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Module 2 Part 1

Lens Dispensing Today

Materials for spectacle lenses

Optical and mechanical performance

Today, in most of the developed world, some 95% of spectacle lenses are made from plastics materials. Owing to its inherent lightness and safety, plastics has almost completely replaced glass as the first choice of spectacle lens material. What little glass is still used is mainly confined to very high index glasses with refractive indices in excess of 1.80, and to photochromic lenses with specialised properties, such as Corning's CPF glasses.

Requirements for spectacle lens materials are given in BS EN ISO 8980:2004, "*Uncut finished spectacle lenses*"[1] and BS EN ISO 14889:2003, "*Fundamental requirements for uncut finished lenses*"[2]. BS 7394: Part 2:1994, "*Specification for complete spectacles*"[3], also contains some important definitions relating to lens material. When a new material is produced, certain items of physical data are published either by the material supplier or by the lens manufacturer, which is offering a range of lenses in the new material. The data enables most of the optical and mechanical properties of the material to be assessed. The usual information published for the material includes:

- Refractive index
- Density
- Abbe number (constringence or V-value)
- UV cut-off point

Given the refractive index, two other useful items of information can be deduced for the material – the curve variation factor (CVF) and the reflectance of the surface of the material, ρ.

Table 1 gives a typical selection of lens materials and lists these various properties. The significance of the physical data is discussed below.

Refractive index

Refractive index expresses the ratio of the velocity of light of a given wavelength in air, to the velocity of light of the same wavelength in the refracting medium.

At present, in the UK and the USA, refractive index is measured on the *helium d*-line (wavelength 587.56nm) whereas in Continental Europe it is measured on the *mercury e*-line (wavelength 546.07nm). Both indices, n_d and n_e, are given in **Table 1** to facilitate identification of the material. Note that the value for n_e is a little greater than for n_d, so that when the value of n_e is given, the material appears to have a slightly higher refractive index. Here, the CVF, Abbe number and the reflectance, ρ, are quoted for n_d.

Table 1

Physical data for typical lens materials

Medium	n_d	n_e	CVF	Density	UV cut-off	Abbe	ρ(%)
Glasses							
White Crown	1.523	1.525	1.0	2.5	320	59	4.3
Light flint	1.600	1.604	0.87	2.6	334	42	5.3
1.7 glasses	1.700	1.705	0.75	3.2	340	35	6.7
	1.701	1.706	0.75	3.2	320	42	6.7
1.8 glasses	1.802	1.807	0.65	3.7	332	35	8.2
	1.830	1.838	0.63	3.6	340	32	8.6
1.9 glasses	1.885	1.893	0.59	4.0	340	31	9.4
Plastics							
CR39	1.498	1.500	1.0	1.3	355	58	4.0
INDO Superfin	1.523	1.525	0.95	1.3	350	48	4.3
Trivex®	1.532	1.535	0.94	1.1	380	46	4.4
Sola Spectralite	1.537	1.540	0.93	1.2	385	47	4.5
Corning SunSensors®	1.555	1.558	0.90	1.2	380	38	4.7
PPG HIP	1.560	1.563	0.89	1.2	370	38	4.8
AO Alphalite 16XT	1.582	1.585	0.86	1.3	380	34	5.1
Polycarbonate	1.586	1.589	0.85	1.2	385	30	5.2
Hoya Eyas 1.6	1.600	1.603	0.83	1.3	380	42	5.3
Polyurethanes	1.600	1.603	0.83	1.3	380	36	5.3
	1.609	1.612	0.82	1.4	380	32	5.4
	1.660	1.664	0.75	1.4	375	32	6.2
	1.670	1.674	0.74	1.4	395	32	6.3
Hoya Eyry 1.7	1.695	1.710	0.72	1.4	380	36	6.7
High index 1.71	1.710	1.715	0.70	1.4	380	36	6.9
Very high index	1.740	1.746	0.67	1.5	400	33	7.3

About the author

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BS 7394: Part 2, "*Specification for complete spectacles*"[3], classifies materials in terms of refractive index as follows:

Normal index $n \geq$ 1.48 but < 1.54
Mid index $n \geq$ 1.54 but < 1.64
High index $n \geq$ 1.64 but < 1.74
Very high index $n \geq$ 1.74

Curve variation factor (CVF)

It is useful to know the likely change in volume and thickness which will be obtained when another material is compared with a standard Crown glass. This information can be obtained from the CVF, which enables a direct comparison in thickness to be obtained. For example, a 1.700 index material has a CVF (see **Table 1**) of 0.75, which informs us that the reduction in thickness will be about 25% if this material is substituted for Crown glass.

One of the most practical uses for the CVF is to convert the power of the lens that is to be made into its Crown glass equivalent. This is done, simply, by multiplying the power of the lens by the CVF for the material. For example, suppose we wish to dispense a -10.00D lens in 1.700 index material, the Crown glass equivalent is 0.75 x -10 or -7.50. In other words, the use of a 1.700 index material would result in a lens that has a power of -10.00D, but in all other respects looks like a -7.50 lens made in Crown glass. A 1.600 index material has a CVF of 0.87 so that we may expect a 13% reduction in thickness and a -10.00D lens made in this material would look like a -8.75 made in Crown glass. CVF is simply the ratio of the refractivity of Crown glass to that of the material, $0.523/(n_d - 1)$, and compares the actual curves obtained on Crown glass and the material in question for a given curvature of the surface. Plastics materials are compared with CR39, when CVF = $0.498/(n_d - 1)$.

