OPHTHALMIC LENSES

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JAYPEE

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Ophthalmic Lenses

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My parents Mr Ashok Kumar Bhootra and Mrs Kamalesh Bhootra My late grandparents Sri Bhagwan Das Bhootra and Smt Shanti Devi Bhootra My beloved uncle Sri Radhe Shyam Bhootra Who have always been appreciating all my books

Tribute to Mr Sudershan Binani Mr Sarat Binani

A tribute to the essence of approach—the farsightedness and the elegance of business acumen.....

Everyday, every place and every occasion, they provide the perfect reason to think about business, talk about business and dream about business expansion.

I proudly pay a tribute to their elegance in approach.

We, at Himalaya Optical, are bound to see an evolutionary and stunning change which will change the structure of Optical retail and LASIK centers.

Ajay Kumar Bhootra

Preface

As we travel across the world, we see that numerous countries are still missing out on developments. We are fortunate to have almost all the latest developments in the field of ophthalmic lenses. The availability of wide range in the material and design of ophthalmic lenses has made it indispensable to understand the principles of optics behind them to understand their use and practical application. In developed countries, the newer developments in the lens design and material are immediately accepted irrespective of their cost and necessity. This kind of "ready to accept new development" approach is generally not seen in the countries which are on the brink of developments. In those places, the availability of wide range of products creates a typical situation for low income group who look for best at most economical cost. They need to be understood that technological developments are meant to cater to the increasing complexities of life and ever changing lifestyle. And products developed after extensive research and studies also carry the cost of research involved in it. This necessitates the need for detailed information about their technology and application.

Lots of new ophthalmic lenses have been introduced, but unfortunately there is a dearth of good books on this subject. This book is an effort to fill this gap. The need for a book that describes the choice of ophthalmic lenses has been already seen by the kind of acceptance given to author's first book Optician's Guide. But the information presented in this book is designed to provide comprehensive details about the ophthalmic lenses and their dispensing tips. Most of the information will replicate my 22 years of experience in the field of optical dispensing and will be helpful to the students of optometry. In addition, this book may also be of great help to ophthalmologists, opticians, ophthalmic lens manufacturers and all those who would like to excel in the field of optical dispensing.

Finally, it is hoped that the readers of this book will enjoy its simplicity and appreciate its organized presentation.

Ajay Kumar Bhootra

Acknowledgements

Essilor is the world's leading ophthalmic lens manufacturer and distributor. Year after year, Essilor continues to live out its corporate mission—"Helping the world see better by providing excellent vision through premium products and services". Technological advancements and exclusive training programs are the main cornerstone of their every product launch.

Essilor continues to bring innovation to life through research, advances in lens technology, and educational services to the eye care professionals. These three components set Essilor apart from its competitors and characterize Essilor as the world leader in ophthalmic optics. To me, Essilor has always been very humble and kind in sending me information and new ideas on ophthalmic lenses and allied services. Even this book also features lots of pictures, graphical representations and ideas supplied by them.

I firmly accept that I could not have completed this book without Essilor's support. Many thanks to Mr K Sugavanam, General Manager, Essilor Brand who has been so much cooperative to me.

I cannot end without acknowledging the support of Mr Chakravarthy, National Sales Manager, Beauty Glass, Essilor. I am highly indebted to them and the entire team of Essilor for their wholehearted support to me. Without their support, it would have been very difficult for me to transform the idea into a book.

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We live in a wonderful age where miracles can happen. The men and women who helped me write this book and getting it published are helping to create such a wondrous event.

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Basic Optical Principle

Ophthalmic lens theory is based upon the basic laws of Geometric Optics. The ophthalmic lenses are used to alter the path of light passing through it usually to correct some errors of the eyes. For theoretical calculations on ophthalmic lenses, light is assumed to travel in straight lines and that the incident light travels from left to right. It meets a surface that separates two media. What happens to the light, then, depends upon the nature of the surface and the two media on either side. In this chapter, we will consider these fundamental laws of physics and how they relate to the theory of spectacle lenses.

LAWS OF REFLECTION

Light travels in straight line until it meets a surface that separates the two media. When light meets the surface, its behavior depends on the nature of the surface and the two media on either side. Light may be absorbed by the new medium, or transmitted onwards through it, or it may bounce back into the first medium. The bouncing back of light into the incident ray medium is called Reflection of light. The light may reflect specularly if the surface is acting as true mirror or it may reflect diffusely, scattering it in all directions if the surface is incompletely polished. In case of specular reflection, the reflected light obeys the laws of reflection, which states that:

- 1. The incident ray, the reflected ray and the normal ray to the reflecting surface all lie in the same plane.
- 2. The angle of incidence equals the angle of reflection.

It follows from the laws of reflection that, when an object is placed in front of a plane mirror, the image formed by the mirror lies as far behind the mirror surface as the object lies in front. Also the straight line that joins the object and its reflected image is normal to the mirror surface (Fig. 1.1).



Fig. 1.1: Reflection at the plane surface

LAWS OF REFRACTION

Refraction is defined as the change in direction of light when it passes from one transparent medium into another of different optical density. The incident ray, the refracted ray and the normal – all lies in the same plane. The refracted light undergoes a change in velocity. The ratio of the velocities of light in the first and second media is called the relative refractive index between the media, which slows with denser medium. The absolute refractive index of a medium "n" is defined as the ratio of the velocity of light in vacuum to the velocity of light in the respective medium:

Refractive Index (n) = $\frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in the medium}}$

The Figure 1.2 illustrates a ray of light that is incident, in air at point D on the surface of a plane – solid glass block. The refractive index of the first medium (air) is denoted by n and the refractive index of the second medium (glass block) is denoted by n'. The angle of incidence that the incident ray makes with the normal to the surface at D is denoted by 'n' and the angle of refraction is denoted by n'. The laws of refraction (Snell's law) state that:

- 1. The incident ray, the refracted ray and the normal to the surface at the point of incidence all lie in one plane.
- The ratio of the angle of incidence, i, to the angle of refraction, i', is constant for any two media.

The most important application of this Snell's law of refraction is to determine the effect of prisms and lenses on the incident light, that is to determine the change in direction and the change in vergence produced by a lens.



Fig. 1.2: Refraction of light entering an optical dense medium from air

VERGENCE

Vergence is the term that determines the direction and power of light transmission. It is the wavefront of light of a particular position in a particular time. The vergence of light is defined by:

$$V = \frac{n}{L}$$

Where n = refractive index of the material.

L = the distance in accordance with the Cartesian Sign Convention.

Since the distance L_1 is measured from the wavefront and the light is traveling from left to right, it is a negative distance and the vergence is negative (divergent). L_2 is positive since it is directed to the right from the wavefront (convergent) (Fig. 1.3). Parallel light rays are said to have zero vergence. The unit to measure vergence is "dioptre". The change in vergence when the light encounters a refracting surface is equal to the power of the surface.



Fig. 1.3: Vergence is measured from the wavefront. Positive is in the direction of light travel

CURVATURE OF SURFACES

Most of the optical lenses have curved surfaces; the surface may be described as convex, if it bulges out of the material and concave if it is depressed into the material. Figure 1.4 illustrates a cross- sectional view of different curved forms. The measure of the shape of a curved surface is known as curvature. Spherical surface has uniform curvature in all its zones, whereas, surfaces other than spherical, the curvature varies in different zones and from one meridian to another.



Fig. 1.4: Forms of curvature

The curvature of a spherical surface can be read with a simple instrument called "spherometer", which measures the height of the vertex of the curve above a fixed chord (Fig. 1.5).



Fig. 1.5: Spherometer

The common form of spherometer normally available is the "Optician's lens measure" which is calibrated for a refractive index of 1.523 and gives the dioptre power of the surface directly. More accurate version of this simple lens measure is used in surfacing laboratory and is known as "Sagometers" (Fig. 1.6).



Fig 1.6: Sagometer

FOCAL POWER

The total power of a lens or lens surface to bend light is referred to as its focal power. Units of focal power are expressed as "dioptre" and are related to the focal length of the lens. The relationship between focal length and focal power can be expressed by the formula:

$$F = \frac{n}{f}$$

Where F = Focal power in dioptre.

- f = Focal length of the lens in metres.
- n = Refractive index of the medium in which the light is traveling.

Since, the spectacle lenses are always in air, the relationship can be simplified to:

$$F = \frac{1}{f}$$

THIN LENS POWER

In optical dispensing while calculating the power of the lens, the effect of the lens thickness is ruled out. The total thin lens power of the lens is the sum of its surface powers. For example, if a lens has a front surface power of + 8.00D and back surface power of - 4.00D, then its thin lens power is + 4.00D.



Fig.1.7: Various forms in which + 4.00D lens might be made

Theoretically, we could make + 4.00D lens in any form as shown in Figure 1.7 in which the first form has both sides convex surfaces and is known as biconvex lens form. The second form which has one plane surface is known as plano convex lens form. The other forms in the figure, each has one convex surface and one concave surface and are known as curved or meniscus lenses. In practice, modern lenses are curved in form. The surface power of a curved lens may be different at its two principal meridians, in which case the lower numerical surface power is taken as the base curve.

The relationship between the two surface powers F_1 and F_2 and the total thin lens power of the lens F is:

$$\mathbf{F} = \mathbf{F}_1 + \mathbf{F}_2$$

If the refractive index of the lens is denoted by 'n' and radii of curvature of the front and back surfaces are r_1 and r_2 respectively then the individual surface power is given by:

$$F_1 = \frac{n-1}{r_1}$$

And, $F_2 = \frac{1-n}{r_2}$

These two equations can be combined into the lens maker's equation: $F = (n - 1) (1/r_1 - 1/r_2)$

EFFECT OF THICKNESS ON LENS POWER

When the thickness of the lens is taken into account the actual power of the lens cannot be found from the simple sum of the surface powers, but it can be found by considering the change of vergence that the light undergoes after refraction at one surface and finally at the back surface. In case of a thick lens, the light after refraction from F_1 will have a chance to travel a given distance before reaching F_2 as it continues to travel through the lens thickness, it will have a slightly different vergence from when it left F_1 . It is this new vergence that F_2 alters to produce an existing vergence.

SIGN CONVENTION



Fig. 1.8: Sign convention

Light is assumed to be passing from left to right and the measurement taken in the course of light is taken as positive and the measurement taken against the course of light is taken as negative. All distances are measured from the vertex of the lens to the point in question. The sign convention is used to represent whether the corresponding surface is convex or concave (Fig. 1.8). It says that:

- Distances to the left are negative
- Distances to the right are positive
- Distances above the optical axis are positive
- Distances below the optical axis are negative.

Ophthalmic Lens Material and Design

Ophthalmic lens materials means all materials used during manufacturing, i.e. all materials entered into the composition of the basic ophthalmic lens. The end result is the specific lens geometry with specific topographical features, giving the lens its corrective function – what is referred to as lens design or form. All the ophthalmic lenses currently available in the ophthalmic industry are:

Glass material

2

Resin material

GLASS MATERIAL

When we consider raw glasses for spectacle lenses, we talk about a material which has been given a specific composition, shape and size for meeting its final application, i.e. refracting the rays of light and thereby improving the eyesight. Raw glasses for spectacle lenses possess all the necessary optical features but is not delivered in the form of a ready-to-use lenses. It is, in fact, a molding blank requiring certain finishing operations.

From an optical point of view, a spectacle lens is a medium aimed at directing light along a specific course and therefore, must possess specific optical properties. They are designed for day-to-day use under all conditions. This demands certain mechanical and chemical properties for comfort, safety and long lasting usage. Lastly, it calls for special manufacturing techniques which make allowance not only for the qualities demanded by spectacle lenses but also for economical production.

The components used for glasses for spectacle lenses are vitrifiable mixture which is put into the melting tank in the form of extremely pure raw materials so as to obtain perfect quality glass. The basic components such as silica and alumina are introduced in the respective forms of ironfree sand and feldspar.

