA and blue light is the trigger for the process, and **figure 3a**[5] shows the transmission curve of the currently available Zeiss Umbramatic lens, showing how the attenuation of the wavelengths changes on exposure to this radiation, confirming the photochromic reaction is removing the harmful radiation as well as reducing the amount of visible light being transmitted.

History and performance

Commercially available since 1964, it was not until the late 60's that Corning produced the Photogray and Zeiss the original Umbramatic lenses that achieved a reasonable amount of darkening to about 45%LTF. A further improvement in performance came with the Reactolite glass from Chance Pilkington which darkened to 21%. By Mid 70's there was a major improvement in the speed of reaction,
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Figure 3a: Zeiss Umbramatic (unactivated v activated)

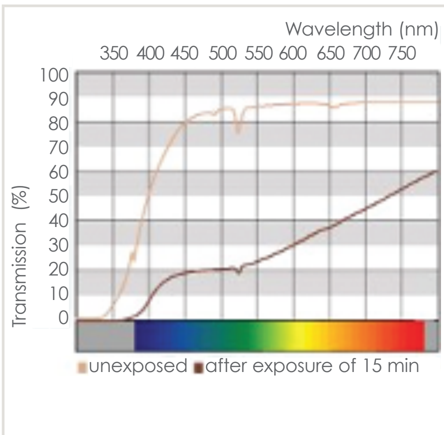

Figure 3b: Zeiss Umbramatic (darkening/fading)

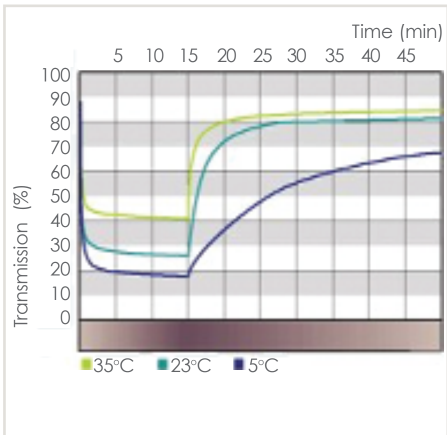

Figure 4: Zeiss Umbramatic Equitint

different colours, pre-tinted forms available, high refractive index, bifocals (fused and solid) and progressives, Photogray Extra, Photobrown Extra, Reactolite Rapide Gray, Brown and Zeiss Umbramatic and Umbramatic Brown, some of which are the glass photochromic lenses available today. Typically these achieved 90% to 30% transmission in just 20 seconds exposure, recovering to 65% in 5 minutes **(Figures 3a** and **3b)**.

There are a number of factors that affect the photochromic performance and appearance of the lenses. Amount of light and type of radiation will have a significant effect of the depth of tint and speed of reaction since the activating band is quite narrow. Situations where the UV and blue light are absorbed by other factors such as dense cloud, or the windscreen of a car will mean the lenses may not darken by more than about 15%. The temperature of the lens has such an effect that BS EN 1836:2005 requires manufacturers to provide LTF details at three specified temperatures 35°C, 25°C and 5°C. It can be seen from **figure 3b**[5] how as the temperature decreases, the photochromic performance increases and the lens will appear darker with up to 25% difference in the darkest state at 35°C and 5°C. Since the method of manufacture requires the silver halide crystals to be added to the glass melt, this produces a solid tint. The thicker parts of the lens the greater the density of the crystals, producing a darker appearance. As such, higher power lenses, where there becomes a noticeable thickness difference across the lens, will produce