A further practical application of the CVF is given later, where it is shown how it can be used to determine an approximate value for the refractive index of an unknown lens.

Density

Density tells us how heavy the material is, and a comparison of densities can give the likely change in weight to be expected by using the material.

The value given is the weight in grams of 1cm³ of the material. Densities of high refractive index glasses are seen to be greater than that of Crown glass (about 2.5), but in order to compare the weights of lenses made in different materials it is also necessary to consider the saving in volume. For example, if the density of a material is quoted as 3.0, it means that the material is 20% heavier than Crown glass. As a guide, provided that the saving in volume obtained (indicated by the CVF) is greater than the increase in density, the final lens would be no heavier than if it had been made in Crown glass. For example, the CVF for a 1.802 index glass

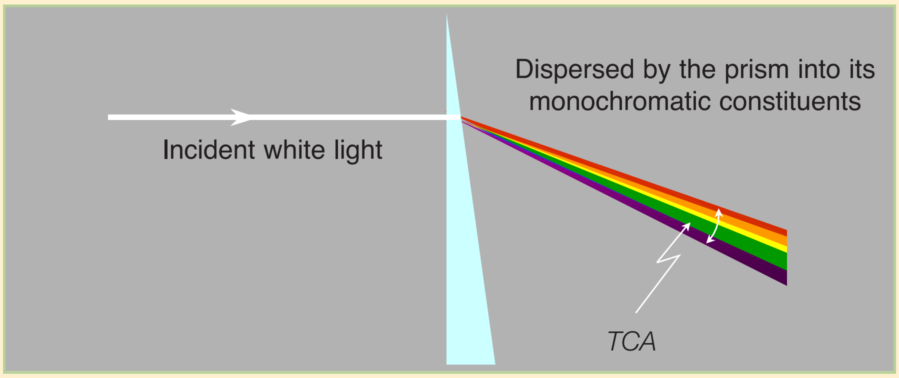

Figure 1
Dispersion by a prism. White light is dispersed into its monochromatic constituents by a prism. In the case of a lens, the dispersion is due to the prismatic effect of the lens at the point

material is 0.65, indicating that there would be a saving in volume of some 35% compared with white ophthalmic Crown glass. The density of this material, however, is 3.7 indicating that, per unit volume, it is 48% heavier than Crown glass. Hence, we can anticipate that the 1.802 index lens will be some 15% heavier than its Crown glass equivalent.

Abbe number

The Abbe number informs us of the optical properties of the material rather than of its mechanical characteristics. The Abbe number is the reciprocal of the dispersive power of the material and indicates the degree of transverse chromatic aberration (TCA) which the wearer will experience. The values quoted in **Table 1** are the Abbe numbers for the *helium d*-line, V_d, where

$$V_d = (n_d - 1)/(n_F - n_C)$$

n_C is the refractive index of the material for the wavelength, hydrogen red, C (656.27nm) and n_F is the index for the wavelength, hydrogen blue, F (486.13nm); these two wavelengths being selected to denote the red and blue ends of the visible spectrum respectively.

The effects of chromatic aberration are well known. When light from a small white object is refracted by a prism, it is dispersed into its monochromatic constituents, the blue wavelengths being deviated more than the red (**Figure 1**). To an eye viewing through the prism, the image of the object appears fringed with blue on the apex side of the prism. Under conditions of low contrast, colour fringing may not be noticed. Instead, the effect of TCA is to cause a reduction in visual acuity (off-axis blur). This often presents in the complaint, "These lenses are fine when I look through the centres but vision is blurred when I look through the edge".

BS 7394: Part 2, "*Specification for complete spectacles*"[3], classifies materials in terms of their Abbe number as follows:

Low dispersion V ≥ 45
Medium dispersion V ≥ 39 but < 45
High dispersion V < 39

Ordinary Crown glass and plastics materials, such as CR39, have *V*-values in the region of 59. Experience has shown that these low dispersion materials almost never give rise to complaints of coloured fringes or off-axis blur.

To a good approximation, the magnitude of the TCA at any given point on a lens can be found by calculating the prismatic effect, *P*, at that point and dividing by the Abbe number of the material[4], that is, TCA = P/V. It is generally considered that the average threshold value for TCA is 0.1Δ. TCA less than 0.1Δ is unlikely to give rise to complaints. The Abbe numbers for some normal index materials (e.g. Crown glass and CR39) is about 60 and the prismatic effect at the visual point would need to be about 6Δ before the typical threshold is reached. Using paraxial theory, this amount of prism would be encountered, for example, at a point 15mm from the optical centre of a +4.00D lens.

Materials whose Abbe numbers are in the region of 40 would give rise to 0.1Δ of TCA at a point where the prismatic effect is 4Δ, i.e. 10mm away from the optical centre of a +4.00D lens. It is for this reason that it is wise to select a material with the highest possible Abbe number.

It is useful to be able to determine the diameter of the zone concentric with the optical centre of the lens within which the visual point must remain before the threshold value of 0.1Δ is reached. This is given by:

$$c = V / F$$

where *c* is the radius of the zone in mm, *V* is the Abbe number and *F* is the power of the lens. Thus, for a lens of power -2.00D, made in polycarbonate (*V* = 30), the eye would not detect TCA in a zone 30mm in diameter concentric with the optical centre of the lens.