The alkaline oxides (sodium or potassium) are generally added in the form of carbonates or nitrates. Lime and magnesia are sometimes replaced

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by limestone and dolomite. These basic components are accompanied by numerous other ingredients such as rare earths. The role of different components is:

Oxides

Oxides are used in the lens compositions primarily into two major categories:

- (a) Network Formative Oxides Network formative oxides are used at the base of any composition which could almost form a lens on their own. For example, SiO₂, B₂O₃, P₂O₅.
- (b) Modifier Oxides They are used to modify the basic properties contributed by formative oxides. These may range from viscosity to electric properties or from chemical resistance to coefficient of expansion. For example, K₂O, Na₂O, BaO.

According to composition, some oxides behave either as formatives or as modifiers. They are called intermediary oxides. For example, AI_2O_3 , ZnO, TiO_2 .

Refiners

Refiners have the basic function of eliminating gaseous inclusions (bubbles) in molten glass. Examples are Antimony Oxide, Alkaline Nitrates.

Colorants

Complete absence of colorants is essential to obtain clear 'white' glass. When added deliberately, they lead to selective absorption for each wavelength in the spectrum and so determine the tints. Example: Cobalt oxide gives rise to blue, Nickel oxides for brown.

The most common glasses currently popular in the industry for ophthalmic lenses are:

Crown

Crown is the most commonly used glasses for spectacle lenses. They belong to the family of the window glasses. They differ essentially through the choice of raw materials and certain additions of ingredients to adjust optical and physical properties. Their composition is characterized by high silica, lime and sodium. The extra white crown is very pure silica-based glass which is extremely transparent. Some crown glasses through the addition of metal oxides like nickel and cobalt show specific tints and absorbent properties.

Photo Chromic Glasses

Owing to the need for the glass to have the special properties of reaction to certain light radiation, the composition is more elaborate. The vitrifiable structure is extremely stable, i.e., a borosilicate with a high boron content to which is added a series of elements introduced to develop microcrystals of silver halide which are responsible for the photochromic phenomenon.

High-Index Glasses

Lead oxide has been traditionally included in the glass composition to produce high index glasses. This produced "flint" glass. Today, for high refractive index glass lead oxide is replaced by titanium oxides, thus preserving high index while reducing glass density. Certain other elements such as niobium, zirconium and strontium are also included for adjusting optical properties.

To obtain an improved range of segment glasses for fused multifocals, lead oxide is replaced by barium oxide.

RESIN MATERIAL

Resin lenses are made up of small molecular units called monomers which link together to form long chain known as polymers and the process of linking the monomers together is known as polymerization. There are two processes to make resin lenses:

- 1. Thermosetting
- 2. Thermoplastic.

Thermosetting and thermoplastic differ basically in the lining up of the molecules in their structure (Figs 2.1A and B). Thermosetting are crosslinked molecular structure, resembles a ladder with extra rungs. They do not melt or flow when heat is applied and makes the material less flexible.



Figs 2.1A and B: (A) Thermoplastic (B) Thermosetting

Therefore, allows for superior optical processing. CR_{39} is the good example. Most hi-index resin lenses are made by thermosetting process. The monomer liquid is poured into a mould where chemical process of polymerization takes place to form a solid material.

Thermoplastic are not cross-linked molecular structure. Molecular chains are independent of each other, looks like a ladder without rungs. Optically they are not so stable during process. They soften under heat and therefore, good for injection molding process. They are very sensitive to abrasion. Polycarbonates are the good examples.

Currently following resin materials are popularly available in the ophthalmic lens industry:

CR₃₉

 CR_{39} is thermosetting resin, 'i.e. in its basic form it is liquid monomer which is hardened by polymerization under the effect of heat and a catalyst. Diethylene glycol bis, better known as CR_{39} (1) is the material most widely used to manufacture currently marketed plastic lens. It was discovered during forties by chemists from the "Columbia Corporation", hence, its name "Columbia Resin # 39. The refractive index of CR_{39} is 1.498, which is close to standard crown glasses, specific gravity is 1.32 gram/cm³ and abbe value is 58, ensuring low chromatism. The material is highly impact resistant and carries high transparency. Multiple tinting and coating is possible. Only drawback is weak resistant to abrasion.

Polycarbonate

Polycarbonate is a relatively old material, but its use in ophthalmic optics has grown over the past few years. It is linear polymer thermoplastic with an amorphous structure. It is atleast ten times more impact resistant than CR₃₉. A high refractive index of 1.586 makes it comparatively thinner. Specific gravity of 1.20g/cm³ makes it very light in its weight. The material has efficient protection against ultra violet rays. Abbe value is 30, which is significantly low for good optical performance. The material is very soft in nature and hence prone to scratches. Tinting is relatively difficult with polycarbonate lens material which is usually obtained by impregnating a tintable scratch-resistant coating.

Trivex

Trivex is a partially cross-linked material and uses the best attributes of thermoplastic and thermosetting processes. The result is the superior impact resistance with superior optical performance. The refractive index is 1.53 with a specific gravity of 1.11 gm/cm³ make the lens thin and light. Probably

this is the only lens which is best for rimless frame. Abbe value is 45 and the material has 100% UV protection property. It can be easily tinted and coated with anti-reflection coating.

PROPERTIES OF OPHTHALMIC LENSES



Fig. 2.2: Incident light on an ophthalmic lens

When a beam of light falls on a lens surface, some of the light passes through the lens, some of the light is reflected from the lens surface and some of the light is absorbed by the lens material (Fig. 2.2). The measure of the proportion of light reflected from the surface is called reflectance. The measure of proportion of light absorbed is the absorption and the measure of the proportion of light transmitted is the transmittance. Each one is expressed as a fraction of the total quantity of light in the beam. If the intensity of the beam of light is represented by the number 1, reflectance by R, absorption by A and transmittance by T, the intensity may be expressed as follows:

$$\mathbf{R} + \mathbf{A} + \mathbf{T} = 1$$

The aim of the ophthalmic lenses is to restore clear vision to an ametropic eye by placing a corrective lens between the viewed object and the eye and the dioptric function of the lens depends on the characteristics of the lens material. Extensive knowledge of the properties of these materials is, therefore, needed in the following areas:

- 1. Optical properties
- 2. Mechanical properties

- 3. Electrical properties
- 4. Chemical properties
- 5. Thermal properties

Optical Properties

Optical properties are essential properties of the ophthalmic lens material to calculate the dioptric function and control of optical performance. These properties describe the following features of the lens material:

Abbe Value

Abbe value is the number that is the measure of the degree to which light is dispersed when entering a lens material. Dispersion stands for the amount that the material spreads out the different wavelengths of light passing through it. Abbe number represents the relative degree of distortion generated while looking through off centre area of the lens. The lower the abbe number, the greater the dispersion of light, causing the chromatic aberration in the periphery of the lens. The higher the Abbe number, the better the peripheral optics. Abbe number of 60 is considered to have the least chromatic aberrations and abbe number of 30 is for the most chromatic aberrations.

When the wearer moves the eyes away from the centre and looks through the periphery of the lens, the prism is created. The amount of prism created together with the dispersion value of the lens material affects the amount of "colour fringes" the wearer sees.

Abbe value is the property of the lens material and can not be affected by any surface technique. Generally higher the index of refraction, the lower the Abbe value, but this is not a linear proportion. Lenses of the same index can have somewhat different Abbe value. Standard plastic lenses have an abbe value of 58. Most high index materials have a much lower Abbe value. However, the effect of dispersion can be minimized by correct cent ration and by reducing the vertex distance, putting the edges of the lens farther from the normal line of sight.

Reflectance

Reflectance is the phenomenon of light reflection occurs at each of the lens surfaces. The result is the loss of lens transparency and undesirable reflections on the lens surfaces. The reflectance of the lens surface is calculated from the refractive index of the material. When the light is normal on the lens surface, the percentage of light reflected at each surface is given by:

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

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

100(1.5 – 1) ² / (1.5 + 1)² Or, 100 (0.5)² / (2.5)² Or, 100 × (0.5 / 2.5)² Or, 3.9 % per surface.

The higher the refractive index, the greater the proportion of light reflected from the surfaces. The unwanted reflection can be almost completely eliminated by applying an efficient anti-reflection coating, the need of which is more in higher index material.

Refractive index	% of light reflected
1.5	7.8%
1.6	10.4%
1.7	12.3%
1.8	15.7%
1.9	18.3%

Absorption

The amount of light which goes through a lens can be reduced because of absorption by the lens material. This is negligible in case of a non-tinted lens, but constitutes an intrinsic function of a tinted or photochromatic lens. Absorption of an ophthalmic lens generally refers to its internal absorption, i.e. to the percentage of light absorbed between the front and the rear lens surfaces. Lens absorption occurs according to Lambert's law and varies exponentially as a function of lens thickness.

Refractive Index

The refractive index of a transparent medium is the ratio between the velocities of the light in air to the velocity of light in the given medium and is denoted by 'n'.

 $n = \frac{\text{Velocity of light in air}}{\text{Velocity of light in the medium}}$

This is a number, which has no unit and is always greater than 1. When the light passes from air to, say glass, i.e. rare medium to denser medium, the speed of their propagation slows down. How slowly they pass through the various transparent material is called the index of refraction of that material. Refractive index of material describes the ability to bend light. The higher the index of the material, the more it is able to bend light. A higher index of refraction results in a lower angle of refraction which means the bent light ray comes closer to the normal (perpendicular) line. In other words, for a given angle of incidence, the higher the index, the more light is bent. That is why "high index" lenses can be thinner for a given prescription compared to the lower index lenses although the reduction is not quite pro-rata (Fig. 2.3).

As the velocity of light in a transparent medium varies with wavelength, the value of the refractive index is always expressed for a reference wavelength. In Europe and Japan, this reference is ne ... 546.1 nm (mercury green line), whereas in other countries like USA it is nl ... 587.6nm (helium yellow line). The problem that this can cause is that a lens manufacturer may calculate the surfacing curves for a lens base on one refractive index, while the user may measure the same lens on a focimeter calibrated for another. But the difference only changes the 3rd decimal of the value of the index. So in fact it has no real effect.

An index over 1.74 can be described as "a very high index", 1.54 to 1.64 as "mid index" and anything lower is "normal index" if we assume that nothing less than 1.498 will be dispensed.



Fig. 2.3: Edge thickness reduces in high index concave lenses

Mechanical Properties

Mechanical properties define values relative to mass, volume and dimension, and resistance to deformation and shock.

Specific Gravity

Specific gravity is the measurement of physical density or weight of the material in grams per cubic centimeter. In designing light weight lenses,

a lens material with low specific gravity will produce a lighter lens. Reduction of weight improves wearing comfort, and eliminates the indentations from nose pads that are produced by wearing heavy glasses. However, low density does not always mean a lighter lens – the amount of material depends on the refractive index and the minimum thickness. But low specific gravity is very important for prescriptions that require high powered plus or minus lenses. Patients with high power prescriptions are usually advised to use higher index glasses. Although they offer thinner lenses, they are not necessarily more comfortable to wear because of their high specific gravity. The following table shows the specific gravity of various lens materials:

Material	Refractive Index	Specific Gravity
Polycarbonate	1.590	1.20 Gram/cc
CR ₃₉	1.498	1.32 Gram/cc
Crown glass	1.523	2.54 Gram/cc
High index glass	1.60	2.63 Gram/cc

Impact Resistance



Fig. 2.4: Drop ball test for impact resistance

In 1971, the Food and Drug Administration (FDA) adopted a procedure to ensure the level of protection provided to the consumer for "street wear". More stringent standards are applied for industrial protection. The standard involves dropping a 5/8" steel ball from a height of 50" onto the lens and the lenses that survive this test are deemed impact resistant. The implementation of this standard in the USA led to increased use of hard resin lenses. Only a sample of hard resin lenses is needed to be tested for impact resistance, whereas every glass lens is needed to be tested. This accelerated the shift towards the plastic lenses (Fig. 2.4).

Scratch Resistance

One of the straight features of glass lenses is abrasion resistance. Plastic lenses need to be coated with an additional resin to approach the scratch resistance of glasses. These resin coatings can be applied in a number of ways. Lenses may be dipped, or a thin layer of resin may be spun onto the lens surface. These coating layers are usually 5 micron thick.