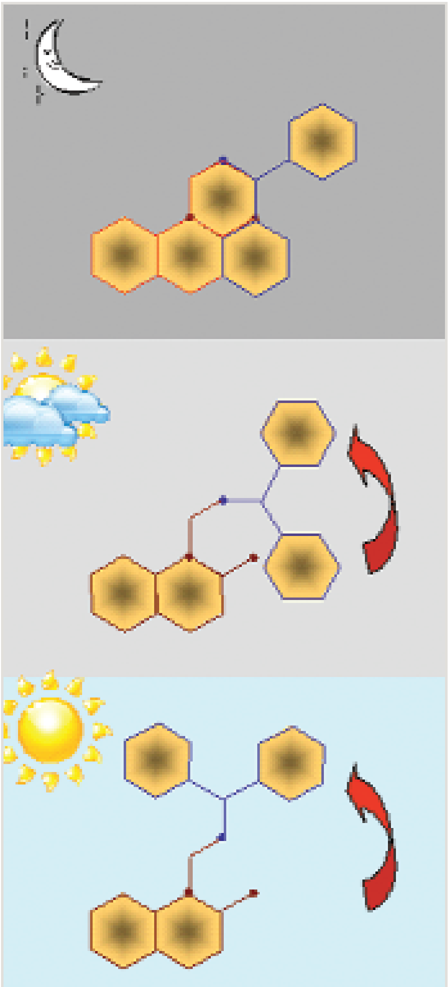

Figure 5: Spiropyrans-type molecule in varying stages of exposure to UV

a variable depth of tint, obviously darker towards the edge of a negative lens and darkest at the centre of a positive powered lens. High cylindrical powers will also give rise to a variable appearance for the same reason. It is possible to bond a 2mm thick plano lamina to a crown glass or 1.7 glass to produce an equitint **(Figure 4**[5]**)**. The performance of photochromic lenses also is affected by the number of previous cycles. As we will see later, the fatiguing effect is greater with plastics materials than glass, but BS also details the measuring of LTF in clear and dark states both before and after 500 activations and comparing the difference. The variation should not exceed 5% in the light state and 20% in the dark state. One advantage of glass photochromic lenses is that their original performance can be restored by immersion in boiling water for 30 minutes.

Although glass lenses can be toughened and naturally are more scratch resistant than plastics lenses, there is always the weight issue and generally if a plastic version is available, it may be preferable if the performance is otherwise equivalent.

Photochromic plastics materials

Potentially safer and certainly lighter in weight, photochromic lenses in plastics material have been available from 1970's but speed of reaction and depth of tint was inferior to glass and also fatigued relatively quickly it took a number of years before a plastics photochromic became available that could compare favourably in performance.

Transitions launched in 1990, used a different type of photochromic material that was applied as a form of coating in a special chemical bath. Spiro-oxazines, spiro-pyrans and fulgides added to lens material creating spiral type molecular chains. Exposure to UV causes a portion of each molecule to rotate and so radiation is absorbed in this process, removal of exciters causes molecules to flip back to original orientation **(figure 5)**. Applied by a type of coating process, the photochromic dye is imbibed into the lens surface to a depth of 100 -150 microns, lens form and thickness therefore has no effect on appearance. Temperature has a greater effect on the photochromic performance as does the fatiguing effect compared to glass. Fatiguing affects speed of darkening/fading and a decrease in transmission. Some plastics photochromics may only have transmission of 80% at night after a time, although the night-time or indoor transmission can be considerably improved with the addition of anti-reflection finishes. DVLA Medical Advisory Panel[6] recommends drivers should avoid using photochromic lenses when driving at night, a recommendation since the Maritime Accident Investigation Branch[7], a division of the Maritime and Coastguard Agency (MCA) of the Department of Transport reported on the loss of Ouzo yacht in 2006. This relatively small yacht with three crew members was thought to be in collision or very close contact with very much larger P&O cross channel ferry, the Pride of Bilbao in the early hours of a clear August morning in

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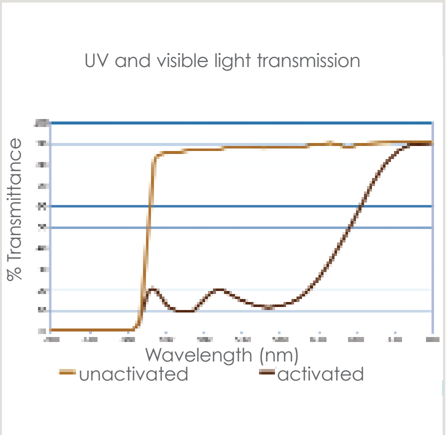

Figure 6a: Transitions VI (unactivated v activated)

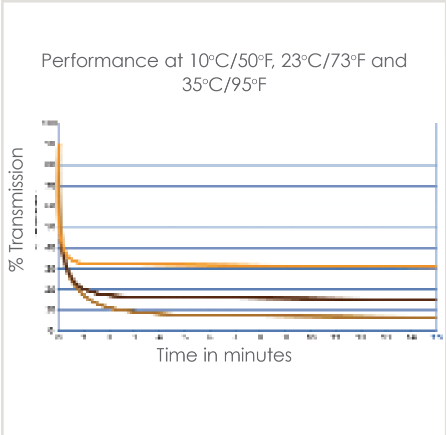

Figure 6b: Transitions VI (darkening performance at different temperatures)

2006. The conclusion for the apparent non-sighting of the yacht by the ferry's watch may in part have been attributed to the lookout wearing spectacles with photochromic lenses which, when tested, only had a 80% LTF in its lightest state. As a result the MCA issued a guidance note to all ship operators, masters/skippers, officers and lookouts which made two recommendations, one of which was 'Photochromic lenses should not be worn for lookout duties at night.' The other was with regard to dark adaption time for lookouts coming on duty[8].

