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Part 7 – Coatings and tints

Recommending a coating or tint to a client can greatly enhance the durability, optical performance and functionality of their new spectacles, while providing a valuable stream of extra revenue. **Andrew Keirl** and **Richard Payne** discuss the benefits and advantages of coatings, tints and other lens enhancements. Module C10586, two general CET points suitable for optometrists and dispensing opticians

With the popularity of thermosetting plastics such as CR39 and the softer thermoplastic materials like polycarbonate, abrasion resistance has become an important issue when considering the durability and longevity of a spectacle lens. Compared to mineral glasses, plastic lenses are far more susceptible to surface damage and degradation. This is clearly evident when we consider Table 1.

The Bayer abrasion test is one of the most widely cited test methods for abrasion resistance, subjecting coated and uncoated lenses to a cycle of abrasive tests using oscillating sand or alumina zirconia. The difference between plastics materials and mineral glasses is quite startling and provides very good justification for the recommendation of a protective coating for most plastics materials.

While it may be preferable to coat all spectacle lenses, there are some materials that provide an acceptable level of abrasion resistance without being coated, such as Crown glass, which is generally accepted as a bench mark for abrasion resistance. The hard coating of CR39 lenses is also generally considered as optional when no reflection-free (RF) coating is specified. For all other materials, the provision of either a hardcoat or an RF coating and hardcoat is essential if a reasonable level of surface durability is to be expected.

A hard coating should exhibit some or all of the following features:

- Increased scratch resistance to help withstand the damage caused when a sharp object comes into contact with the lens surface
- Increased abrasion resistance to withstand the wear caused by rubbing the lens surface when cleaning
- Be permeable enough to allow the substrate lens to be tinted or in the case of non-tintable materials like polycarbonate, the coating itself or prima should be tintable
- The refractive index should closely match that of the substrate to minimise reflections at the interface and avoid birefringence
- Have a lack of friction across the surface so that particles glide easily across the surface without scratching it.

Manufacture

Hard coatings are generally specified in one of two ways, on their own, solely for improved durability or as part of a multi-layer reflection-free coating. The main types of hardcoat application are:

Vacuum deposited – commonly manufactured by depositing a layer of around 1.70µm of SiO_2 (Siloxane-based matrix) particles onto the lens using a vacuum coating machine. Because the SiO_2 is a glass-based compound, this method produces any extremely scratch resistant coating. However, it has a very low permeability that necessitates the substrate being tinted before the coating is applied. Adhesion problems can also occur due to stress between the glass based hardcoat and substrate lens when softer plastic substrates are used.

Absorbed coating – applied in a similar way to conventional tinting. This method can be very convenient for in-practice labs providing a quick and easily applied hardcoat. However, the chemicals used are often combined with low friction ingredients resulting in a very thin coating considered inferior to other methods.

Cured lacquers – are produced in two ways, the most common being a thermally cured lacquer. This method is used in high volume manufacture due to its availability in a wide range of indices, making it ideal for use with a variety of substrate materials. Thermally-cured lacquers are applied by either dip-coating the lens or by spin coating, the latter being more popular due to its versatility and reduced proneness to dust contamination. The dipping technique for hard coating is generally used for large volume production. UV-cured lacquers, although very similar to the thermally cured version, tend to be less abrasion resistant. This method is often employed for in-mould coating during the casting of semi-finished lenses.

TABLE 1
Bayer abrasion results

Uncoated materials	Result
Polycarbonate	0.2
Mid-index plastics	0.3 - 0.5
Trivex	0.4
Hi-index plastics	0.5
CR39	1.0
Mineral glasses	12 -14
Coated material example	
Hoya Super Hi-Vision coated plastic	12.43

SERIES MODULES

- Practice development, marketing and communication
- Prescription interpretation
- Frame design
- Spectacle lenses
- Tints and coatings
- Dispensing
- Specialist lenses
- Ordering, checking and collection
- Non-tolerance
- Glossary

It is important that the thickness of a hard coat is uniform across the surface of a lens as any variation in the coating thickness will cause interference patterns to become visible when the lens is reflection-free coated.