While abrasion resistance is an important property for spectacle lenses, it is not crucial to the normal use of the product. Appropriate education of patients can assist them in avoiding situations where abrasion resistance becomes important, especially since the majority of scratches are put into the lenses by wearers themselves.

Initially plastic lenses were made from polymethylmethacrylate, which has poor abrasion resistance. A variety of other plastics and coated plastics have been used in the past 40 years, with scratch resistance steadily improving as the results of research and development are applied. These advances will continue and in near future, it is predicted that the abrasion resistance of plastic will get even closer to that of glass.

Electrical properties characterize effects of electromagnetic waves and electricity on the materials. Thermal properties state changes of state and the effect of temperature on materials. And chemical properties shows the reaction of materials to the chemical substances usually found during lens manufacture, in every day life, or to certain extreme conditions to which materials can be subjected. These substances are usually hot or cold water, acids and organic solvents. Therefore, a hypothetical ideal lens material from both the patient's and practitioner's point of view – a high refractive index with low dispersion, unbreakable, unscratchable, low density, available with aspherical surfaces in all multifocal form, easy to tint and to add "inexpensive", and from the financial point of view, we do not really want them last forever. Unfortunately, there is no lens material that fits this description, and we have to use compromise.

CURVE VARIATION FACTOR

Curve variation factor shows the variation in surface power when the lens material is other than crown glass. It is useful to know the likely change in the volume and thickness which will be obtained when another material is compared with the standard crown glass. This information enables a direct comparison in the thickness to be obtained. For example, 1.70 index materials have a CVF of 0.75D, which will be about 25%, if this material is substituted for crown glass. For a given refractive and a standard index, the CVF is given by:

$$CVF = \frac{Ns - 1}{Nr - 1}$$

Where, Ns = refractive index of standard lens material.

Nr = refractive index of substituting lens material.

CVF in above example would be:

$$CVF = \frac{1.523 - 1}{1.70 - 1}$$
$$= \frac{0.523}{0.700}$$
$$= 0.747 D$$
$$= 0.75 D \text{ approx.}$$

Alternatively, if we know the CVF, we can use the same 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, to make – 10.00D in 1.70 index lens, the crown glass equivalent would be $0.75 \times -10.00D$, i.e., – 7.50D. In other words the use of 1.70 index material would result in a lens that has a power of – 10.00D, but in all other respect looks like a – 7.50D lens made in crown glass.

OPHTHALMIC LENS DESIGN

The goal of ophthalmic lens design is to give the patient clear vision at all distances through any portion of the lens. The lens designer has a very limited degree of freedom. Practical condition specifies lens materials, safety consideration fixes lens thickness; fashion dictates lens position before the face, weight and cosmesis means only two lens surface can be used. In addition various mechanical and optical factors impose further on the difficulties while designing the ophthalmic lenses. The primary responsibility of the lens designer is to design a lens which provides maximum dynamic field of vision for the patient through all its portions.

The basic lens design is determined by the "base curve selection". The base curve of the lens is the surface that serves as the basis or starting point from where the remaining curves will be calculated. It affects the wearing comfort of the patient and is the least understood principle of refractive optics. The concept of base curve is little confused in ophthalmic optics because of its innumerable definitions.

A dispenser defines the term "base curve" as the singular curve on the front side of the lens which he measures with the lens measure watch. He is most often guided by such measurement before beginning to work on the new prescription since this will dictate the curves that must be placed on the ocular surface to derive the proper prescription.

In case of semi-finished blanks the manufacturer is responsible for creating and finishing the front surface and from the front surface so created

the laboratory calculates the variables needed to grind the back surface and thus creates the finished lens with the given prescription. The manufactured front surface is defined as base curve.

In the earliest days, when the lenses were very simple, they were only ground as sphere. But with the advancement in the lens design, toric cylinder grinding was introduced. The type of lens produced was called cylinder lens, the two principal meridians of curvature were ground on the front side of the lens. The flatter of these two principle meridians of curvature was referred to as the base curvature of the toric surface (Figs 2.5 and 2.6).

Sometimes in early 1970s, the industry saw a dramatic change in the frame style. Consequently, bulgy front surface of the plus cylinder was found unsuitable. The hand edgers were pushing the vee bevel back and forth to achieve a good fit. The introduction of more automated system of



Fig. 2.5: Plus cylinder



Fig. 2.6: Minus cylinder

edging commanded the industry to move the cylinder grinding to the back side. With minus cylinder grinding in place the single curve on the front of the lens became to be known as the base curve and the back side curves are known as ocular curves. This is now universally accepted definition of the base curve.

The base curve of a lens may affect certain aspects of vision, such as distortion and magnification, and the wearer may notice perceptual difference between lenses with different base curves. Moreover, the wearer will adjust to these perceptual changes within a short span of time. That is the reason why some practitioners go with the idea of "match base curve" theory on the new prescription. There are certain exceptions to this rule. Some wearer with long eyelashes may be fitted with steeper base curves in order to prevent their eyelashes from rubbing against the back lens surface when their vertex distance is small. Additionally, some wearer with significant difference in prescription between right and left eyes may suffer from aniseikonia, or unequal retinal image size. Such case may require unusual base curve combinations in order to minimize the magnification disparity produced by the difference in the lens power.

Since the power of the lens can be produced by infinite range of lens forms, choosing one base curve over another needs an extensive mental exercise on the following two factors:

- 1. Mechanical factors
- 2. Optical factors

Mechanical Factors



Fig. 2.7: Lens curvature

The maximum thickness of a lens, for a given prescription, varies with the form of a lens. Flatter lens forms are slightly thinner than the steeper lens forms, and vice versa. Since the thinner lenses have less mass, they are lighter in weight as well. In addition to lens thickness, varying the lens forms will also produce significant difference in the sagittal depth or overall bulge. Plus lenses with flatter form do not fall out of the frame, which is very important with large or exotic frame shapes (Fig. 2.7). Flatter lenses are cosmetically more appealing. Flatter lens in plus power is also associated

with reduction in magnification and in minus power reduction in minification. This gives the wearer's eyes a more natural appearance through the lens.

Optical Factors



Fig. 2.8: Categories of lens form

The mechanical factors for base curve selection clearly establish the advantage of the flatter lens. But the principal impetus behind the ophthalmic lens designing is their optical performance, not the cosmetic appearance. If the lens is designed flatter to make it look cosmetically appealing, it may perform optically poor. The whole idea behind choosing a correct base curve is to provide wider dynamic field of clear vision. Vision through the centre of the lens may be relatively sharp, no matter whatever the lens form is, it is the vision through the periphery of the lens that will be greatly affected. However, the lens designed as the best form lens will not only look good , but will also minimize the disturbing lens aberration and will improve their off-axis performance, thereby ensuring the wider field of vision. If the lens looks good but performs poorly, it is bad lens. The patients vision should always be held in highest regard. It is, therefore, important to balance optics with cosmesis while selecting the best form lens (Fig. 2.8).

The first step while selecting the correct base curve is to check the base curve of the existing glasses before fabricating a new set of lenses, if the patient is using any. Since the base curve will dictate the curves that must be placed on the ocular surface to derive the proper prescription, it is imperative to note the curves that the patient is currently wearing. If the patient is comfortable with the existing lenses and the new prescription is



Fig.2.9: Lens form comparisons

within a range of + or - 1.00D, then the base curve should generally be duplicated in the new pair of lenses. If the prescription is noticeably different, a slight adjustment in the base curve may be suggested (Fig. 2.9).

While selecting a new base curve for a new wearer or adjusting the base curve of an existing wearer, it is important to understand how the selection of a curve will affect the finished product. Under ideal circumstances, a spectacle lens would reproduce a perfect image on the retina. However, this is not always the case. The lens designer has to deal with varieties of aberrations which prevents perfect image through the lens. There are six types of aberrations that prevent perfect imaging through the spectacle lens:

- 1. Chromatic aberration
- 2. Spherical aberration
- 3. Coma
- 4. Marginal aberration
- 5. Curvature of field
- 6. Distortion

Chromatic aberration is caused because shorter and higher energy wavelengths are bent more readily and to a greater degree than the longer and lower energy wavelengths. The lens designer must deal with this kind of aberration by selecting a lens material with low dispersive value.

Spherical aberration results in a slight blurring of the image due to lenses having the tendency to focus the light rays from the periphery sooner than the rays passing through the central portion of the lens. This results in separate foci which prevent a sharp clear image on the retina. But in general spherical aberration is not a great problem to the lens designer as the small pupillary size is effective in keeping out its effect. Coma is produced when wider beam of light passes obliquely through the lens. Depending upon the angle of incidence, the rays at the lower end of the beam will bend a different degree than rays at the upper end. This causes uneven magnification and degrades and defocuses the image. Like spherical aberration, the small aperture of the pupil is effective in limiting the aberrant peripheral rays. Consequently, the lens designer pays little attention to this particular aberration.

Marginal astigmatism is a real concern for the lens designers as it involves narrow beam of parallel rays that strike the lens at an oblique angle. Pupil does not limit the effect of marginal astigmatism. When a narrow beam of light rays strike a lens obliquely, there is a tendency for the rays in the opposite meridians to focus at different points. The distance between the two points of focus equals the degree of astigmatism created. The presence of astigmatic error led the lens designer to work upon corrected curve theory. The idea was if the specific curvature can be controlled for specific correction, the effect of marginal astigmatism can be reduced. Such lenses are known as "best form lens", and they are usually in meniscus form.

The curvature of field refers to the phenomenon that the eye viewing an object through a lens does not create a true reproduction of the object. A flat plane may appear to look slightly curved. The effect is dependent upon the refractive index of the lens material and the curvature of the lens surfaces.

Distortion occurs when an extended object is viewed through the periphery of the spherical lens. The edges of the object are distorted. This is due to the increased prismatic effect of the lens periphery which produces uneven magnification of the object. A strong concave lens causes "barrel distortion", i.e., outward bulging, whereas a strong convex lens causes "pincushion effect". These effects prove a real nuisance to the wearer of high power spectacle lens.

The lens which is centered perfectly and also fits closer to the eyes and is able to keep the patients vision within the central area of the lens reduces most of the troubles of these aberrations. Such a procedure may enable us to control some of the aberrations, but not all. Moreover, the lens designer does not try to concentrate on eliminating lens aberrations, but he intends to find a formulation that balances them out to reduce their effect. The science of creating the proper optical balance is referred to as "corrected curve theory" (Fig. 2.10). The corrected curve theory is the best form lens for a given prescription. Each lens designer has a slightly different application of the optical principles that control and balance the six lens aberrations. It is out of this optical reality that the theory of base curve selection has its application. Lot of mathematical computations are needed



Fig. 2.10: Corrected curve theory

to determine the most suited base curve to the prescription. The computations are based on delivering the best optics in any given situation and not just creating the flattest profile. A flatter lens may look good, but the wearer may complain about compromised optics. Corrected curve theory outlines an effective method for minimizing the effect of lens aberrations. Only one combination of curves will yield the best form and will focus light to the clearest image by eliminating the most amounts of lens aberrations, and if the dispenser combines proper base curve along with good fitting and perfect optical centre, the result is good cosmetics and great optics.

There are many Corrected Curve Theories. The ellipse, a graphical representation developed by Marcus Tscherning shows the best base curve for every prescription to minimize marginal astigmatism. It says that there is a range of power from about -23.00D to about +7.00D that can be made free from particular aberration. Outside this range there is no perfect base curve. He demonstrated that there are two recommended best form base curves for each lens power. Tscherning's ellipse is the locus of points that plot out the recommended front curves for each lens power. The two curves are "Ostwalt bending" which is flatter form and "Wollaston bending" which is the steeper form. The flatter form is most commonly employed today. Wollaston is a deep curve form and is difficult to produce. For example–5.00D lens requires a back surface power in the region of –9.50D in Ostwalt form, whereas the Wollaston form needs a back surface power in the region of – 22.00D, made with a lens of 1.523 refractive index.

Another method for matching the best curve for a given lens comes in the form of Vogel's Formula. When selecting the proper base curve for a given prescription it is important to follow some rules. Keep basic prescriptions (+ 1.50D to - 1.50D) on 6.00 dioptre base curve and adjust

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higher powers in plus to steeper front curves and while moving greater minus powers to flatter front curves.