From the original launch of Transitions in 1990 came Transitions II (TrPlus) 1992, Transitions III 1997, Transitions IV 2001, Transitions V 2005 and Transitions VI 2008. This latest version has clearest 93%LTF, darkest 20%LTF after 2 mins, 25% after 1 minute, 40% Transmission after 30 seconds and 5 minutes to fade back fully **(Figure 6a&b)**. It also attenuates all radiation below 400nm even in its unactivated (lightest) state. All improvements on reaction time, unreacted and reacted transmissions, temperature performance, fatiguing effects etc.

Available in a huge range of lens forms and materials, CR39, Trivex (1.53), Spectralite (1.54), Polycarbonate, 1.6 and 1.67 index plastics. Other plastics materials using an alternative 'in-cast' manufacturing method include Rodenstock Colormatic (1.54 and 1.67) and Signet Armolite (Kodak) Sunsensors 1.56 which derives ultimately from Corning, as well as spin-cast procedure for higher index materials such as Hoya's production method for their Suntech 2, available in brown and grey, on 1.6 and 1.67 index materials.

There has been a steady rise in spectacles dispensed with variable tints, the majority being plastics, according to Opticians Index September 2009 at an average of 13% of all dispensings[9].

Polarising lenses

The nature of light directly from above and that from reflected surfaces differ. Polarising filters will eliminate horizontally reflected light. This reflected light can be described as optical noise, and can cause considerable discomfort glare, as well as masking detail. A polarising filter shows different absorption characteristics according to the plane of polarisation of the incident light. Ordinary or unpolarised light may be represented by a wave motion which is vibrating in every direction. When light is reflected from certain surfaces it becomes polarised (vibrations restricted to one meridian only – **figure 7a**). For a particular angle of incidence the light will be completely plane polarised. (Brewster angle where $i + i' = 90^\circ$ and tan i =refractive index of material). A polarising filter will only transmit polarised light in one meridian (transmitting polarising axis) and therefore will completely absorb light if plane polarised at 90° to this. Water, snow, road surfaces, concrete and glass will all produce a certain amount of reflected glare, but sunglass polarising transmitting axis will always be set vertically to eliminate the horizontal polarised light **(figure 7 b)**. Not only does this cut out the discomfort glare caused by reflections, it also enables the observation of detail below the reflecting surface. **Figures 8a & 8b** show photographs taken without and with a raw polarising filter placed over the camera lens that was obtained by dismantling a polarising visor normally used as part of a fixation disparity unit from the consulting room. Many hours of fun can be had with such a filter, observing reflected light from various surfaces, and rotating the filter to establish the transmitting or absorbing axes, which are at 90° to each other. Obviously in sunglasses, both lenses will have the same axes orientation, whereas there is a huge application of utilising a pair of filters set orthogonally **figures 9a & 9b**, either side by side such as binocular vision equipment (fixation disparity) and 3-D films or in series such as with liquid crystal displays, optical microscopes, cameras, inspection equipment, etc **(figures 10a, 10b & 10c)**.

Manufacture

Although the manufacturing process has altered since Polaroid film was

Figure 7a: Polarised light produced by surface reflection

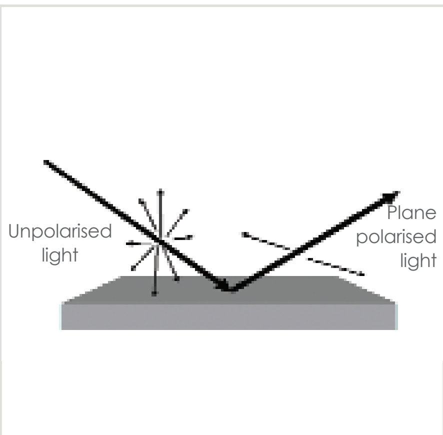

Figure 7b: Polarised light produced by surface reflection

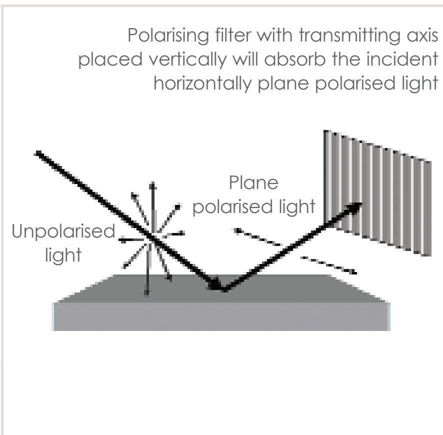

Figure 8: Identical scene photographed without (a) and with (b) polarising filter