Surface protection and enhancement

Practitioners can also specify a surface enhancement or top-coat, often as part of a premium multi-layer reflection free coating. The hydrophobic and oleophobic properties of these top-coats when combined with new manufacturing techniques produce ultra smooth lens surfaces that are surprisingly easy to keep clean and dust free. Hoya's Super Hi-Vision coating is a good example of this type of coating, combining a multi-layer reflection-free hardcoat and a top coat to produce a Bayer abrasion test result close to that of mineral glass that is incredibly easy to keep clean.

Hydrophobic surfaces are generally formed from oligomers of large perflourated carbon chains, vacuum coated or dip coated to a thickness of only around one molecule. The hydrophobic properties electro-statically repel water molecules, preventing water from spreading across the lens surface. Water instead forms spherical droplets that easily run off the lens, reducing the amount left to dry and trap dust particles on the lens surface. Oleophobic properties provide a similar function but repel grease deposits. Combining these two functions along with anti-static properties and an ultra-smooth finish produces a lens surface with the following attributes:

- Very low surface energy that resists deposits
- Anti-static properties that repel dust
- Very low friction coefficient allowing liquids to easily run off the surface
- Hydrophobic and oleophobic properties that repel water and grease.

The lenses feel smooth, slippery and very easy to wipe clean. They attract less dirt, dust and grease and are therefore less prone to abrasion through repetitive cleaning routines.

Reflections

Any highly polished object will produce a reflection when light is incident upon the surface. For spectacle wearers, the reflections from their highly polished lenses can cause visual fatigue as well as being extremely frustrating. Jalie refers to these reflections as 'troublesome reflections' and lists five ghost images that can be formed due to:

- Total internal reflection at the lens surfaces (usually the most troublesome in practice)
- Reflection at the cornea and the back surface of the lens
- Reflection at the cornea and front surface of the lens
- Reflection at the back surface
- Reflection at the front surface.

The reflectance of a surface in air for normally incident light is given by:

$$p = \frac{(n-1)^2}{(n+1)^2}$$

Reflectance factors for various optical media in air are given in Table 2.

It is evident from Table 2 that higher index materials have greater surface reflectance and thus an increased risk of troublesome reflections. It is generally accepted that mid, high and very high index lenses should always be specified with a RF coating for this reason. Thankfully, much of the work here is taken up by the lens makers who generally insist on coating their higher index lenses whether we specify it or not.

TABLE 2
Reflectance factors for different materials (normally incident light)

Material	Refractive index	Reflectance (%)
CR39	1.498	4.00
Crown glass	1.523	4.30
Mid-index	1.600	5.32
High Index	1.700	6.72
High index	1.800	8.16
Very high index	1.900	9.63
Diamond	2.420	17.24

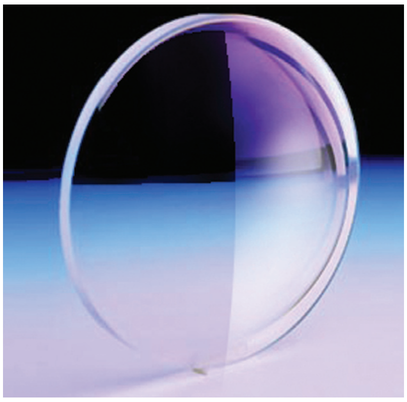

Figure 1 RF-coated lens

Reflection-free coatings

To overcome reflectance and thus increase the transmission of light passing through a lens a phenomenon known as wave-cancellation is employed. Because light travels in waves, if a coating with a thickness of one quarter of the wavelength of incident light is applied, the reflections from the front and back surfaces of the coating layer will be out of phase. Providing they are exactly out of phase, they will cancel each other out. This is known as the path condition (Figure 2) which is satisfied when the thickness of the coating is $\lambda/4n_F$ where λ is the wavelength of light and n_F is the refractive index of the coating film.