The rule of thumb for selecting an appropriate base curve is take the spherical equivalent of the given prescription, if it is plus – add + 4.00 to that power to get a good approximate base curve. If it is minus – add + 8.00 to that power to get a good approximate base curve.

Example—Given prescription + 4	4.00Dsph + 1.00Dcyl × 90
5	Spherical equivalent + 4.50D
J	Base curve $+ 4.50 + (4.00) = + 8.50D$
Given prescription –	4.00Dsph – 1.00Dcyl × 90
S	Spherical equivalent – 4.50D
J	Base curve $(-4.50D) + 8.00 = +3.50D$

However, while selecting a proper base curve, it is necessary for the dispenser to utilize knowledge of theory, practical availability and common sense. To simplify the concept further we can say that as minus power increases the selection of base curve flattens and as plus power increases selection of base curve steepens. Care has to be taken when changing the lens material from lower index to higher index material. In order to do a professional job, the dispenser must monitor all the options and then make the decision:

- 1. Determine the old prescription.
- 2. Determine the old curve what the wearer is used to.
- 3. Evaluate the new prescription in accordance with theoretically ideal curve.
- 4. Determine the best lens design and availability.
- Check that the design could be fabricated by the laboratory or not. Basically the gist is "just pay attention".

SUMMARY

All these current base curve theories are based on spherical lenses, and they do not apply to the thinner and flatter aspheric designs that are becoming a staple in today's industry. This enables the lens designer to use the combination of bending and asphericity to be employed to improve the off-axis performance. As a result, the designer can choose any form for a given power and then determine the asphericity required for that particular choice of bending to eliminate oblique astigmatism. 3 Spherical Lenses

A lens is defined as a portion of a refracting medium bordered by two curved surfaces which have a common axis. When each surface forms a part of sphere, the lens is called a spherical lens. There are various forms of spherical lens, some of them also have one plane surface. This is acceptable because a plane surface can be taken as part of a sphere with infinite radius. (Fig. 3.1)



Fig. 3.1: Basic forms of spherical lens
Spherical surfaces are either convex or concave. A convex lens causes convergence of incident light, whereas a concave lens causes divergence of incident light (Fig. 3.2).



Figs 3.2A and B: Light passing through a lens obeys Snell's Law at each surface (A) Convex lens, (B) Concave lens

The total vergence of a spherical lens depends on the vergence power of each surface and the thickness of the lens. Since, most of the lenses used in ophthalmology are thin lenses, thickness factor is ignored (Fig. 3.3). Thus, the total power of a thin lens is the sum of the two surface powers. Refraction can be thought of as occurring at the principal plane of the lens. In Figures 3.4A and B principal plane of the lens is shown as AB. The point at which the principal plane and the principal axis intersect is called the principal point or nodal point, of the lens which is denoted by N. Rays of light passing through the nodal point is undeviated. Light rays parallel to the principal axis is converged to or diverged from the point F, the principal focus (Fig. 3.5).



Figs 3.4A and B: Cardinal points of thin spherical lenses (A) Convex (B) Concave



Fig. 3.5: The principal foci of thin spherical lenses

Since, the medium on both sides of the lens is the same, i.e., air, parallel rays incident on the lens from the opposite direction, i.e., from the right in Figure 3.4 will be refracted in an identical way. There is, therefore, a principal focus on each side of the lens, equidistant from the nodal point. The first principal focus F_{1} , is the point of origin of rays which, after refraction by the lens, are parallel to the principal axis. The distance F₂N is the first focal length. Incident rays parallel to the principal axis is converged to or diverged from the second principal focus – F_2 . The distance F_2N is the second focal length. By the sign convention, F₂ has a positive sign for convex lens and negative sign for the concave lens. Lenses are designed by their second focal length. Thus, the convex or converging lenses are also called "Plus Lenses" and are marked with "+", while concave or diverging lenses are also called "Minus Lenses" and are marked with "-". If the medium on either side of the lens is the same, i.e. air, then $F_1 = F_2$. However, if the second medium differs from the first, e.g. in case of contact lenses, then F₁ will not be equal to F_2 .

DIOPTERIC POWER OF LENSES, VERGENCE

Lenses of shorter focal length are more powerful than lenses of longer focal length. Therefore, the unit of lens power, the diopter, is based on the reciprocal of the second focal length expressed in metres, gives the vergence power of the lens in diopters (D).



Figs 3.6A and B: Vergence of rays

Thus, $F = 1/f_2$

Where F = Vergence power of lens in dioptres.

 f_2 = Second focal length in metres.

So, in the above Figure 3.6A vergence at the lens is:

F = 1 / 0.25 = 4.00 D.

And in Figure 3.6B vergence at the lens is:

F = 1 / 0.10 = 10.00 D.

A converging lens of second focal length + 5 cm has a power of + 1/0.05 or + 20.00D, and a diverging lens of second focal length 25 cm has a power of -1/0.25 or -4.00 D.

SPHERICAL LENS DECENTRATION AND PRISM POWER

Rays of light incident upon a lens outside its axial zone are deviated towards (Convex lens) or away from (Concave lens) the axis. Thus, the periphery portion of the lens acts as a prism. The refracting angle between the lens surfaces grows larger as the edge of the lens is approached (Fig. 3.7). Thus, the prismatic effect increases towards the periphery of the lens. Use of paraxial portion of a lens to gain a prismatic effect is called decent ration of the lens. Lens decent ration is frequently employed in spectacles where a prism is to be incorporated. On the other hand, poor centration of spectacle lenses, may produce an unwanted prismatic effect. The prismatic power of the lens is given by the formula:

$$P = D / d$$

Where, P = Prismatic power in prism dioptre.

D = Deviations produced by lens in cms.

d = Distance in metres.

The increasing prismatic power of the more peripheral parts of a spherical lens is the underlying cause of spherical aberrations.



Fig. 3.7: Prismatic deviation by spherical lenses

DETECTION OF SPHERICAL LENS

It is possible to determine the spherical lens by studying the image formed when two lines crossed at 90°, are viewed through the lens. Spherical lens causes no distortion of the cross. However, when the lens is moved from side to side and up and down along the axis of the cross, the cross also appears to move. In the case of a convex lens, the cross appears to move in the opposite direction to the lens, termed as "against movement", while a movement in the same direction termed as "with movement" is observed if the lens is concave (Fig. 3.8). Rotation of a spherical lens has no effect upon the image of the crossed lines. The power of a lens can also be found using the neutralization method. Once the nature of the unknown lens is so determined, lenses of opposite type and known power are superimposed upon the unknown lens until a combination is found which gives no movement of the image of the cross line when the test is performed. At this point the two lenses are said to "neutralize" each other and the dioptric



power of the unknown lens must equal that of the trial lens of opposite sign, e.g, a + 2.00 D lens neutralizes a – 2.00 D lens. To measure this accurately, the neutralizing lens must be placed in contact with the back surface of the spectacle lens. However, with highly curved lenses, this is not possible and an air space intervenes. It is, therefore, better to place the neutralizing lens against the front surface of the spectacle lens. Neutralization is, thus, somewhat inaccurate for curved lenses of more than about 2.00D. An error of up to 0.50D may be possible with powerful lenses. Nevertheless for relatively low power lenses, neutralization is still a very useful technique.

The Geneva lens measure can be used to find the surface powers of a lens by measuring the surface curvature (Fig. 3.9). The total power of a thin lens equals the sum of its surface powers. However, the instrument is calibrated for lenses made of crown glass and a correction factor must be applied in the case of lenses made of materials of different refractive indices.

Focimeter is used to measure the vertex power of the lens. The image of the target is seen as a ring of dots when a spherical lens is tested (Fig. 3.10).







Fig. 3.10: Target as seen in Focimeter



In an astigmatic lens, all the meridians do not have the same curvature and a point image of a point object cannot be formed. The lens effectively gives a minimum power in one direction, gradually changing to a maximum power in the other, at right angle to the first. These meridians of minimum and maximum power are referred to as the principal meridians of the lens. There are two types of astigmatic lenses, namely cylindrical and toric lenses.

CYLINDRICAL LENSES (FIG. 4.1)

Cylindrical lenses have one plane surface and the other curved surface forming the part of a cylinder. Thus, in one meridian the lens has no vergence power which is known as the axis of the cylinder. In the meridian at right angle to the axis, the cylinder acts as a spherical lens. The total effect is the formation of a line image of a point object. This is called focal line. It is parallel to the axis of the cylinder (Fig. 4.2).



Fig. 4.1: Cylindrical Lens



Fig. 4.2: Image formation by convex cylindrical lens of point object O

NOTATION FOR CYLINDER LENSES AND ORIENTATION OF AXIS



A lens with purely cylinder power would be described as, say – 4.00Dcyl (diopter cylindrical) in order to differentiate from the spherical one, which is described as – 4.00Dsph (diopter spherical). As cylindrical surface is not rotationally symmetrical about the midpoint, a notation is required for their positioning in front of the eye. This is achieved by specifying the angle between the axis of symmetry of the cylinder and the horizontal. The universally used "standard" axis notation uses a protractor that reads anticlockwise when looking at the face of the lens wearer. Angles upto 180 are



Fig. 4.4: Standard axis notation

used for the axis of cylinder, the full 360° protractor is only required for the base direction of prism. When describing a horizontal cylindrical axis, it is conventional to use the angle 180°, rather than zero. The orientation of cylindrical axis is opposite the dispenser's side as compared with viewing the axis from the subject's side (Figs 4.3 to 4.5).



Fig. 4.5: Orientation of cylindrical axes on a protractor

A good way to recognize cylindrical axes from dispenser's side is to view the back of your left hand; the thumb will point to the zero degree (Fig. 4.6).



Fig. 4.6: Thumb will point to zero degrees

TORIC LENSES

Toric lenses, also known as sphero-cylinder lenses can be explained as spherical lens that has been placed in contact with a plano-cylinder lens (Fig. 4.7).



Fig. 4.7: Convex spherical surface combined with plano-convex cylindrical surface

Since a plano-cylinder lens has no power along its axis meridian, the power along the axis meridian of the combination must result from spherical element alone. The power along the other principal meridian of the lens, at right angles to the axis meridian of the cylinder surface, is the sum of the sphere and cylinder. Under the rotation test, it exhibits scissor movement in the same way as a plano-cylindrical lens and under the movement test; it exhibits movement along each of its principal meridians. The power of a sphero-cylindrical lens is expressed by stating the power of the spherical component first, followed by the power of the cylindrical component, and finally the direction of the cylindrical axis. Thus, the specification:

 $-3.00/-2.00 \times 90^{\circ}$

It signifies that spherical component of the lens is -3.00D, the cylindrical component is -2.00D and the axis of the cylindrical surface lies along the 90° meridian. On representing the power of the sphero-cylindrical lens by means of optical cross, the principal meridians show -3.00D on vertical meridian and -5.00D on the horizontal meridian as shown in Figure 4.8.



Fig. 4.8: Optical cross representation of - 3.00/- 2.00 × 90°

The pencil of light that results from refraction at an astigmatic lens is depicted in the Figure 4.9. Since the light does not focus as a point, the interval between two line foci is called the 'Interval of Sturm'. The best focusing occurs somewhere inside the interval of Sturm. This point is called the 'Circle of least confusion', and the complete envelop of the light near the circle of least confusion is called the 'Sturm's Conoid', named after the mathematician CF Sturm.



Fig. 4.9: Pencil of light results from retraction at an astigmatic lens

Figure 4.10 illustrates the toroidal surface of the sphero-cylinder lens. The lower power is usually referred to as the base curve of the surface and the higher power as the cross curve. In the plano-cylindrical surface, the base curve is along the axis meridian which is zero and the cross curve is simply the power of the cylindrical surface. In case of the toroidal surface, the "axis meridian" is curved and the cylindrical power of the surface is the difference between the cross curve and the base curve.