Reflectance, ρ

The reflectance of the lens surfaces is calculated from the refractive index of a material. When light is incident normally on a lens surface in air, the percentage of

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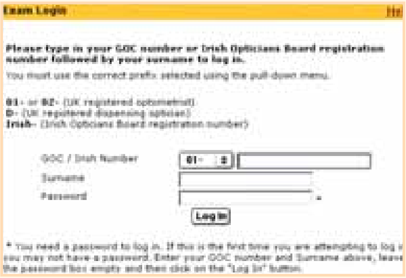

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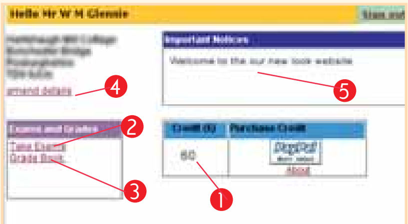

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n_d / D	ct	Diameter 40 et	Diameter 40 wt (g)	Diameter 50 et	Diameter 50 wt (g)	Diameter 60 et	Diameter 60 wt (g)	Diameter 70 et	Diameter 70 wt (g)
1.498 / 1.32	2.0	4.1	5.1	5.4	9.5	7.2	16.7	9.5	27.8
1.523 / 1.36	1.4	3.4	4.1	4.6	8.0	6.3	14.3	8.4	24.5
*1.523 / 2.54	1.0	3.0	6.4	4.2	12.9	5.9	23.9	8.0	41.8
1.532 / 1.10	1.0	3.0	2.7	4.2	5.5	5.8	10.2	7.8	17.8
1.537 / 1.20	1.0	3.0	3.0	4.1	6.0	5.7	11.1	7.7	19.2

*glass material, all others listed are plastics

Table 2
Comparison of edge thickness and weight of -5.00D lenses at various diameters made in normal index materials

light reflected at each surface is given by:

$$\rho = 100\ (n-1)^2/(n+1)^2\ \%$$

Thus a material of refractive index 1.5, has a reflectance of

$$(0.5/2.5)^2 \times 100 = 4\% \text{ per surface}$$

Normal index materials

Normal index materials are those whose refractive index lies in the range, $n \geq 1.48$ but < 1.54. It can be seen in **Table 1** that this includes five materials currently available:

Glass	n_d
White Crown	1.523
Plastics	
CR39	1.498
INDO Superfin	1.523
Trivex	1.532
Sola Spectralite	1.537

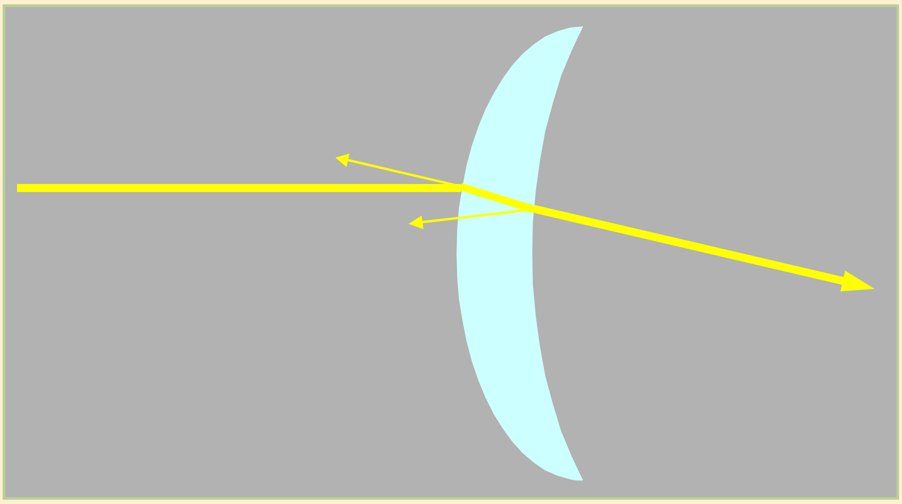
Some of these materials are also distributed by other manufacturers using their own brand names for their lens ranges, and are also available in photochromic form.

The mechanical characteristics of spectacle lenses made in these various materials is best understood from the information given in **Table 2**, which gives a comparison in edge thickness and weight of -5.00D lenses which are circular in shape and of various diameters from 40mm to 70mm.

Study of the information given in **Table 2** reveals some interesting facts about the variation in thickness and weight of finished spectacle lenses and provides several useful pointers to successful dispensing. For example, if the diameter of the lens is kept fairly small, there is very little to choose between CR39 and glass lenses as far as weight is concerned, owing to the increased centre thickness necessary for the plastics material. On the other hand, for really lightweight lenses, the more rigid plastics materials Trivex and Spectralite offer lenses almost half the weight of either CR39 or glass. Note also that these two materials are sufficiently rigid to be produced with the same centre thickness as glass for the power under consideration. As the lens diameter increases, the weight advantage of plastics versus glass becomes more and more apparent.

The influence of diameter upon the lens weight is also easy to see from the table.