To ensure that the two waves are of equal strength the reflections must be of equal amplitude (the amplitude condition). This is achieved by carefully controlling the refractive index of the coating material, so that it is very close to the square root of the underlying lens material. For example, the ideal coating

Figure 2 Wave-cancellation

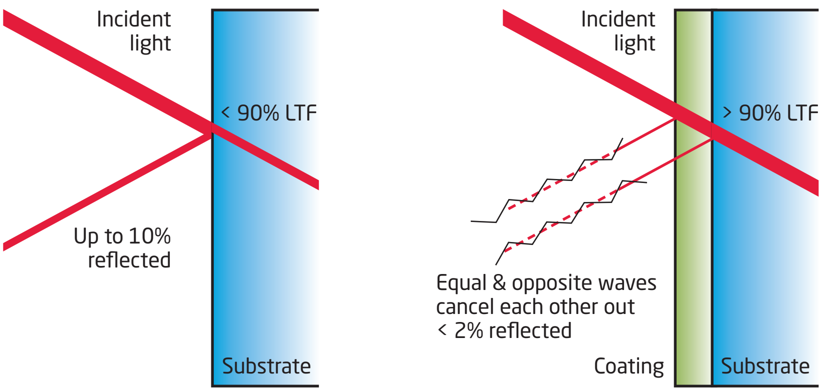

Figure 3 Simple RF coating

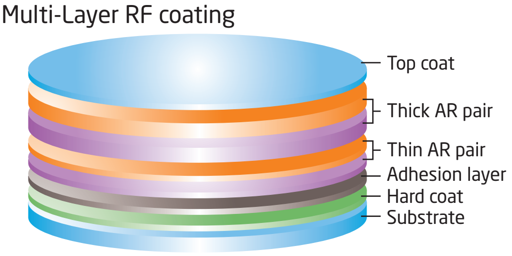

Figure 4 Multi-layer multi-functional coating

for a 1.5 index lens will have a refractive index of 1.22. A 1.7 index lens will require a coating with an index of 1.30 and a 1.9 index lens will require a coating with an index of 1.38. Magnesium fluoride (index 1.38) is often used to coat glass lenses. As a reflection-free coating, this material is obviously more effective when applied to high refractive index materials. If both of the path and amplitude conditions are satisfied, there will be little surface reflection, with most incident light energy passing through the surface, achieving close to 100 per cent transmission.

Simple RF coatings (Figure 3) can however only work for one specific wavelength of light, leaving strong residual reflections from other wavelengths to form a visible coloured reflex or bloom. To achieve a lower level of reflection across a wider range of wavelengths, multiple layers of differing indices are required. These layers, each in themselves must still retain the principles of wave-cancellation by having square root relationships to each other. Broadband multi-layer, reflection-free coatings are now common place and used by most lens manufacturers. One added advantage of this process is the improved cosmesis that multi-layer coatings offer as the coated lenses also appear less obvious to onlookers.

Manufacture

Reflection-free coatings are generally vacuum deposited using a vacuum coating machine, although dip coated, thermally cured single layer coatings are still available. Common materials used are silicon oxide (n=1.46), zirconium oxide, (n=2.0) and titanium oxide (n=2.3). Since the square root of 2.13 is 1.46, these materials are close enough to be used in pairs of layers, as they retain a square root relationship.

To produce a simple RF coating on a CR39 lens (n=1.498), a coating material of about n=1.22 would be needed, however in practice such a material is not available. To overcome this problem the substrate is first coated with a higher index material such as titanium oxide (n=2.3). A top layer of silicon oxide (n=1.46) can be applied, with both layers still conforming to the square root relationship. The glass-like silicon oxide also provides a hard, durable top layer, affording extra protection for the lens surface.

TABLE 3
UV light

UVA	400nm-315nm
UVB	315nm-280nm
UVC	280nm-200nm

Multi-layer multi-functional coatings

Modern coating technologies now permit lens manufacturers to apply a vast complexity of layers by combining various pairs of thick and thin layers along with a hardcoat, various adhesion layers and top coats. A low level of reflection is thus achieved over a wide range of wavelengths, creating a broadband reflection-free lens with glass like abrasion resistance, water and grease repellence, anti-static properties and a super smooth top surface (Figure 4).