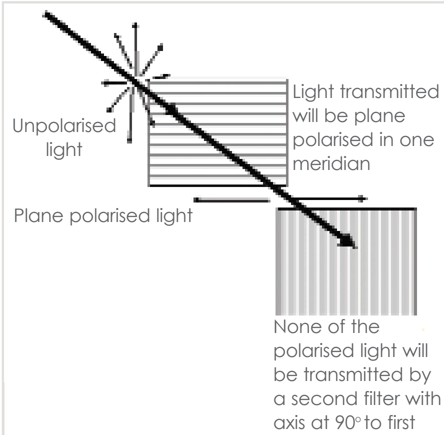

Figure 9 a: A crossed polarisor

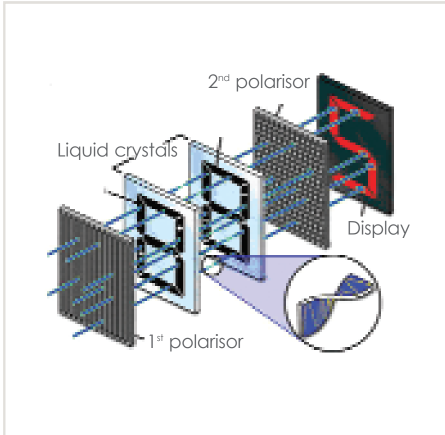

Figure 9 b: A crossed polarisor in LCD

invented in 1938 by Edwin Land, a polarising sheet is made of polyvinyl alcohol (PVA) polymer which is impregnated with iodine. During manufacture, the PVA polymer chains are stretched such that they form an array of aligned, linear molecules in the material. The iodine pigment attaches to the PVA molecules and makes them conductive along the length of the chains. Light polarised parallel to the chains is absorbed, perpendicular to the chain is transmitted. Although this method has been around since the 1950's as laminated sheets between glass or plastics lens materials. Nupolar was introduced by Younger Optics in 1994 which had a slightly different manufacturing approach. Still a sandwich of polarising film between CR39 or Polycarbonate lens material, it involves casting the polarising filter around its host material. This forms a 1mm polarising laminate to the front of a semi-finished blank but set much closer and following the front curve of the semi-finished blank, thus allowing for finished lenses to be of comparable thickness to standard form lenses. All methods are therefore equitint but due to the nature of manufacture some may not suitable for supra glazing. Due to the iodine, the laminate will always have a LTF of <50% but also have added UV filters and made darker by further tinting or lamination to around 15% LTF, thus rendering it suitable for sunglass use class 3.

Polarisation will show up strain patterns on some mobile phone screens (toughened glass car windscreens used to be a problem) and does render certain types of liquid crystal displays (LCD) invisible. This can be an inconvenience when many information systems and in-car entertainment units employ a LCD. By the nature of manufacture these have cross polarised filters as part of the display for them to work, but means that, when wearing polarising lenses, the display will appear much darker. Most of these have axes set obliquely at 45° or 135°, which means if your head is tilted in one direction, the display will appear totally black. Obviously, a solution will be to tilt one's head in the opposite direction to render the display clear! A prime example of this disadvantage is when wearing polarising sunglasses while driving, and stopping to refuel. Not only are fuel, pump displays often LCDs but certainly the chip and pin machine will be when going to pay for your fuel becoming very difficult to view without removing sunglasses: fine if planos but not so convenient if wearing prescription lenses.

When ordering toric uncuts, or semi-finished blanks from a manufacturer, the cylinder axis must be stipulated for the polarising axis to be correctly set.