Fig. 4.10: Toroidal surface of the sphero-cylinder lens

DETECTION OF CYLINDRICAL LENS

Cylinder lenses are often referred to as cylinder or toric lens because of their out of round surfaces. In order to determine the cylinder lens and to detect its dioptric strength, hold the lens a few inches away from your eyes; sight a straight lined object, such as window or the door frame. Rotate the lens slowly as you would turn a steering wheel – first to the right

(clockwise), then to the left (anti-clockwise). If a section of the door frame appears slanted, it establishes that the lens under examination is a cylindrical lens. This is called "scissors like movement".



Fig. 4.11: Looking through a plano-cylinder, a section of the door's frame appears to be slanted



Fig. 4.12: Upon rotating the lens, a position will be found in which the door frame appears straight

Next step is to find out two principal meridians of the lens. To do so continue rotating the lens and at one position on rotation, the frame of the door would not look slanted. This is one of the principle meridians. The meridian opposite to this is the other principal meridian. They are at 90 degree to each other. Now, neutralize both the meridians separately. If the movement in one meridian is nil, it is a plano-cylindrical lens and nil movement meridian is taken as the axis of the lens. Contrarily, if both the meridians show movement, it is a sphero-cylindrical lens. The weaker movement meridian is taken as the axis of the lens under observation. Now, neutralize both the meridians as before to determine exact spherical and cylindrical elements.



Α

Axis meridian

parallel with vertical

limb of chart



Plus cylinder rotated clockwise causes vertical limb to rotate anti-clockwise

Fig. 4.13







Fig. 4.14



Fig. 4.15

Lensometer can also be used to determine the lens power of an astigmatic lens. The procedure is as under:

- Place the lens on the lens stage and start from zero.
- Focus the target image by rotating the dioptre power knob.
- Read the dioptre power scale when the target image is cleared. This is taken as either plano for a plano-cylinder lens or spherical for a toric lens.
- Now focus the target for other meridian by rotating the knob.
- The difference between the second absolute value and the first is taken as cylinder.
- Align the cross line with the second focused point by rotating the axis wheel. The angle of the indicator shows the axis.



When the rays of light pass through a piece of material as shown in Figure 5.1, travelling from air, it bends towards the normal. Then it leaves the material travelling back into the air and bends away from the normal. In this figure the sides of the material are parallel to each other, so the rays emerges travelling in the same direction as its original travel – it has been displaced, but not deviated.



Fig. 5.1: The ray appears to be displaced

In the Figure 5.2, the sides of the material are not parallel to each other, so the ray emerges travelling in a different direction than its original travel. This happens to every ray that passes through a refracting medium bordered by two plane surfaces which are inclined at a finite angle. The medium is called Prism and the angle between the two surfaces is called the apical angle or refracting angle. A line bisecting the angle is called the axis of the prism and the opposite surface is called the base of the prism.

The prism, therefore, can be defined as the wedge-shaped lens material which deviates light towards its base without changing its vergence. All varieties of spectacle lens has the effect of a prism when viewed through a point away from the optical center. The further the away from the optical center, the greater is the prismatic effect.



Fig. 5.2: Rays emerging, travelling in different direction

Look at the Figure 5.3, one plane on the edge, i.e. the base of the prism is thicker than any other portion and the plane opposite to base is the thinnest – known as apex of the prism. The thickest edge is exactly opposite the thinnest edge (provided prism has no power).



When the prisms are prescribed, the orientation of it, is indicated by the position of base, i.e., 'base - in', 'base - out' and so on. Light rays entering and leaving a prism are bent towards the base of the prism. This causes objects to be displaced away from the base of the prism towards its apex. Thus, if an object is viewed through a base down prism, it will be seen to be displaced upward. Similarly, objects appear to shift downward when viewed through a base up prism, to the right or left when seen through a base-out or base-in prism.

The amount by which a ray will be deviated when it passes through the prism depends on:

- The apical angle
- The index of refraction of the material
- The wavelength of the ray
- The angle from which the ray approaches the prism.

CHARACTERISTICS OF PRISM

- A prism has a thickest edge, the base and a thinnest edge, the apex.
- A prism displaces the incident rays towards the base of the prism.
- A prism displaces the image towards the apex of the prism.
- A prism does not change the vergence of the rays.
- A prism does not magnify or minify the image.
- A prism also disperses incident pencil rays into its component colours.

DEVIATION PRODUCED BY PRISM

The deviation produced by a prism is measured in terms of prism dioptre and is given by the symbol Δ . A prism with a power of 1 prism dioptre deviates light by 1 cm measured at a distance of 1 metre from the prism. Similarly, a prism of 2 prism dioptre produces a deviation of 2 cm measured at a distance of 1 metre from the prism. The deviation so produced can be measured by the Prentice's Rule:

 $Prism \ diopter = \frac{Deviation \ in \ cms}{Distance \ in \ metres}$

E.g: If the light is deviated 6 metres at a distance of 3 metres, then the prism diopter would be:

$$P = \frac{0.6}{3} \text{ cms}$$

or, P = 0.2\triangle

PRISM ORIENTATION

Prism can be oriented in front of the eye using notations base-in or baseout, base up or base down when the directions are horizontal and vertical. All other base directions require 360° notation. E.g: RE 2 Δ at 160° .



Fig. 5.4: Orientations of prism





SPLITTING OR DIVIDING PRISM

When prism is prescribed, it is usually divided equally between the two eyes to:

- Distribute the weight more evenly.
- Reduce thickness of the intended lens.
- Minimise chromatic aberration.

For example, Right eye 3Δ IN causes right eye to deviate outwards by 3Δ . If we place 1.5Δ IN before each eye, the required total deviation will be still achieved. Therefore, RE 3Δ IN can be divided as RE 1.5Δ IN combined with LE 1.5Δ IN. Such a division in the horizontal meridian do not have to be equal in magnitude. For example:

Re Zero	$LE 4 \triangle OUT$	
R combined with L		
0.5∆ out	3.5∆ out	
1∆ out	3∆ out	
1.5∆ out	2.5∆ out	
2∆ out	2∆ out	
2.5∆ out	1.5∆ out	
3∆ out	1∆ out	
3.5∆ out	0.5∆ out	
4Δ out	ZERO	

Exactly the same principle applies for BASE IN prism. While splitting the prism in vertical meridian, care must be taken to ensure correct base orientation. For example, RE 1.5Δ Up and LE 1.5Δ Down is not the same as RE 1.5Δ Down and LE 1.5Δ Up. The splitting can be done as under:

Prisms	45
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RE 3∆ UP	LE ZERO
R COMBINED WITH L	
0.5∆ UP	2.5∆ DOWN
1Δ UP	2A DOWN
1.5∆ UP	1.5∆ DOWN
24 UP	1A DOWN
2.5∆ UP	0.5∆ DOWN
34 UP	ZERO
1.5Δ UP 2Δ UP 2.5Δ UP 3Δ UP	1.5Δ DOWN 1Δ DOWN 0.5Δ DOWN ZERO

In practice usually splitting is done evenly.

TYPES OF PRISM

Prisms are used to change the path of the propagation of light. The following types of prisms may be used in practice:

Prism by Decentration

A larger uncut lens can be used to move the lens so that the optical center is no longer in front of the pupil and hence create a prismatic effect at the centre point. In case of anisometropia, the more powerful lens will need less decentration to create the same prismatic effect. Today a significant proportion of single vision lenses are aspherics where it is very difficult to decenter the lens to create prism at the center point. With the spherical curves, the effect away from the centre is a simple continuous curve, in case of an aspheric lens, the surface geometry is much more complex and the design has been calculated to work around the center of rotation of the eye. If an aspheric lens is decentred then the vision would be compromised, especially in the periphery opposite to the direction of decent ration. On an aspheric lens, using prolate ellipsoid surface, the actual surface power



Fig. 5.6: Decentration IN

GC = Geometrical center OC = Optical center

reduces from the center to the edge, the outcome of this flattening is the reduction of prismatic effect in comparison with the same point on a spherical lens. The flattening is not the primary effect of aspheric lenses but is the side effect of the surface geometry.

Worked Prism for Decentration

Worked prisms work in exactly the same way, but creates the opposite effect. Here, we are looking to avoid creating unwanted prismatic effect at the center point. When the uncut is not available in the required diameter, working a prism on the lens will move the optical centre across the uncut lens creating a greater effective diameter.



Prescribed Prism

The prisms may be prescribed to create a desired effect upon the binocular balance of the eyes; this may be to reduce the visual stress to a tolerable level where a phoria is involved or to relieve a convergence insufficiency.

Differential Prism at Near

In case of anisometropic population looking away from the optical center create a loss of contrast and reduction in visual acuity which causes a breakdown in binocular vision and diplopia due to the induced differential prismatic effect. For a single vision spectacle wearer, this can be kept in check by looking through the optical center, but for the multifocal wearer, this differential prism must be tackled. In a multifocal lens, the zone that is used to read lies below the distance visual zone. The center of the near visual zone, is usually taken to lie somewhere around 8 mm below DVP and 2.5 mm inwards. Assuming that the impact of pantoscopic tilt has been taken care of, the prismatic effects between the eyes is called differential prism and requires the eyes to rotate by different amounts to maintain binocular single vision of the object of regard. Remember eyes can cope with quite big horizontal differential prism, as it quickly produces

diplopia. The eyes can cope with maximum 2Δ of vertical differential prismatic effect for longer hours.

Take for example a prescription in RE – 3.00Dsph and LE – 6.00Dsph, the vertical prismatic effects that the subject encounters at points 8 mm below the distance optical centres are RE 2.4 Δ base down and LE 4.8 Δ base down. The differential prismatic effect between the eyes is 2.4 Δ base down in the left eye. This prevents comfortable binocular vision and hence some form of prism compensation may need to be provided for near vision. Such a compensation for vertical differential prism can be provided in several ways:

- 1. Two separate pair of spectacles one centred for distance vision and the second pair centred for near vision can be provided.
- 2. Split design bifocals can be made where separate distance and reading lenses are cut in half and mounted together in a frame, each component being separately centred for distance and for near vision.
- 3. A Plano prism segment can be bonded to the lower half of the lens. For example in the above example 2.4Δ base down prism might be bonded to the right lens to increase the prismatic effect at the right NVP to 4.8Δ base down which would match that of the left eye.

Different Prism at Distance and Near

There are occasions where different prisms are required at distance and near. These may be horizontal or vertical and require a different set of solutions.

Thinning Prism

Because of the decreasing radius of the front curve in the lower portion of an E-style bifocal or a progressive addition lens, the top of the lens ends up thicker than the bottom. Removing base up prism (work base down) will reduce the thickness at the top of the lens. The usual amount of thinning prism applied is 2/3rd of the near addition power. The benefit of thinning prism varies depending on the fitting position and the size of the frame. A progressive addition lens set low in the eye of a shallow frame will not benefit much from thinning prism but a progressive addition lens set high in a deeper aviator will definitely benefit because of this.

USES OF PRISM

Diagnostic Use of Prism

Prisms are used to assess the squint and heterophoria. Prism from the trial lens set and the prism bars are usually used for this purpose. These bars are composed of adjacent prisms of increasing power.

Therapeutic Use of Prism

The commonest therapeutic use of prisms in the orthoptics is in building up the fusional reserve of patients with convergence insufficiency. The base out prism is used during the patients exercise period. They are not worn constantly. Another therapeutic use of prism is to relieve diplopia in certain cases of squint. Prisms used in treatment include clip-on spectacle prisms for trial wear. An improvement on these is fresnel prism. Permanent incorporation of prism can be done in patients spectacles.

FRESNEL PRISM

In case of high prisms, the thick bases become cosmetically unappealing. An improvement on these is Fresnel prisms. A Fresnel prism consists of a plastic sheet of parallel tiny prisms of identical refracting angle. The overall prismatic effect is the same as that of a single large prism. Fresnel prisms are moulded from PVC (Polyvinylchloride) to form a flexible sheet of prism. The sheet can be cut to the shape of the spectacle lens and fixed with the smooth side attached to the rear surface of the lens.

Functionally, Fresnel prisms reduce visual acuity and contrast sensitivity, particularly for prisms greater than 10Δ . The reductions in functions are mainly due to chromatic aberration, and are more pronounced for Fresnel prisms than for conventional prisms.