Figure 2
Reflection at the lens surface. A fraction of the light incident upon the lens surface is reflected back by the lens surface. Assuming n = 1.50, the fraction reflected is given by 100x $(0.5 / 2.5)^2$ = 4% per surface. Thus, in the figure, 4% of the incident light is lost by reflection at the first surface and 96% enters the lens material; 4% of this is lost by reflection at the second surface (3.84%) so the amount of the original intensity transmitted by the lens is 92.16%. Note that this theory ignores any losses due to absorption by the lens material or by multiple internal reflections within the lens



Considering spectacle Crown glass (1.523 / 2.54), tabulated in the third row of the table, when the lens diameter is increased from 40mm to 50mm, the edge thickness increases by 40% and the weight of the lens doubles. Increasing the diameter again from 50mm to 60mm causes the edge thickness to increase by another 40% and, once again, the weight of the lens doubles. Compared with a lens diameter of 40mm, at 60mm diameter, the edge thickness has virtually doubled and the weight has increased four times. Although the table considers only lenses of power -5.00, these tendencies are similar for all lens powers.

BS 7394: Part 2, "*Specification for complete spectacles*"[3], classifies materials whose Abbe numbers are greater than 45 as low dispersion materials. The Abbe numbers of normal index materials are all in excess of 45, so all these materials would be classified as having low dispersion. The dispersion produced by a lens (transverse chromatic aberration, or TCA) is not normally troublesome until it exceeds about 0.15Δ. It is generally considered that the average threshold value for TCA is 0.1Δ. TCA less than 0.1Δ is unlikely to give rise to complaints. For a material whose Abbe number is 45, the value of 0.15Δ for TCA is reached when the prismatic effect at the point on the lens is 6.75Δ. For a 2.00D lens, this amount of prism is not encountered until the eye is using a point some 34mm from the optical centre of the lens. For a 6.00D lens, the eye would encounter this magnitude of prism some 11mm from the optical centre.

Ordinary Crown glass and the hard resin plastics material, CR39, have Abbe numbers in the region of 59. Experience has shown that these low dispersion materials almost never give rise to complaints of coloured fringes or off-axis blur.

Normal index photochromic and tinted materials

All the normal index materials listed in **Table 1** are available in both photochromic and tinted form. Crown glass photochromic material is available as Photogray and Photobrown Extra with most lens types being available in these two materials.

Photochromic plastics lenses are available in each of the different materials listed in the table, as either Transitions® III or Transitions® Next Generation designs in which the photochromic property is imbibed in the form of a dye by the lens material, or by a special coating applied to the lens surface. It is also possible to obtain photochromic plastics materials where the photochromic property of the material exists throughout the entire mass of the lens material.

Crown glass is available in several different fixed tint forms, from white with special UV attenuating properties (UV400 glass), through grey, green, yellow, amethyst and brown shades. It is also possible to vacuum coat glass lenses with metallic coatings which reflect away unwanted radiation, these too being available in various colours and shades.

Plastics materials can be dyed with photographic dyes to any colour and shade including graduated tints and rainbow effects. Plastics polarising lenses are also available in various lens designs, which attenuate reflected glare in addition to offering strong absorption in the visible spectrum.

Coatings for normal index materials

All normal index materials can be coated in high vacuum to offer multilayer reflection-free surfaces. The transmission of white reflection-free lenses can be as high as 99%, offering improved contrast and freedom from the ghost images often experienced by wearers of uncoated lenses.

Plastics lenses can be supplied with hard, anti-abrasion coatings in several different forms. The hard coating may be applied in the form of a polysiloxane lacquer to the lens surfaces by a dipping or a spinning process, or by an in-mould treatment during the casting process, or by applying quartz-like layers to the surfaces during the vacuum coating process. Most multilayer coatings are finished with a topcoat, which has anti-static and hydrophobic properties, helping to maintain the transparency of the surfaces and making them easier to clean.

Mid index materials

CR39 lenses were first manufactured by the Armorlite Corporation in California in 1947. They were the first real alternative to glass lenses in terms of hardness and abrasion resistance and compared with glass, offered big advantages in terms of lightness and safety. By 1960, they had become familiar in Europe, introduced by the French company, Silor, under the trade name Orma 1000. The original CR39 monomer was produced by the American company, Pittsburg Plate Glass Industries Inc (PPG), which now licenses production of the monomer all over the world.

CR39 was to remain the foremost plastics material for over 20 years until PPG introduced a second, mid index, monomer with a refractive index of 1.56. Like CR39, it is a thermosetting resin material, even lighter in weight, with an Abbe number of 38 (see **Table 1**). The PPG high index plastics (HIP) material has another advantage over CR39 in that it is more rigid and can therefore be surfaced down to a thinner centre substance. This gives it a real advantage over CR39 in terms of thickness and weight of lenses made in this material.

Since 1980, several mid index materials have appeared, such as polycarbonate, which is very light and tough, and 1.60 index polyurethanes from Japan with improved Abbe numbers to reduce problems due to chromatism in lenses.

The mechanical characteristics of spectacle lenses made in these various materials are shown in **Table 3**, which gives a comparison in edge thickness and weight of -5.00D lenses, which are circular in shape and of various diameters from 40mm to 70mm.