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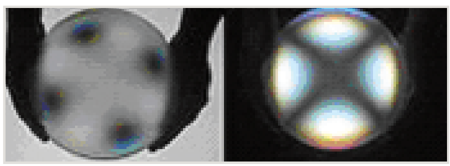
Figure 10: Some uses of cross-polarised filters (a) stereopsis tests

Figure 10: Some uses of cross-polarised filters (b) near fixation disparity test

Figure 10: Some uses of cross-polarised filters (c) strain testers



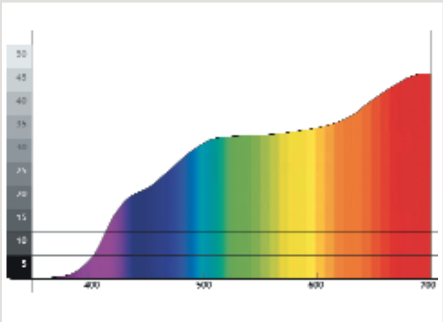


Figure 11a: Transmission data for Drivewear lenses - low lighting conditions

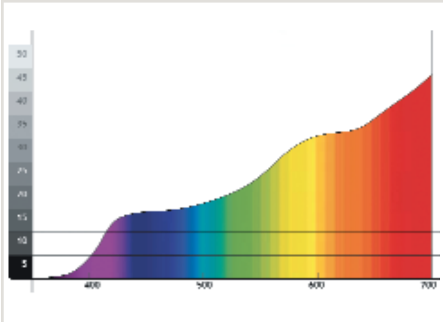


Figure 11b: Transmission data for Drivewear lenses - bright lighting conditions (behind windscreen)

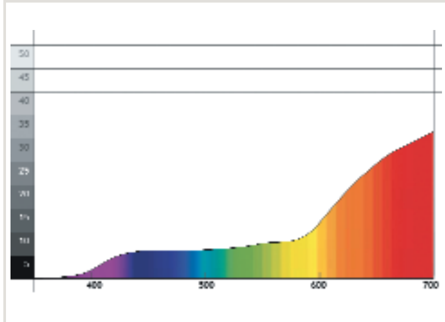


Figure 11c: Transmission data for Drivewear lenses - outside bright lighting conditions

This is usually marked on the lens as a horizontal line, to be set at 180°. According to BS, this has a tolerance of 5°.

Availability

Polaroid is available as 15% transmission grey or brown (CR39). Nupolar, in addition to the same basic grey and brown, also has a green option as well as lighter 35% grey. UVSun (Signet Armolite) has 25% Rose and Blue,1.6 also available from Hoya, Nikon and Norville. Also available are flat top 28mm bifocals in CR39, Norville can supply a D35 and Flat top 728 Trifocal in CR39 and progressive lenses from BBGR, Birmingham, Essilor, Hoya, Norville, Rodenstock, Signet Armolite, Shamir and Taylor Lenses[10].

Combination filters

As already stated, a raw polarising filter needs to have a UV filter added and is also tinted darker to be used as sunglasses. There are also a few combinations of other types of tints available that feature polarising filters. For example Zeiss Skypol[4] has a contrast filter added, and Maui Jim produce multi laminated lenses that combine dark filters and mirror coatings with a polarising lamina available in glass and polycarbonate materials.

Polarised and photochromic

These lenses combine the advantages of changeable amount of lens colour with lighting conditions and are polarised to eliminate horizontally reflected glare. The polarising filter must have a higher transmission of visible light than usual in order to make use of photochromic properties. Younger Optics[10] has combined Transitions with the lightest grey Nupolar CR39 (and more recently also available in polycarbonate) to produce the Drivewear lens. At low lighting conditions, Drivewear lenses provide 35% visible light transmission. The polariser removes horizontally reflected glare. In this stage Drivewear lenses are a high contrast green/yellow colour. As a class 2 category tint[3] **(figure 2)**, this is its lightest LTF and so obviously not suitable for night driving. The windscreen of a car during bright light conditions lowers overall transmission to 21%. Under these conditions, the lenses turn a copper colour. A polarising filter will reduce reflection from road surfaces. In outside bright light conditions the Drivewear lens will be at its darkest, and turns reddish-brown. LTF is 12% at 23°C (class 3) but will be darker if colder at 5°C. Technically, at this low temperature, it would be too dark for driving in open-top vehicles as the LTF is likely to be less than 8% (class 4). **Figure 11** shows the transmission curves of Drivewear Lenses from the Younger Optical website[11] when the lens is behaving in its three modes.

Another well known example of this combination is the Serengeti series of lenses which were first launched in 1985, based on the Corning photochromic glass lenses as a laminate with a polarising filter. More recently Serengeti lenses are available as single vision prescription lenses, and also now available is the Polar PHD, combining the polarising filter with Trivex base lens.