COMPOUNDING AND RESOLVING PRISMS

At times prescription calls for a vertical prism in conjunction with a horizontal prism, for example:

LE 3 Δ BD with 4 Δ BO

The combined effect of above example could be produced by a single prism of appropriate power with its base in some oblique setting. To find this resultant prism, draw an accurate diagram. Remember standard notations, which say that the axis starts at zero on the right hand side of each eye and goes around anti-clockwise from the observer's point of view.



Fig. 5.9: Standard notation

Draw a set of lines at right angles to one another and mark the nasal area along with the primary directions based on this.



Fig. 5.10: Left eye representation showing principal directions

Picking a suitable scale, i.e., 1 cm = 1 diopter, mark a point equivalent to 3Δ down and 4Δ out.



Fig. 5.11: Shows 3Δ down and 4Δ out to scale

Now construct a rectangle based on this and draws in a diagonal from the center of the cross lines to the corner of the rectangle as drawn in Figure 3.12.



Fig. 5.12: Construction completed to show magnitude and angle of oblique prism

This line represents both the magnitude and the base setting of the resultant prism. The line measures 5 units and therefore equals 5Δ diopters. The direction in relation to the center of the cross lines and nasal area is down and out. Expressed in terms of a 360° notation the base direction is 323°.

If a 180° notation is required the diagonal line needs to be extended so that it lies above the horizontal, measuring the axis indicated as shown in Figure 5.13. Therefore, the answer to compounding the prisms is:

 5Δ base at 143° out

or, 5∆ base at 323°



Fig. 5.13: Showing angle of prism in standard notation

There is a mathematical solution to compounding prisms. The formula is:

$$P_{R} = \sqrt{Pv^{2} + Ph^{3}}$$
Where, P_{R} = Single resultant prism
 P_{V} = Prism vertical
 P_{H} = Prism horizontal

Putting the values from the previous example:

$$PR = \sqrt{3^{2} + 4^{2}}$$

$$PR = \sqrt{9 + 16}$$

$$PR = \sqrt{25}$$

$$PR = 5\Delta$$
Now to obtain the base setting use:
$$\tan \theta = \frac{F_{V}}{P_{H}}$$

$$\tan \theta = \frac{3}{4}$$

 $\tan \theta = 37^{\circ}$

This needs to be converted to standard notation by subtracting from 180° (180-37=143).

Therefore, the answer is 143°.

PRISM AND LENS DECENTRATION

The general theory is if the lens power is 1.00D and we decenter the lens by 10 mm, it produces 1Δ prism or if the lens power is 10.00D and we decenter it by 1 mm, it also produces 1Δ prism. This is constant. The equation is:

(i)
$$d = \frac{10 \times P}{D}$$

(ii) $P = \frac{D \times d}{10}$
Where, $d = Decentration in mm$
 $D = Dioptre or lens power$
 $P = Prism degree$

The required prism degree can be found out with the help of above equation. Now while grinding or surfacing, the lens prisms can be produced by keeping the edge difference for which the equation is:

Prism × Size of lens × 0.019 = Edge difference.

DETECTION OF PRISM IN AN OPTICAL LENS

Hold the glass up between the eye and an object which forms a straight line. If the continuity of the line in broken as seen in Figure 5.14, it implies that the prism is present and since the line appears to be deviated towards the apex, we know the direction of apex of the prism. The amount of displacement produced is the strength of the prism, and can be measured by neutralising. To do so put the prism lens of known strength in contact with the lens under checking with its apex in opposite direction. The prism lens with which the continuity of the lens is again established, represents the strength of the prism.







Fig. 5.15: Detection of prism in a lens using lensometer showing 2.5∆ prism

Lensometer can also be used to detect the prism dioptre. To check this get the best focus point of the target image and read the prismatic power. In most of the lensometer, each circle of the scale indicate one prism dioptre, as shown in the Figure 5.15. An additional accessory called 'prism compensator' is to be attached to the lensometer for higher dioptre of prism. Figure 5.15 shows 2.5 prism dioptre towards 90° in PENTAX OLH-1 lensometer.

SUMMARY

The optics of ophthalmic prism is still nightmare to many optical students but in day-to-day practice, there is little complicated about them. Prisms, if used with care, can be used to improve the appearance of spectacles.



One of the first decisions to be made while dispensing a new prescription is the choice of lens form. When the eye views along the optical axis of the spectacle lens, the form of the lens does not matter and image formed by the lens is not afflicted with any defects or aberrations which might affect its sharpness or its shape. But in actual world, the eyes turn behind the lens to view through off-axis visual points and it is then that the form assumes importance.



Figs 6.1A to C: Our eyes turn behind the lens to view through the off-axis. It is then the lens aberrations assume importance (A) Primary direction, (B) Secondary direction, (C) Tertiary direction

Ideally, the off-axis performance of the lens should be the same as its performance at the optical centre. But it is never so. The off-axis images are afflicted with various types of aberrations, which spoil the quality of image formed by the lens. There are six major lens aberrations that work against obtaining a perfect image through the periphery of the lens. They are:

White light Optical axis Green light Green light

CHROMATIC ABERRATION

Simple thin lens



Chromatic aberration is a defect in the lens in which the various colours of the spectrum are not brought to the same focus. Blue light is refracted more than the red light when it passes through a lens. The result is out of focus image. The wearer complains of peripheral colour fringes around the object which is more pronounced off-axis. The higher the power of the lens—the greater is the chromatic aberration.

Chromatic aberration depends upon the material of the lens. Since, the lens materials have a different refractive index for each wavelength—the lens will have a different focal length for each wavelength. The refractive index is larger for blue than the red wavelength, so focal length is less for blue than the red.

Importance

Since chromatic aberration occurs because the refractive index of the lens material varies with the wavelength of the incident light, it gives rise to what is called the Abbe value of the lens material which is denoted by V-value. Higher Abbe value implies low chromatic aberrations and *vice versa*. So polycarbonate lens with Abbe value of 30 causes more chromatic aberration than CR₃₉ lens with Abbe value of 58.

Correction

- 1. The easiest solution to minimize chromatic aberration is to change the lens material to higher abbe value.
- 2. Careful placement of optical centre with monocular pupillary distance and its height in a small frame may reduce the chromatic aberration.

- 3. Reducing the vertex distance may also result in minimizing the effect of chromatic aberration.
- 4. Anti-reflection coating with consumer education may also be tried to minimize the effect of chromatic aberration.
- 5. The best solution is the Achromatic lens system. The achromatic lens uses two different lens materials one has a regular focal length and the other corrects the dispersion of the first lens. For this purpose one lens is made of crown glass, i.e. low dispersion, while the other is made of flint glass, i.e. high dispersion. The crown lens concentrates on optical effect and introduces some dispersion and the flint glass aims at balancing this dispersion while having least possible optical influence on the lens function.



Fig. 6.3: Achromatic lens system

Ocular Chromatic Aberration



Fig. 6.4: Far point of an individuals focus varies with the wavelength of light

Refraction by the human eye is also subject to chromatic aberration. As a result, the focusing power of the eye is different for different wavelengths of light in the real world of polychromatic objects. Consequently there is no place in the visual space where one can place an object and expect it to be well focused on the retina for more than one wavelengths of light at a time. Hence, blue wavelength focuses before the retina and red beyond the retina, i.e. the far point of an individuals focus varies with the wavelengths of light. In terms of foveal vision, the dominant chromatic aberration is axial or longitudinal chromatic aberration.

The causes of chromatic aberration are dispersion in the cornea, aqueous, crystalline lens and vitreous humor. Dispersion is simply a variation in the refractive index of the material with various wavelengths of light and causes white light to be dispersed into the various spectral colours, just as prism disperses light into a rainbow. Refractive surgery techniques can not correct chromatic aberration as this error is inherent to the properties of ocular structures and not to the shape of the ocular components.

Influencing Factors

Spectral sensitivity of the eyes helps reduce the effect of chromatic aberration by making the visual system more sensitive to the green wavelength focused onto the retina.

Clinical Application

In clinical practice ocular chromatic aberration is made use of in Duo chrome test.

SPHERICAL ABERRATION

Spherical aberration is an axial and wide beam aberration. The light rays from the peripheral edge of the lens are refracted to a greater degree than the light rays passing through the center of the lens. Peripheral rays bend more than the paraxial rays. This creates a slight blurring of the image that is minimized by the size of the lens.



Correction

- 1. Spherical aberration may be reduced by occluding the periphery of the lens such that only the paraxial zone is used.
- 2. Lens form may also be adjusted to reduce spherical aberration. Aplanatic surface where periphery curve is less than the central curvature may be used.

Ocular Spherical Aberration

Refractive power of ocular structure is greater for peripheral rays than paraxial rays. The effect of spherical aberration on retinal image is a symmetrical blur like defocus which is reduced by the size of pupil.

Influencing Factor

The effect of spherical aberration in the human eyes is reduced by several factors:

- 1. The anterior corneal surface is flatter at the periphery than at its centre, and therefore acts as an applanatic surface.
- 2. The iris acts as a stop to reduce spherical aberration. The impairment of visual acuity that occurs when pupil is dilated is almost entirely due to spherical aberration.
- 3. The nucleus of the lens of the eye has a higher refractive index than the lens cortex. Hence, the axial zone of the lens has greater refractive power than the periphery.
- 4. Finally, the retinal cones are more sensitive to light which enters the eye paraxially than the light which enters obliquely through peripheral cornea. This directional sensitivity of the cone receptors limits the visual effects of the residual spherical aberration in the eye.

Clinical Application

Spherical aberration accounts for much of the phenomenon known as "Night Myopia". At low light levels, the pupil enlarges and allows more peripheral rays to enter the eye. The peripheral rays are focused anterior to the retina, rendering the eye relatively myopic in the lower light levels. The typical amount of night myopia is about 0.5D, but it can be as large as 1.25D.

MARGINAL ASTIGMATISM

Marginal astigmatism or oblique astigmatism aberration is a small angle aberration. When a narrow beam of light enters obliquely to lens axis of a spherical lens, the refracted rays become astigmatic. The emerging rays, instead of uniting in a single image point, form two foci at right angles to



Fig. 6.6: Light rays entering obliquely to lens axis of a spherical lens, the refracted rays become astigmatic

one – another with a disk of least confusion. On joining the two foci, a line image is created . The plane containing the optical axis of the surface is referred to as the "tangential plane" and the plane at the right angle to the tangential plane is referred to as the "sagittal plane". Another way to understand the effect of marginal astigmatism is – tilting a spherical lens adds spherical and cylinder of the same sign as the original lens and is called astigmatism of oblique incidence. The effect of marginal astigmatism is that it produces blurring of image due to imposition of unwanted spherical – cylinder between the lens and the eye. It also reduces contrast, and as the aperture is opened wider and wider, the astigmatic figure of marginal astigmatic aberration becomes the typical cometic figure.

Correction

Since marginal astigmatism is a small angle aberration, it is very important in ophthalmic lens designing. It is considerably affected by the form of the lens used. It is much worse in bi-convex and bi-concave lens than meniscus lens form. It may be reduced by the use of an aspheric surface or by a suitable choice of lens bending, i.e. by using corrected curve theory. Proper use of pantoscopic tilt with optical centre height may help reducing marginal astigmatism.

Marginal astigmatism is very important in ophthalmic optics and it is the aberration modern corrected curve design seeks to eliminate.

Ocular Astigmatic Aberration

Oblique rays passing through the pupil of the eyes create astigmatic aberration in human eyes. The visual effect is not more than reduction of contrast.

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Lens Aberrations

Influencing Factor

- 1. Applanatic curvature of the cornea reduces marginal astigmatism as well as spherical aberration.
- 2. The spherical surface of the retina also results in minimizing the effect of marginal aberration.
- 3. Finally, the astigmatic image falls on the peripheral retina , which has relatively poor resolving power compared to the macular area. Visual appreciation of the astigmatic image is, therefore, limited.