A good quality multi-layer coating should have the following attributes:

- Low luminous reflectance
- Good scratch/abrasion resistance
- Good hydrophobic and oleophobic properties
- High degree of layer adhesion
- Good overall cleanability
- Good long-term durability
- Consistent reflex colour (Bloom).

Reflex colour

In most cases the reflex that is still visible from a RF coating will appear pale green or blue/green in nature. Many of the major suppliers have developed their own coating technologies and so the exact nature of this reflex differs from make to make. It can also differ slightly from batch to batch, even when from the same supplier and care should always be taken when ordering a single replacement RF-coated lens as the visible reflex may not always match exactly.

As we have discussed in previous articles, a considerable amount of marketing terminology is now employed by lens manufacturers to sell these premium coatings to both the profession and the public alike. It is vital that practitioners familiarise themselves with the particular attributes of various coatings so that they can recommend an appropriate coating to meet a client's needs.

Sun protection

The risks of exposure to excessive levels of visible light and ultraviolet radiation are well known and it is important that practitioners appreciate these risks when advising clients on suitable types of sun protection. UV radiation ranges from around 400nm to 200nm and is divided into three groups (Table 3). The corneal epithelium and conjunctiva absorb the wavelengths between 200 and 315nm (UV-C and UV-B), the lens nucleus and epithelium absorb the wavelengths between 295 and 400 nm (UV-A and part UV-B). Therefore most of the UV radiation is absorbed by the cornea and some by the crystalline lens, which results in photochemical damage.

When dark tinted lenses are worn, our pupils don't react to bright light in the same way, so if tinted lenses being worn fail to adequately block or reduce the level of UV energy entering the eye, damage may occur. It is therefore vital that any tinted lens incorporates an appropriate level of UV absorption.

BS 2739 part 8 defines the levels of UV that must be absorbed by tinted lenses:

- Pale tints – UV absorption should be reduced by at least the same proportion as the tint absorption
- Dark tints – UV absorption should be reduced by at least twice the tint absorption.

Some materials provide natural UV protection like polycarbonate and photochromic lenses, but for all other lens materials specification of an additional UV absorbing filter is essential when tinted lenses are to be ordered. Although some debate exists as to the exact boundary between visible light and UV it has become widely accepted to specify a UV absorbing filter of 400nm, commonly referred to as a UV400 filter. Activities that specifically benefit from UV protection include climbing and flying where UV increases by about 5 per cent for every 1,000 feet of altitude.

Tints

Spectacle tints are often considered to be a fashionable addition, but the functional applications of tints are far more important especially when they are used to enhance contrast for driving or sporting activities. Some examples are listed in Table 4.

Even when a tint is not required, the inclusion of a UV400 filter and RF coating should be considered, especially for aphakic clients, since the eyes' natural ability to remove UVA has been lost with the removal of the crystalline lens. Specifying a tinted lens with a UV400 filter has been shown to also benefit clients with these conditions:

- Early cataract
- Macular degeneration
- Diabetic retinopathy
- Glaucoma
- Aniridia
- Albinism
- Optic atrophy
- Corneal dystrophy
- Retinitis pigmentosa.

Tints for outdoor use especially when combined with a back surface anti-reflection coating to remove troublesome reflections have a wide variety of applications as shown in Table 4. Perhaps the most common use of tinted lenses is for driving. Contrast enhancement can certainly improve vision while driving, improving depth perception and the tracking of objects; however, care must be taken as there are legal restrictions which must be adhered to. ISO/CEN/BSI 14889 specifies the general transmission levels and particular restrictions applicable to certain classes of tint. These are given in Table 5.

Recognising the need for specialist driving filters, some lens manufacturers have developed specific contrast enhancing tints such as Essilor's Melanin tint and Zeiss's Skylet Road. As these tints are available across a range of lens options they offer the practitioner an opportunity to recommend a specialist driving lens to a wider group of clients. Some commercial sunglass manufacturers have also developed specialist driving ranges like Serengeti and Maui-Jim, both offering off-the-shelf ranges and an Rx service.