Demonstrators

There is point of sale material available from most manufacturers to enable demonstration of the features of both photochromic and polarising filters. The photochromic demonstrators have a UV light source, either in a unit that a demonstration lens or lenses can be placed, or in a hand held torch that can be shone onto the lenses. Most polarising demonstrators consist of a photographic plate, the detail of which can only be rendered visible by viewing this through a plano glazed front that can be held in front of the eyes. The manufacturers' websites also have a wealth of technical information and some have useful animated promotional material demonstrating the effects of the filters mentioned.

Conclusion

Modern photochromic lenses provide 90-100% UVA and 100% UVB protection. Although there is no doubt about the UV protection, users travelling to hotter climates than the UK should be advised that the lenses will not go as dark, by as much as 25% difference. Improvements in performance and a huge range of lens forms makes plastics photochromics something to consider for all spectacle lens wearers. MAR enhancements should also be considered if spectacles are used for general purpose. If this is the case, appropriate advice should be given regarding driving. Polarising lenses will always be dark, and have added UV filters to make them conform to appropriate standards for sunglass use, they do however have a dramatic effect on reflected glare, which can be bothersome. Some advice may be appropriate for observing certain LCDs. Combining the advantages of both photochromic and polarising filters will produce very effective sunglasses, eliminating optical noise as well as offering variable LTF.

The author has no connection with any lens manufacturer and technical information presented is available from catalogues and manufacturer websites. Inevitably, not all products available may have been mentioned in this article, the intention is to give

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examples of what is current at the time of writing. Advantages as well as disadvantages have been highlighted and any endorsements of use are meant to be of a generic nature.

Special thanks to Julian Wiles, Younger Optics, for his help with the graphics.

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Multiple choice questions (MCQs):

Photochromic and polarising tints

1. What is considered to be the visible range of solar radiation in the electromagnetic spectrum?
a. 200 – 280 nm b. 380 – 780 nm
c. 780 – 1400 nm d. 280 – 780 nm

2. Why would the infrared hazard be noticeable at the time of exposure?
a. it would be painful
b. it would be accompanied by blue light
c. all radiation hazards are painful
d. it would be accompanied by the sensation of warmth

3. What proportion of the population over 70 years old are likely to have cataracts?
a. 50% b. 60% c. 70% d. 80%

4. According to CE regulations, what is the minimum Luminous Transmission Factor allowed to be suitable for driving at night?
a. 50% b. 60% c. 70% d. 80%

5. What is added to the glass melt as a catalyst to speed up the photochromic reaction of silver halide crystals?
a. Copper b. Gold c. Lead d. Iron

6. Photochromic dye is imbibed into the surface of a CR39 plastics lens to a depth of:
a. 10 – 15 microns b. 10 – 15 nm
c. 100 – 150 microns d. 100 – 150 nm

7. If the transmission of a modern photochromic lens is 40% when fully darkened measured at a temperature of 35°C, what is the likely transmission of the same lens when fully darkened measured at 5°C?
a. 40% LTF b. 50% - 60 % LTF
c. 20% - 15% LTF d. 8% - 5% LTF

8. If a ray of light has an angle of incidence of 53.13° at a transparent medium and the angle of refraction is 36.87°. What is the medium likely to be?
a. Water b. CR39 plastic
c. Crown glass d. Diamond

9. During manufacture of a raw polarising sheet, what chemical pigment is added which gives it a tinted appearance?
a. Gadolinium b. Iodine c. Cetrimide d. Turmeric

10. If a vertical glass window was observed using polarising sunglasses worn with head upright, how much of the reflected light would be transmitted through the lenses?
a. None b. 50% c. 75% d. 100%

11. When ordering toric polarising uncuts to be glazed in-house, why must the cylinder axis be stated?
a. Uncuts are always ordered stating the cylinder axis
b. So that the cylinder axis is always set at 90°
c. So that the cylinder axis is set at 180°
d. So that the polarising transmitting axis is set at 90°

12. What is the best advice to give a patient considering photochromic lenses as their general use spectacles?
a. To have an alternative clear pair for night driving
b. Not to wear for driving at any time of the day
c. They will react the same outside on a sunny hot summer day to a sunny cold winter day
d. They will go darker on a sunny hot summers day than on a sunny cold winter day

The deadline for posted or faxed response is 15 April 2010 to the address on page 4. The module code is C-12912

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