Clinical Application

- 1. Pantoscopic tilt in the spectacle creates astigmatic aberration which becomes more substantial with higher power and greater amount of tilt.
- 2. Myope sometimes tilts their glasses forward to gain more minus power, indicating a need for stronger prescription. Tilting forward induces both minus spherical and minus cylinder.
- 3. Oblique astigmatism aberration can also be a problem when objective measure of the refractive error of an eye is attempted. This is especially important when retinoscopy is performed on a patient who does not maintain fixation, as commonly seen in small children.

COMA

Coma is a wide beam aberration and is somewhat similar to spherical aberration. It is applied to oblique rays coming from points not lying on the principal axis. Oblique rays passing through the periphery of the lens are deviated more than the central rays and come to focus near the principal axis. The result is unequal magnification of the image formed by the different zones of the lens. The composite image is not circular , but elongated like a comet and coma.



Fig. 6.7: Peripheral rays form larger image than paraxial rays

Coma is associated with the off-axis object points. It occurs because magnification is the function of the height of the rays of the light. It is the worst type of aberration as it degrades and deforms the image of a point object. The funny part is that a lens with considerable coma may produce a sharp image at the centre of the field, but becomes increasingly blurred towards the edges.

Correction

The effect of cometic aberration can be minimized by using parabolic curves. Aspheric lens design helps reduce coma in high plus power.

Ocular Coma

In human eyes, coma gives a comet like image because of small decentration of the cornea and the lens, which results in different magnification in the different parts of the pupil. As most of the day time undilated pupil is around 2-3 mms in size, the ocular cometic aberration does not carry much of practical importance.

CURVATURE OF FIELD

Curvature of field is a phenomenon which causes the image formation of a plane to become curved like the inside of a shallow bowl, preventing the lens from producing a flat image of a flat object. This occurs even when the spherical aberration, marginal astigmatism and coma have been eliminated. The effect is largely dependent upon the refractive index of the lens material and the curvature of the lens surface.

This causes an unequal vertex distance between the centre of the lens surface and its periphery. So the image so focused is either sharp on the edges or in the centre. When the centre of the image is in focus, the periphery is out of focus and when the periphery is in focus, the centre is out of focus.



Fig. 6.8: Light focused through a curved lens forms a curved image

Correction

Curvature of field affects peripheral vision. Curvature of field is minimized with corrected curve design base curvatures. As a rule if marginal aberration is corrected, the effect of curvature of field is also reduced. Good correction of astigmatism results in small curvature of field.

Ocular Curvature of Field

In the human eye the curvature of the retina compensates for the effect of curvature of field. So this is an advantageous aberration in the human eye.

DISTORTION

Distortion is another aberration of thick lenses. In distortion the object is sharply imaged but does not retain its shape. There are two types of distortions resulting from lateral magnification of the image that results in a lateral displacement of the image:



Fig. 6.9: Pin cushion with plus lens and barrel distortion with minus lens

Barrel Distortion

Barrel distortion is produced in minus power lens where the rays in the centre are more magnified than the rays farther off-axis. This is due to minification of corners of a square grid more from minus lens.

Pincushion Distortion

Pincushion effect is produced in plus lens where the central rays are less magnified. This is due the magnification of corners of a square object more
from plus lens. Distortion is of minor importance in ophthalmic lens designing. It is a problem mainly of high power lens. It can be minimized by using steep back surface.

SUMMARY

In designing a spectacle lens, the designer has very limited degree of freedom. Practical conditions specify lens materials, safety considerations fix lens thickness, and fashion dictates lens position before the face, weight and cosmesis mean only two lens surfaces may be used. With so few degrees of freedom, few aberrations may be corrected. The wide angle spherical and cometic aberrations are of no importance since the entrance pupil of the eye is so small. The visual system adapts quickly to distortion, so the additional aberration of spectacle lens may be ignored. Thus, the spectacle lens designer is left only with the job of correcting astigmatism and curvature of field within tolerable limits so as to produce maximum dynamic field of vision for the patients.



THE ELECTROMAGNETIC SPECTRUM

The electromagnetic spectrum is a fast gamut of radiations which include Cosmic rays, Gamma rays, X-rays, Ultraviolet rays, Visible light, Infrared rays, Radiowaves and so on. The classification is based on their wavelengths. In ophthalmic optics, we are concerned with a relatively narrow band of the electro-magnetic spectrum. The wavelengths in this region are extremely short and are expressed in nanometers (nm). This is the unit of wavelength and is one thousand millionth part of a meter or one millionth part of a millimeter.



Fig. 7.1: Electromagnetic spectrum

The visible spectrum gives rise to the sensation of light. It extends from about 380 nm to 780 nm. Various wavebands within this region are associated with different colour sensations. For example, a light of 650 nm gives rise to the sensation of red, 480 nm describes a blue light, and 580 nm describes a light having yellow hue.

The radiations emitted by most sources of light and heat, whether natural or artificial, not only include all the wavelengths of the visible spectrum but also extend into the neighboring region, i.e., the ultraviolet and infrared. Although, not perceived as light, these radiations are capable



Fig. 7.3: Wavelength is the distance between one wave crest to the next

of doing serious damage to the eyes, if they are of sufficient intensity. Other radiations such as X-rays, gamma rays are also damaging to the eyes. But since they are also damaging to the other bodily functions, they are not treated solely as an ophthalmic problem. In addition, eye protection from these radiations cannot be attained by absorptive lenses.

EFFECT OF RADIANT ENERGY ON THE OCULAR TISSUES

Radiation is characterized by its wavelength. The portion of the total spectrum which is of primary ophthalmic concern is usually divided into ultraviolet, the visible and the infrared. Other radiations such as X-ray, gamma ray and many other forms of nuclear radiations are also damaging to the eyes. But since they are also damaging to the other bodily functions, they are not treated as solely an ophthalmic problem.

The visible spectrum: The media of the eye is transparent throughout the visible spectrum which may be taken as existing between 380 nm to 780 nm. Within this region the energy is transmitted to excite the sensation of the vision and has no harmful effects upon the tissues under the ordinary intensities of radiation. In recent years, concern has been expressed over the potential effects of short–wave visible radiation on ocular tissues. The blue light hazard remains a controversial topic and, at present, it is

suggested in the appropriate literature that under normal circumstances not much of the risk is expected.

The Infrared: The region above 780 nm is referred to as the infrared end of the spectrum. The effect of radiant energy from the infrared region, depending upon the intensity and degree of duration, has a thermal effect. Of the total incident infrared radiant energy on the eye, 97% is absorbed by the cornea, iris, lens and vitreous and the remaining 3% reaches the retina. Therefore, the thermal effect of long-wave radiation can involve all the tissues of the eyes, depending upon the degree of concentration of energy.

The Ultraviolet: Extending from 380 nm into the lower regions of the spectrum, ultraviolet energy absorption commences and has an abiotic effect. Abiotic action produces chemical changes in the cornea and lens affecting the protein in the cells. The extent of tissue injury depends on the intensity of the energy reaching the tissue and time of exposure.

The chief natural source of UV rays is the sun. Artificial sources of UV include incandescent light, gas discharge, low pressure mercury, xenon lamps etc.

For convenience, UV radiation is subdivided into three elements -

UV – C: UV – C has the shortest wavelengths from 200 nm to 290 nm and is, therefore, potentially the most harmful to us because the shorter wavelengths always have the highest energy. When this high energy is transferred to human tissue, it can be damaging, especially with repeated exposures. Fortunately the ozone layer of the earth screens it out.

UV - B: Wavelength between 290 nm to 320 nm are responsible for sunburns and snow blindness. The amount of ultraviolet affecting a person is substantially increased by reflection from surfaces such as snow, sand, concrete and water.

UV – A: Wavelengths between 320 nm to 380 nm is possibly the cause of most concern for the ophthalmic professionals, as it enters the eyes, causing chronic damage to the eye.



Fig. 7.4: Components of UV light

It is, therefore, necessary to protect the ocular tissue as much as possible from the effect of UV rays. The cornea absorbs UV radiation below 300 nm. It is susceptible to ultraviolet related problems such as pterygium, snow blindness and photokeratitis. The eyes crystalline lens takes in UV and injures itself. Over years of absorption and exposure, the lens may become yellow or brown, indicating the need for cataract surgery.

ABSORPTION CHARACTERISTICS OF CONVENTIONAL CROWN GLASS

When light is incident on ophthalmic crown lens, some of the light is reflected, some is absorbed and the remainder is transmitted. The percentage of light that is lost by reflection from each surface can be determined by Fresnel's law, assuming normal incident light:

$$(n-1 / n + 1)^2$$

Where n = index of refraction of the lens.

For crown glass having an index of refraction of 1.523, the reflection factor would be:

$$(1.523 - 1 / 1.523 + 1)^2 = 0.043$$
 or 4.3%

The amount of light lost by reflection from the front and back surfaces, therefore would be:

Since the refractive index varies with the wavelength, the surface reflectance varies accordingly. It is the highest at the blue end of the spectrum.

The amount of light lost by absorption, for crown glass, is less than 1% per centimeter of lens thickness. Therefore, for a lens of 0.2 cm thick, loss by absorption would be approximately 0.2%. The transmission for this lens would be:

$$100\% - (8.6\% + 0.2\%) = 91.2\%$$

The crown glass absorbs all the UV light below 290 nm. But unfortunately, it is the UV rays between 290 nm and 380 nm as noted previously, are more disturbing. Infrared rays are transmitted in the same proportion as are visible rays.

FILTER LENSES

The coloured transparent objects are called filters. The filters selectively absorb some colours and reflect or transmit others. How does a coloured lens create or alter colour, when it is essentially acting as a filter which



Fig. 7.5: Different wavelengths giving sensation of different colours

blocks light? The answer lies in the fact that to create one colour in the spectrum, it destroys the "complementary colour". This is best explained with an example, when a lens contains special tint molecules to absorb blue light, this will allow the other colours of the spectrum to pass through and create a lens with a yellow appearance. The body will have the same colour of the part of the spectrum in which it is placed.

Where does the blue light go? Since energy can not be destroyed, it ends up being converted into heat energy by the tint molecules. As an alternative to absorption, it is also possible to reflect light, a method adopted in mirror coatings. Again the complementary colour theory applies, so that a "blue" mirror reflects yellow light.

Various metals and metal oxides are added to glass during its manufacture to change its colour, thereby altering the absorption deliberately in almost any desired way, both within and beyond the visible spectrum. Besides, some oxides like titanium is used to intensify and brighten other glass colourants. The way the glass is heated and cooled can also significantly affect the colours produced by these compounds. The chemistry involved is complex and will not be understood so easily. New coloured glasses are frequently discovered.

Grey: Grey filter is the most popular protection tint. It has an even transmission through the whole visible spectrum. So this is a neutral density filter. This characteristic allows colours to be seen in their natural state relative to one another without destroying them. It does reduce the intensities but not removing any particular wavelength. As they reduce the amount of all light colours transmitted to the eye, dark grey filters may reduce visual acuity slightly. By reducing the total amount of light entering the eye on very bright days, the brightness can be adjusted to give a clearer sight picture which can compensate for any loss in visual acuity compared to not using a filter. So it is likely to be favored by the light sensitive patients.

Those who can not tolerate colour distortion or whose job requires accurate colour discrimination, also favor grey tint. Grey lenses offer good protection against glare, making them a good choice for driving and general use. Because it absorbs light equally over the whole visible spectrum, it is not the best contrast enhancing colour.

Yellow: Chromium or sulphur oxides are used to give rise to yellow tint filter. Uranium oxides can also be used for the same purpose. Yellow filters absorb blue, violet and UV light while allowing a larger percentage of other frequencies through. Since blue light tends to bounce and scatter, it can create a kind of glare known as blue haze, thereby reducing the contrast. The yellow tint virtually eliminates the blue/UV end of the spectrum and has the effect of making everything bright and sharp. The tint concentrates light in the area of the spectrum to which the eye is most sensitive. If an individual is already light sensitive then the experience is heightened looking through a yellow or orange filter. Someone who is not light sensitive would really appreciate the contrast enhancing effect of yellow filter. That is why yellow filter is likely to be favored in visually demanding sports like trap shooting and snow skiing, especially on overcast days. This tint really distorts colour perception, which makes it inappropriate for any activity that relies on accurate colour.