TABLE 4
Benefits of tinted lenses

Colour	Benefit	Application
Grey	Neutral colour reproduction that tends not to distort the integrity of colours	General sun protection
Green/grey	Neutral colour reproduction with some contrast enhancement	General sun protection Driving
Brown/amber	Improves contrast and depth perception by filtering blue wavelengths but colours are distorted. Good in bright, hazy and overcast conditions	Driving Sports - golf
Yellow	Contrast enhancement in poor light	Driving Cycling Sports - tennis and shooting Flying
Orange	Eliminates blue light to improve tracking of objects against a blue sky	Clay pigeon shooting Skiing Hunting
Red/orange	Contrast enhancement	Fishing
Red	Contrast enhancement	Fishing Clay pigeon shooting
Violet	Fashion tint but used for contrast enhancement in some activities	Athletics

Figure 5 Selection of tinted lenses

Manufacture

There are a number of ways in which a tint can be produced, depending on the lens material and level of production required. Glass mass production methods use a tint and UV blocker introduced during the moulding stage, forming a solid-coloured lens. For smaller quantities it is commonplace to vacuum coat the lens, although in both cases, the choice of colour can be limited. For the mass production of plastic lenses such as sunglasses, clear lenses with a built in UV blocker are cast and then tinted on mass, using carefully controlled slow penetrating dyes. For normal prescription work, faster penetrating dyes such as those found in many in-house labs, are used. However the results are often unpredictable, difficult to replicate and lack spectral accuracy. This method is also used to tint coatings where the substrate material itself cannot be tinted. Some manufacturers have developed laminating and bonding processes that allow wafer-thin tinted films to be bonded to or sandwiched within the lens, providing consistent colour accuracy and the opportunity to combine features like contrast enhancement, polarisation and photochromic elements within a single lens.

Photochromic lenses

Although very popular with clients, photochromic lenses should really only be considered as a compromise solution for sun protection. Because they rely on a reaction stimulated by UV radiation, their use is restricted primarily to the outdoors as many drivers will testify to their lack of performance inside a vehicle.

Photochromic lenses use specific molecules that appear transparent in visible light and the absence of UV radiation. When exposed to the natural UV in sunlight, the molecules undergo a chemical change in shape and absorb parts of the visible spectrum, appearing to darken. Traditionally, photochromic lenses have been manufactured by introducing substances such as silver chloride or silver halide during the moulding stage ▶

TABLE 5
CEN tint regulations

Class	Category	Usage	Transmission	Driving restrictions
0	Clear or very lightly tinted	Indoors or overcast	From 82 to 100%	No restriction
1	Light tint	Low sunlight	From 43 to 82%	Not suitable for night driving
2	Medium tint	Medium sunlight	From 18 to 43%	Not suitable for night driving
3	Dark tint	Bright sunlight	From 8 to 18%	Not suitable for night driving
4	Very dark tint	Exceptionally bright sunlight	From 3 to 8%	Not suitable for driving

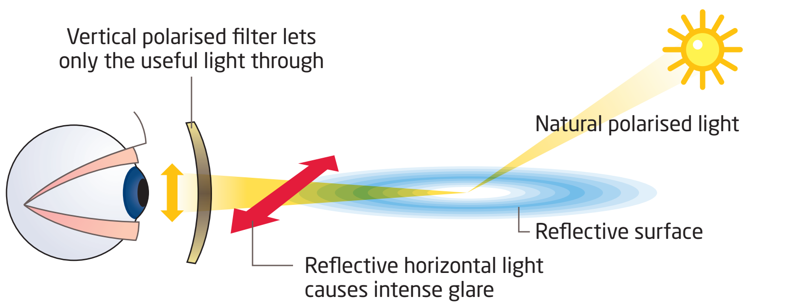

Figure 6 Polarising theory

to produce a solid glass or plastics photochromic substrate. Although still available in solid form, most photochromics are today manufactured using plastics materials and photochromic dyes that penetrate 100 to 150 microns below the lens surface to produce a consistent, even colour. When more complex surfaces such as Hoya's Hoyalux iD progressive are considered, a spin-coating process has been developed to create a uniformly even photochromic layer onto the free-form surfaces. Because of the variety in processes used in photochromic manufacture it is important to study the available data on each specific type, as they do exhibit subtly different performance characteristics.