As with normal index materials, a study of this information reveals some general facts about the variation in thickness and weight of finished spectacle lenses, and provides several useful pointers to successful dispensing. For example, if the diameter of the lens is kept fairly small, there is very little to choose between any of the plastics lenses as far as weight is concerned. The 1.56 index lenses are slightly heavier, owing to the increased centre thickness necessary for this plastics material. It must be said, however, that some prescription laboratories are prepared to surface this material down to just 1mm centre thickness to save another 0.5mm on the edge thickness and provide a lighter lens.

The advantages in terms of weight of the mid index plastics materials, when compared with glass, is immediately apparent especially at the larger diameters.

The same general influence of the diameter upon the lens weight, which was pointed out for normal index materials, can also be seen in **Table 3**. Considering the 1.609 material tabulated in the last row of the table, when the lens diameter is increased from 40mm to 50mm the edge thickness increases by 37% and the weight of the lens doubles. Increasing the diameter again from 50mm to 60mm causes the edge thickness to increase by another 35% and, once again, the weight of the lens almost doubles. Compared with a lens

Table 3

Comparison of edge thickness and weight of -5.00D lenses at various diameters made in mid index materials (* Essilor Airwear with 1.2mm centre thickness)

		Diameter 40		Diameter 50		Diameter 60		Diameter 70	
n_d / D	ct	et	wt (g)	et	wt (g)	et	wt (g)	et	wt (g)
1.555 / 1.2	1.0	2.9	2.9	4.0	5.8	5.5	10.8	7.4	18.7
1.560 / 1.2	1.5	3.4	3.7	4.5	7.0	6.0	12.4	7.8	20.8
1.582 / 1.3	1.0	2.8	3.1	3.9	6.1	5.3	11.2	7.0	19.4
1.586 / 1.2	1.5	3.3	3.6	4.3	6.8	5.7	12.0	7.5	20.1
1.586 / 1.2*	1.2	3.0	3.1	4.0	6.1	5.2	11.0	7.2	18.7
1.600 / 2.6	1.0	2.7	6.1	3.8	12.0	5.1	22.0	6.8	37.7
1.600 / 1.3	1.0	2.7	3.0	3.8	6.0	5.1	11.0	6.8	18.9
1.609 / 1.4	1.0	2.7	3.2	3.7	6.4	5.0	11.7	6.7	20.1

n_d / D	ct	Diameter 40		Diameter 50		Diameter 60		Diameter 70	
		et	wt (g)	et	wt (g)	et	wt (g)	et	wt (g)
1.66 / 1.4	1.0	2.6	3.1	3.5	6.1	4.7	11.0	6.1	18.8
1.67 / 1.4	1.0	2.5	3.1	3.4	6.1	4.6	10.9	6.0	18.5
1.700 / 3.2	1.0	2.5	6.9	3.3	13.5	4.4	24.2	5.8	40.8
1.710 / 1.4	1.0	2.5	3.0	3.3	5.9	4.4	10.5	5.7	17.7

Table 4

Comparison of edge thickness and weight of -5.00D lenses at various diameters made in high index materials

diameter of 40mm, at 60mm diameter, the edge thickness has virtually doubled and the weight has increased almost four times. Although the table considers only lenses of power -5.00, these tendencies are true for all lens powers.

Mid index photochromic and tinted materials

Corning's SunSensors material is only supplied in photochromic form, in both brown (with a transmission swing from 85-20%) and grey (with a transmission swing from 86-17%). All the other mid index materials listed in **Table 3** are available in photochromic form.

1.60 index glass photochromic material is available as Photogray 16 and Photobrown 16, with most lens types being available in these two materials. Corning also offer a 1.60 index pink fixed tint glass.

Photochromic plastics lenses are available in each of the different materials listed in the Table, as either Transitions III or Transitions Next Generation designs in which the photochromic property is imbibed in the form of a dye by the lens material, or by a special coating applied to the lens surface. Hoya, for example, offers its Eyas 1.60 material with a photochromic coating (Eyas 1.60 Suntech) in either brown (with a transmission swing from 93-27%) or grey (with a transmission swing from 91-18%). The company also offers its 1.55 index material in photochromic form, the Solio 1.545 Suntech, which like the Corning SunSensors material, has the photochromic property throughout the entire mass of the lens material.

This month, Essilor launched its latest photochromic treatment for plastic lenses, Transitions® V with ESP™. This latest version of Transitions Next Generation treatment has a fading cycle 2.8 times faster that the previous form and is now available for its Airwear range.

Coatings for mid index materials

All mid index materials can be coated in high vacuum to offer multilayer reflection-free surfaces. The transmission of white reflection-free lenses can be as high as 99%, offering improved contrast and freedom from the ghost images often experienced by wearers of uncoated lenses.

In general, all mid index plastics lenses are supplied with hard, anti-abrasion coatings in several different forms. The hard coating may be applied in the form of a polysiloxane lacquer to the lens surfaces by a dipping or spinning process, or by an in-mould treatment during the casting process, or by applying quartz-like layers to the surfaces during the vacuum coating process. Most multilayer coatings are finished with a topcoat which has anti-static and hydrophobic properties, helping to maintain the transparency of the surfaces and easier to clean.