Polarisation

Tinted lenses that incorporate a polarising filter offer further benefits to the wearer in addition to any tint and UV absorption. Light waves from any source vibrate and radiate outwards in all directions. However, if the vibrations are aligned onto one plane they are said to be polarised (Figure 6).

Most of the glare that prompts a client to ask for sunglasses comes from horizontal surfaces like wet roads, water and snow. Polarised filters are therefore set to an angle that blocks horizontally polarised light from passing through the lens, thus greatly reducing glare. They are manufactured using a chemical compound of molecules that are naturally aligned in parallel to each other. A thin film of this compound is then bonded, laminated to or sandwiched within the lens to form a uniformly even colour. Activities that benefit from polarised lenses include driving, sailing, skiing, fishing and flying.

Drivewear

A new development in both photochromic and polarising technology has come in the form of the Drivewear lens. Developed by Younger Optics and Transitions, this laminated lens form offers the first lightly tinted polarising filter combined with a new visible light photochromic and traditional UV photochromic element.

In overcast conditions only the pale yellow/green polarising filter (approximately 35 per cent LTF – Class 2 tint) is evident, providing glare reduction and contrast enhancement while driving. In brighter conditions, even though most windscreens filter out UV, the visible photochromic element will still darken and enhance reds and greens. Outside the vehicle the traditional UV photochromic element darkens the lens yet further to approximately 15 per cent LTF (class 3 tint).

Figure 7 Drivewear

Mirror coatings

One final aspect of sun protection worthy of note is that of mirror coating. Although the importance of UV absorption cannot be overstated, the luminous intensity of direct and indirect reflected sunlight should also be considered. Bright sunlight provides a luminance of approximately 100,000cd m² at the earth's surface. If viewed directly the intensity of this energy will cause rapid and permanent photochemical damage to the eye. Even if viewed indirectly, nearly 80 per cent is still reflected by snow and 10 per cent by water. Activities that can benefit from mirror coated lenses include skiing, sailing, climbing and flying.

Applied as a coated layer of reflective molecules on the front surface of a lens, a mirror coating will increase the surface reflectance and so avoid the need for a very low transmission tint that might otherwise adversely affect the wearer's visual acuity. A dark tint and/or polarising filter are normally specified at the same time. In recent years it has become fashionable to wear half-silvered or flash mirror coated lenses in either full or graduated form with a pale tint, especially on commercially available sunglass ranges, and many lens manufacturers also offer such coatings on their Rx ranges.

Vocational tints

Pale tints can be useful for indoor use, especially in office environments and other work places where natural daylight is poor, and fluorescent lighting is prevalent. Specialist tints like Norville's 'Dot Com' range have been developed in conjunction with RF coatings to filter out wavelengths which include much of the flicker created by fluorescent lamps.

Tinted lenses are also widely used in some vocations, utilising specific spectral filters to protect the eye. Examples of such applications include dentistry where orange UV550 and UV600 lenses are worn to shield the eyes from powerful UV lamps used to cure white fillings. Welders require even higher levels of UV absorption, combined with very low transmittance tints and glass blowers benefit from glass didymium lenses that block the yellowish light emitted by the hot sodium in glass.

Therapeutic tints

In recent years a number organisations have begun to develop and use specialist coloured filters to alleviate the symptoms of some conditions. Probably the most cited of these is the Irlen lens system, developed by Helen Irlen to remedy scotopic sensitivity syndrome. Colorimetry as it has become known, employs a series of tests and highly accurate, prescribed tints to alleviate various visual/perceptual disorders associated with dyslexia, autism and other developmental disorders. Psychological research has shown that certain coloured lenses have even been found to affect a wearer's mood or help with phobias like motion sickness and vertigo. Therapeutic lenses have also been prescribed for some years now to reduce the onset of photosensitive migraine, and although many therapeutic lenses are now available, there is still strong debate over their effectiveness and practitioners should be wary about prescribing such lenses without first seeking advice from experienced practitioners and organisations that specialise in those specific disorders.

Summary

When prescribed with care and reason, tinted lenses can considerably enhance both the wearer's vision and the functionality of their spectacles. The use of hard and RF coatings can further enhance the wearer's vision, increase the durability and improve the cosmesis of their spectacles, bringing happy clients back to the practice and providing added value to each dispense. ●

Further reading

Fowler C and Latham Petre K. *Spectacle Lenses: Theory and Practice*, Butterworth Heinemann Oxford UK, 2001.

Jalie M. *Principles of Ophthalmic Lenses*, 4th edition, The Association of British Dispensing Opticians London UK, 1984.

Jalie M. *Ophthalmic Lenses & Dispensing*, 3rd Edition Butterworth Heinemann Oxford UK, 2008.

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MULTIPLE-CHOICE QUESTIONS – take part at opticianonline.net

1 What is the most obvious effect of a variation in thickness of a hard coat?

A The hard coat becomes visible
B The hard coat peels from the lens surface
C Interference patterns become visible on the surface when the lens is AR coated
D Interference patterns become visible on the surface when the lens is tinted

2 Which of the following statements is most incorrect? A hard coat provides:

A Increased abrasion resistance
B Reduced surface reflectance
C Increased scratch resistance
D Reduced surface friction

3 Which hard coating method produces the least desirable results?

A Thermally-cured lacquer
B Vacuum deposited
C UV-cured lacquer
D Absorbed coating

4 The most troublesome ghost image is usually formed by?

A Total internal reflection at the lens surfaces
B Reflection at the back surface of the lens
C Reflection at the cornea and front surface of the lens
D Reflection at the front surface of the lens

5 Which of the following statements is most correct?

A Surface reflectance is not dependant on the refractive index of the material
B Greater surface reflectance occurs in high refractive index materials
C Greater surface reflectance occurs in low refractive index materials
D The surrounding medium has no effect on the reflectance of a lens surface

6 Which of the following statements is most correct? For the path condition to be satisfied:

A The thickness of the coating must be equal to the wavelength of incident light
B The refractive index of the lens material must be equal to the square root of the coating material
C The coating material must have a refractive index equal to the square root of the lens material
D The coating must be one-quarter of a wavelength thick

7 A lens of refractive index (n = 1.56) is to be coated with a single-layer RF coating. What refractive index would the coating material need to be in order to satisfy the amplitude condition?

A n = 1.56
B n = 2.43
C n = 1.25
D n = 2.90

8 Which of the following statements is most incorrect?

A Multi-layer RF coatings increase the long-term durability of a lens
B The reflex colour will always be exactly the same for a specific make and index of lens
C Modern multi-layer RF coatings reduce surface reflectance across a broad range of wavelengths
D Multi-layer coatings often exhibit oleophobic properties

9 Assuming normal incidence, the reflectance factor for a material with a refractive index of 1.65 in air is:

A 6.02 per cent
B 7.02 per cent
C 8.02 per cent
D 9.02 per cent

10 To satisfy the path condition for light of wavelength 550nm, which of the following must be the thickness of a single-layer AR coating of magnesium fluoride?

A 99.64nm
B 98.64nm
C 97.64nm
D 137.5nm

11 When dispensing lenses for the aphakic patient, which of the following types of UV radiation is of most concern?

A UVA
B UVB
C UVC
D All of the above

12 A 70 per cent absorption tint is to be specified on a new order. Which class of tint does this absorption represent and what advice should the client be given?

A Class 2 - not suitable for night driving
B Class 1 - not suitable for night driving
C Class 2 - not suitable for driving
D Class 3 - not suitable for night driving

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