High index materials

High index materials are classified as those whose refractive index lies in the range, $n \geq 1.64$ but < 1.74. Until 1973, the only high index materials available for ophthalmic use were dense barium flint, or extra dense flint glasses with refractive indices in the range 1.65 to 1.70. These glasses contained either barium or lead, inclusion of which in the glass mix had the desired effect of raising the refractive index of the material. Unfortunately, each of these heavy elements also caused an increase in the weight of the glass, the resulting density was in the region of 4.0 and their use always resulted in heavy spectacle lenses. It was, therefore, a significant breakthrough when, in 1973, a completely new glass type was introduced by the American division of the German company, Schott Glass. This new glass contained titanium oxide instead of barium or lead oxide resulting in a glass material with a density of around 3.0. Since the saving in density (some 25%) exactly matches the saving in volume of lens material which is obtained owing to the higher refractive index (indicated by the CVF in **Table 1**), spectacle lenses made in the 1.70 index titanium oxide glass are generally no heavier than their Crown glass counterparts.

In 1992, Asahi Pentax introduced a series of 1.66 index lenses made from the Matsui, MR-7 monomer. This was the first of a series of high index monomers which were introduced by various major chemical companies in Japan, culminating in the 1.71 monomer produced by Mitsubishi Gas Chemical Corporation and first marketed in 1997 by Hoya as its Teslalid material. The 1.71 index lens series in this material is now available from several other sources. In the meantime, Hoya has developed its own 1.70 index plastics material (Eyry 1.70, $n_d = 1.695$), with the same, relatively high, Abbe number to replace its Teslalid ranges. A further high index polymer ($n_d = 1.67$) is available from several sources – Essilor Stylis, Hoya Eynoa, Kodak, Nikon, Rodenstock, Seiko and Zeiss.

The mechanical characteristics of spectacle lenses made in these various materials are shown in **Table 4**, which gives a comparison in edge thickness and weight of -5.00D lenses which are circular in shape and of various diameters from 40mm to 70mm.

As pointed out earlier, a study of this information reveals some general facts about the variation in thickness and weight of finished spectacle lenses, and provides several useful pointers to successful dispensing. For example, if the diameter of the lens is kept fairly small, there is very little to choose between any of the plastics lenses, as far as thickness and weight is concerned. The glass high index lenses, on the other hand, are more than twice as heavy as the plastics lenses, and the advantages in terms of weight of the high index plastics materials when compared with glass are immediately apparent, especially at the larger diameters.

It should be noted that in order to be able to compare the thickness and weight of lenses made in these different materials, it has been assumed that they are offered in curved form with spherical surfaces. In practice, the plastics materials are invariably offered as low-base aspheric lens series so the edge thicknesses and weights are slightly less than those given in the table.

The same general influence of the diameter upon the lens weight again can be seen in **Table 4**. Considering the 1.66 material tabulated in the first row of the table, when the lens diameter is increased from 40mm to 50mm the edge thickness increases by 35% and the weight of the lens doubles. Increasing the diameter again from 50mm to 60mm causes the edge thickness to increase by another 34% and, once again, the weight of the lens almost doubles. Compared with a lens diameter of 40mm, at 60mm diameter, the edge thickness has virtually doubled and the weight has increased almost four times. Although the table considers only lenses of power -5.00D, these tendencies are true for all lens powers.

Tints and treatments for high index materials

1.67 plastics material is available in both tinted and photochromic form and all lenses can be coated in high vacuum to offer multilayer reflection-free surfaces. The transmission of white reflection-free lenses can be as high as 99%, offering improved contrast and freedom from ghost images often experienced by wearers of uncoated lenses. A variety of tints is available to special order and the material is available in Transitions Grey. Essilor has also introduced the latest photochromic treatment, Transitions V for its Stylis 1.67 range.

In general, all high index plastics lenses are supplied with hard anti-abrasion coatings, which may be applied in several different forms. The hard coating can be applied in the form of a polysiloxane lacquer to the lens surfaces by a dipping or spinning process, by an in-mould treatment during the casting process, or by applying quartz-like layers to the surfaces during the vacuum coating process. Most multilayer coatings are finished with a topcoat with anti-static and hydrophobic properties, helping to maintain the transparency of the surfaces and making them easier to clean.

1.700 glass is made in tinted form as 1.7/35 Rose (luminous transmittance, LT, 83%) 1.7/35 Brown (LT 80%), 1.7/35 Pink B (LT 81%) and 1.7/42 Rose A (LT87%). In practice, these tints are chiefly cosmetic, since the glasses transmit almost as much UVA radiation as the white version. In any case, when these glasses are selected for moderate to high power prescriptions, they will exhibit a variation in transmission since, in the case plus lenses they will be darker at the centre and in the case of minus lenses, darker at the edge.

Zeiss offers a high index photochromic glass bonded equitint version of its 1.70 glass Tital series, where a 1.3mm layer of photochromic glass is attached to a white base layer of high index Tital glass (Umbramatic Tital 1.7 Equitint).

All high index glass lenses should be supplied with an AR coating, not only to reduce the intensity of the reflections from the lens surfaces, but also to prevent them from oxidising causing stains to form on the surface that the wearer cannot remove with an ordinary cleaning regime.

Very high index materials

Very high index materials are classified as those whose refractive index is 1.74 or greater. There are currently three glass materials and one plastics material available within this group. The significant physical data for these materials are listed in **Table 1**.

Lens ranges made in the 1.802/35 and the 1.885/31 very high index glasses from Corning are available from several sources in single vision form, and the 1.802/35 material is also available in progressive power form. The 1.802/35 material is available from Nikon in single vision lenses.

The 1.74 plastics material was developed by Asahi Optical, Japan, in 2000 and lenses made in this material are available from various sources.

The mechanical characteristics of spectacle lenses made in these various materials are shown in **Table 5**, which gives a comparison in edge thickness and weight of -5.00D lenses which are circular in shape and of various diameters from 40mm to 70mm.

As before, it is seen that if the diameter of the lens is kept fairly small, there is very little to choose between any of the lenses as far as thickness is concerned. However, the advantage in terms of weight of plastics materials when compared with glass is immediately apparent, especially at the larger diameters. The glass lens data shows that lenses made in this material are more than twice as heavy as the 1.74 plastics lens material listed in **Table 5**.

n_d / D	ct	Diameter 40 et	Diameter 40 wt (g)	Diameter 50 et	Diameter 50 wt (g)	Diameter 60 et	Diameter 60 wt (g)	Diameter 70 et	Diameter 70 wt (g)
1.80 / 3.7	1.0	2.3	7.6	3.0	14.5	3.9	25.6	5.1	42.7
1.83 / 3.6	1.0	2.2	7.3	2.9	13.9	3.8	24.4	4.9	40.5
1.90 / 4.0	1.0	2.2	7.9	2.8	14.9	3.6	26.1	4.7	43.0
1.74 / 1.4	1.0	2.4	3.0	3.2	5.7	4.2	10.2	5.5	17.1

Table 5
Comparison of edge thickness and weight of -5.00D lenses at various diameters made in very high index materials

Again, in order to be able to compare the thickness and weight of lenses made in these different materials, it has been assumed that they are offered in curved form with spherical surfaces. In practice, the plastics material is invariably offered as a low-base aspheric lens series, so the edge thicknesses and weights are slightly less than those given in the table.

The same general influence of the diameter upon the lens weight can also be seen in **Table 5**. Considering the 1.80 material tabulated in the first row of the table, when the lens diameter is increased from 40mm to 50mm, the edge thickness increases by 30% and the weight of the lens doubles. Increasing the diameter again from 50mm to 60mm causes the edge thickness to increase by another 30% and, once again, the weight of the lens almost doubles. Compared with a lens diameter of 40mm, at 60mm diameter, the edge thickness has virtually doubled and the weight has increased almost four times. Although the table considers only lenses of power -5.00D, these tendencies are true for all lens powers.

In practice, very high index materials are normally used for very strong lenses, over about 8.00D. For this reason, **Table 6** has been included to show how the edge thickness and weight of -10.00D lenses vary for a range of materials from normal, through to the very high index materials. Finished lens diameters of 40mm and 50mm have been tabulated since these correspond with the likely diameters of edged lenses, and both a plastics and a glass lens are compared within each of the groupings.

Table 5 shows quite clearly that as the refractive index of the material is increased, the edge thickness decreases and that, in general, the plastics lens is some 50% lighter than the glass lens in each group.

Tints and treatments for very high index materials

The Corning 1.80/35 material is also offered in a light pink glass, 1.8/35 Rose A with a luminous transmittance of 84%. The Nikon 1.802/35 material (Pointal High Power II) is available in both white and light brown BR 15 tint, which has 15% absorption. In practice, these tints are chiefly cosmetic, since the glasses transmit almost as much UVA radiation as the white version. In any case, when these glasses are selected for moderate to high power prescriptions, they will exhibit a variation in transmission since, in the case of plus lenses, they will be darker at the centre and in the case of minus lenses, darker at the edge.

All very high index lenses should be supplied in AR-coated form and the transmission of white reflection-free lenses can be as high as 99%, offering improved contrast and freedom from ghost images often experienced by wearers of uncoated lenses.

The very high index plastics material is currently available from various sources as low base aspheric single vision lens series, which are automatically supplied with top quality, anti-abrasion resistant, broadband AR coatings.

Estimation of refractive index of lens material

With the large range of lens types available today, it is sometimes difficult in practice to identify precisely the material from which a given spectacle lens has been made. It is fairly easy to establish if the material is

Table 6
Comparison of edge thickness and weight of -10.00D lenses at various diameters made in various materials

	n_d / D	ct	Diameter 40 et	Diameter 40 wt (g)	Diameter 50 et	Diameter 50 wt (g)
Normal index	1.498 / 1.3*	2.0	6.3	6.7	9.1	13.8
	1.523 / 2.5	1.0	5.1	9.4	7.7	20.7
Mid index	1.600 / 2.6	1.0	4.5	8.9	6.7	19.1
	1.600 / 1.3*	1.0	4.5	4.5	6.7	9.6
High index	1.700 / 3.2	1.0	4.0	9.9	5.7	20.1
	1.710 / 1.4*	1.0	3.9	4.3	5.7	9.0
	1.740 / 1.4*	1.0	3.8	4.2	5.5	8.8
Very high index	1.802 / 3.7	1.0	3.6	10.6	5.1	21.8
	1.885 / 4.0	1.0	3.3	10.8	4.7	22.1

* plastics materials

glass or plastics and some lens series incorporate a trademark on the front surface. However, it is possible with ordinary equipment to obtain an approximate value for the refractive index of the material by employing a focimeter to determine the back vertex power of the lens, and a lens measure to obtain the thin-lens power from the sum of the surface powers. From thin lens theory, the ratio of the thin lens power to the true back vertex power is the same value as the CVF for the material. For example, suppose the power of a finished lens is found by means of the focimeter to be -6.00D, but when a lens measure is applied to each surface, the sum of the surface powers is found to be -4.50D. The ratio of the lens measure power to the back vertex power is 4.5/6 = 0.75. Inspection of **Table 1** shows that a material with a refractive index of 1.700 has a CVF of 0.75, and so the refractive index of the lens material must lie in the region of 1.70

In the absence of a table giving CVF, the refractive index, n_T, of the unknown material can be found from:

$$n_T = 1 + F_T(n_{LM} - 1)/F_{LM}$$

where F_T = true power of lens read from the focimeter;

F_{LM} = sum of surface powers as given by lens measure; *and*

n_{LM} = refractive index for which the lens measure has been scaled.

References

1. BS EN ISO 8980:2004 Ophthalmic Optics – Uncut finished spectacle lenses – Fundamental requirements for uncut finished lenses.
2. BS EN ISO 14889:2003 Ophthalmic Optics – Spectacle Lenses – Fundamental requirements for uncut finished lenses.
3. BS 7394 : Part 2:1994 Specification for complete spectacles.
4. Jalie M (1984) Principles of Ophthalmic Lenses. 5th Edition. ABDO, London.

Part 2 of Lens Dispensing Today, on February 25, will look at "Best form lenses: off axis performance".

MCQs

Module 2 Part 1 of Lens Dispensing Today

Materials for spectacle lenses - Optical and mechanical performance

Please note there is only ONE correct answer

1. Which one of the following is not a mid index material?
a. PPG HIP
b. AO Alphalite 16XT
c. Polycarbonate
d. Polyurethane 1.66

2. Which of the following cannot be described as a normal index, low dispersion material?
a. CR39
b. Corning SunSensors
c. Trivex
d. INDO Superfin

3. The transverse chromatic aberration exhibited by a +4.00D lens made in plastics material with a *V*–value of 40, when the eye looks through a point 8mm below the optical centre, is:
a. 0.08Δ
b. 0.10Δ
c. 0.12Δ
d. 0.16Δ

4. How far from the optical centre of a -6.00D lens made in polycarbonate material can the eye roam before it meets the threshold value for TCA, 0.1Δ?
a. 4mm
b. 5mm
c. 6mm
d. 7mm

5. Which one of the following is true for a glass type with n_d = 1.747?
a. CVF = 0.65 reflectance = 7.2%
b. CVF = 0.70 reflectance = 7.2%
c. CVF = 0.70 reflectance = 7.4%
d. CVF = 0.71 reflectance = 7.4%

6. Which one of the following is true for a plastics material type with n_d = 1.635?
a. CVF = 0.80 reflectance = 5.6%
b. CVF = 0.78 reflectance = 5.8%
c. CVF = 0.76 reflectance = 6.0%
d. CVF = 0.74 reflectance = 6.4%

7. At 40mm diameter, a -5.00D lens made in polycarbonate material is thicker and heavier than a lens made to the same power and diameter in Trivex material. Why is this so?
a. Polycarbonate has a lower refractive index and higher density
b. A polycarbonate lens has a smaller centre thickness and higher density
c. A polycarbonate lens has a higher refractive index and lower density
d. A polycarbonate lens has a greater centre thickness and higher density

8. Taking only losses by surface reflectance into account (i.e. ignoring any loss of radiation by absorption), what would be the transmittance of a plastics lens made in material of refractive index 1.61 assuming no AR coating is applied?
a. 94.5%
b. 90.4%
c. 89.4%
d. 88.4%

9. A -6.00D lens is made in a 1.80 index material that has a density of 3.3g/cm³. Which one of the following statements best describes the weight of the lens when compared with the weight of the same power lens made in Crown glass?
a. Much heavier
b. A little heavier
c. More or less the same
d. A little lighter

10. At 70mm diameter, a -5.00D lens made in polycarbonate material is thinner but heavier than a lens made to the same power and diameter but in Trivex material. Why is this so?
a. It has a higher refractive index and higher density
b. It has a greater centre thickness and higher density
c. It has a greater centre thickness and higher refractive index
d. It has a higher refractive index and lower density

11. A lens measure calibrated for refractive index 1.523 reads +4.25 and -11.00 when applied to a lens made in a material of refractive index 1.60. What power will be found for this lens when it is tested in a focimeter?
a. -7.25
b. -7.50
c. -7.75
d. -8.00

12. The power of a lens as determined by focimeter is +1.50D and a lens measure calibrated for CR39 material when placed on its surfaces reads +4.50 and -3.50. What is the refractive index of the lens material?
a. 1.75
b. 1.70
c. 1.65
d. 1.60

An answer return form is included in this issue. Paper entries ONLY should be completed and returned by February 23 to: CET initiatives (c140), *OT*, Victoria House, 178-180 Fleet Road, Fleet, Hampshire, GU51 4DA.

Please note that model answers for this *Pay-As-You-Learn* series will not be available until July 15, 2005. This is so that readers submitting answers online can join at any time from now until July 12, 2005 and take part in any or all of the six articles as they are published. Paper entries will be marked on the normal monthly basis.