Blue: Small concentration of cobalt (0.025% to 0.1%) yield blue glass. Blue filter glass is likely to transmit more dangerous high energy part of the spectrum, i.e. shorter wavelengths blue and UV while absorbing the light into the yellow and orange wavelengths. The eyes lack of sensitivity to this part of the spectrum adds to the danger. But the absorption in the yellow wavelength makes it good for light sensitive individuals. But the light scattering effect of the blue light out weighs the relief they get from the elimination of peak sensitivity wavelength of yellow and orange. Because of the danger of high energy blue light intensified by the brilliance of the sun, blue tint is not advisable for outdoor use. It can be prescribed for boiler tender, smelters, foundry work and certain types of furnace work. As it is not good UV and IR filter, it is not intended for welding application.

Green: The green tinted glass lens obtains its colour and characteristic transmission curve from ferrous oxide metal. Green filters transmit wavelengths of around 500 nm, i.e., green as well as yellow, orange and at the higher end red while absorbing some, but not all of the blue – violet region. It has a good UV as well as infrared heat absorbing properties. It makes a very good sunglass tint because of its contrast enhancing properties. It allows true colour perception and real protection in bright light. It reduces eyestrain in bright light and also glare. It is a good intermediate filter to use when grey or yellow does not seem right.

Red: Red filter gets its colour characteristics because of higher concentration of selenium. Red filter strongly blocks the transmission of blue and blue – green wavelengths, resulting in very sharply defined contrast. It allows excellent depth perception in low light, and is good for skiing and hunting. Red tint can be helpful for hue discrimination in colour deficiency. This effect might be enhanced by relating the tint to the anomaly, a red tint for protanopes and a green for deuteranopes. It is also possible that the choice will not be as simple as this or the reverse or that the greatest effect is achieved by another colour or different colour in each eye.

Pink: Pink is an example of unsaturated red. Cerium is added to the batch mix to give rise to pinkish tint. Psychologically pink has been judged as the "sweetest" colour. They are prescribed mainly to attenuate the light in a pleasing way. They have the absorption properties in the UV and blue light region. Pink may be the colour of choice when there is some neurological problem.

Amber: Amber is fluorescent that increases the contrast of the objects so that every cracks and curbs stand out in our field of vision. Non-metallic element sulphur is used with iron to produce amber glass, the colour of which can vary from very light straw to deep reddish brown. Night vision with amber tint brightens the darkness in front of a vehicle so that the subject can see more details. In addition, the amber tint also reduces the glare from front headlights. Amber is more of a selective filter. It also offers excellent light management properties on cloudy or rainy days. Therefore, it is great for lower light conditions like – golf, shooting, fishing, skiing etc. This "light enhancing effect" reduces the eye strain. It also improves visual acuity and depth perception.

Brown: Brown tints are good general purpose filters. They have added benefit of reducing glare and molecules that mainly absorbs total UV light below 400nm. In the visible region of spectrum, transmission is controlled with high peaks in the blue, green and red region, resulting in a colour enhancing effect. It is an excellent contrast enhancing filter and is very much suitable for sun protection. Brown is an ideal tint for drivers for day time driving as it has three effects - eliminates the "blue blur" substantially, increases the contrast and gives the wearer an impression of higher light transmission.

Orange: In normal use, orange is the essence of brown, so a tint diagnosis of orange would transmit to a brown tint. Orange filter allows transmission of light that is the same colour as the filter and promote tonal separation in that colour. They tend to reduce the transmission of blue and green wavelength, thus increasing the contrast. So the image appears sharper. It is an ideal support for cycling, mountain tours, skiing and a lot more.

Violet: Violet is the least chosen tint of all. It is almost as photoactive as ultraviolet and can irritate eyes and even cause eye damage.

METHODS OF LENS TINTING

A spectacle lens is said to be tinted if the transmission of light is deliberately decreased by any means, either over the whole of the visible spectrum and its neighbouring regions, or merely a part of it. They offer selective absorption for each wavelengths of the spectrum, and this determines their tints. Such absorption may be fixed or variable. Fixed absorption is the case with all traditional fixed tinted glasses, whereas, photochromic glasses offer variable absorption where transparency varies according to light conditions.



Fig. 7.6: Types of tinted lens

Colour results from the absorbent properties of glasses in the visible spectrum. The body will have the colour of the part of the spectrum in which it is placed.



Tinted lenses should not alter the colours of objects viewed through them and force the eye into constant efforts of adaptation. However, colours sometimes happen to be inspired by fashion, especially when it comes to sunglasses. To ascertain the real properties of tinted lenses, we have to refer to their transmittance curves which show the percentage of light transmitted in the different zones of the spectrum and reveal the absorbent properties of the lens.

Spectacle lenses may be tinted in two different ways:

Integral Tints

For many centuries this was the only method by which a glass lens could be tinted. Various oxides were added to the batch materials to give the lens a specific colour. It is to be noted that the colour of the lens is somewhat immaterial, the important factor being what wavelength the tint absorb. Cerium added to the batch mix would give rise to pinkish tint while cobalt oxide would give rise to blue tint lens.

Light passing through a homogeneous material suffers a continuous loss by absorption. The loss can be understood by imaging the lens or filter to be made up of a number of very thin layers, each of which absorbs a constant proportion of the radiant energy emerging from the previous layer. This proportion is not necessarily the same for all wavelengths. By adding the various metallic oxides or other compounds to the glass constituents, the absorption can be deliberately increased in almost any desired way, both within and beyond the visible spectrum. If the absorption is uniform within the visible spectrum, the tint imparted to the material will be grey or neutral. Selective absorption gives rise to a definitive hue. Thus, a relatively higher absorption in the red region of the spectrum would produce a greenish tint.

The effect of thickness on the percentage of light transmitted can be illustrated by the following example: Suppose that, for a given wavelength, a certain material absorbs about 40% per millimeter of thickness, i.e., it transmit 60%. The second millimeter transmits 60% of this 60, i.e., 36%, which is 21.6% and so on. Since white crown glass available today absorbs less that 0.1% per millimeter throughout the visible spectrum, it remains free from discernible colour even at considerable thickness.

Due to the problems of manufacturers having to produce all their products in all the different bases and additions in all the various tints, and the prescription houses having the problem of stocking those, the integral tinted or solid tinted glasses have disappeared from the optical scene. Add to this the problem caused by a combination of high power and solid tints, whereby there is a change in density across the lens due to the change in thickness from centre to edge, and the fact that unless both prescriptions are identical, there could be a tint mismatch problem between right and left.

Surface Tinting/Coating

An absorptive coating may be applied to a clear glass lens through the use of a metallic oxide applied to the lens in a vacuum. There are several advantages of such coatings. First, they are uniform in density regardless of the lens prescription to which they are applied. Colour coated lenses have a predictable transmission, whereas solid tinted lenses which exhibit a darker tint as the glass thickens. Colour coated lenses do not have such problems. In addition, they are available in a wide range of colours and transmission. Colour coatings may be removed and the lens may be recoated to give the effect of new colour. One drawback to the colour coated lenses is that they must be cared for in a manner similar to that used for plastic lenses.

Transmission curves for colour coated lenses are generally more even across the spectrum than either glass with integral tinting or dyed plastic. Surface coating may be possible in the following ways:

1. *Mirror Coating* – A mirror coating can be applied by a vacuum process to the front surface of the lens causing the lens to have the same properties as a two way mirror. The observer, unable to see the wearer's eyes, sees his own image reflected from the lens. The wearer is able to look through the lens normally. There is, of course, a reduction in the transmission of the lens simply because of the high percentage of light reflected. Mirror coatings are often used in combination with a tinted lens to provide more protection from intense sunlight. Mirror coating may be full, i.e. uniform throughout the lens surface or it may be graduated. The process is also capable of obtaining a whole variety of effects, i.e. a range of colours and mirrors, which is for reasons of fashion are highly popular in sunglasses. In case of lens having thick edges, only edge coating is also possible for cosmetic improvement. Edge coating is the application of the colour that matches the frame to the bevel area of the lens, camouflaging the edge. The purpose of such a process is to rid the lenses of the concentric rings visible to the observer. These rings accentuate the effect of the thick glasses. But it should be done very cautiously with a laboratory expert in this area. Mirror coated lenses work by reflecting back specific wavelengths, whereas solid tints work by absorbing the wavelengths or light energy. Light energy so absorbed expresses itself in the form of heat which might irradiate the eyes. But this does not occur in case of vacuum tints as the energy is reflected away. The wearer also gets the benefits because the depth of

the tint is uniform over the whole lens area, whatever the power and the thickness of the lens. The prescription house benefits because it minimizes the necessity for keeping stocks of necessary blanks.

2. Dye Tinting – Resin lenses can be tinted by immersing in a container of dye. The container is put in a unit that allows heat to be transferred to the dye. The longer the lenses remain in the dye, the more dye will be absorbed. Thus making them darker. The dye penetrates the lens material and becomes the part of it. It can not be rubbed off. Red, yellow and blue are the three primary dyes form with which almost all other colours can be made. For example, blue and yellow can be mixed together to make green.

The dye can be purchased either in powder or liquid form which are then mixed with previously boiled water. The concentrate so prepared is brought up to a temperature of 92 to 96°C and a pair of lens is immersed together to have the similar tint. Interesting tint combination can be created to an individuals imagination. Graduated and double graduated effects are comparatively easy to achieve with the aid of a pulley mechanism which gradually lifts the lenses out of the tint tank, thus imparting more tint on one part of the lens than the others.

One thing must be kept in the mind that it is difficult to predict how a pair of lens will react when immersed into a tint bath. Even though both the lens may be of the same material and also from the same manufacturer, the "take up" rate between the right and the left lens may be different. This can be due to a number of factors. One reason could be that one lens has been in storage for longer period than the other and thereby react differently when immersed into the tint bath. To reduce such problems always try to ensure that same manufacturer's lenses are tinted together and both the lenses must be of the same index because higher index resin materials exhibit different characteristics that prevent them from being tinted to the darker shades.

The dye tints are absorbed into both surfaces equally; they are not affected by the power of the lens and will therefore have an even tint regardless of prescription.

PHOTOCHROMIC LENSES

Photochromic lenses are lenses that visibly darken and fade indefinitely under bright and dull light respectively. They were developed by Dr WH Armistead and SD Stookey at Corning Incorporated in 1964. A photochromic glass lens contains billions of microscopic crystals of Silver Halide. When exposed to direct sunlight or UV light, these crystals absorb energy and cause the formation of metallic silver deposit on silver halide



Fig. 7.8: Darkening process of photochromatic lens

crystals. It is this metallic silver that absorbs the light. This reduces the amount of light passing through the lens and the lens turns darker. With the disappearance of UV rays or sunlight, the lens returns to its faded state by the reconvertion of deposited metallic silver into silver halide. Since these crystals are within the lens material, the process of darkening and fading can be repeated.

FACTORS AFFECTING PHOTOCHROMATISM

Although, exposure to ultraviolet light is one of the conditions that influence photo chromic lens transmission most, several other factors also contribute to lighting and darkening phenomenon. They are somewhat temperature dependent. Assuming the same degree of illumination, they will be darker when it is colder and lighter more than when it is warmer. This is slightly ironic as of course they are looked upon as a sunglass lens to be used in warm conditions. Because they react more in colder climates, there are some photochromic lenses where the manufacturer uses a warning stating that they should not be worn in freezing or cold conditions as the lens would darken to virtually zero transmission.

Lens thickness has an effect on the density of the tint. The silver halides run evenly through the lens, and therefore the thicker the lens, the more of them is there to absorb the light, hence the tint would be darker. Care must

be exercised when looking at transmission graphs or curves put out by the various photochromic lens manufacturers. They are all usually based on 2 mm thick sample at a specific stated temperature. Any variance in these values will affect the transmission characteristics.

Photochromic lenses achieve their full changing range and speed only after a "break - in" period, i.e., they tend to improve with age. The more light/dark cycles that they go through, the better they perform. It is, therefore, very common for patients supplied with a new pair of photochromic lens to complain that they do not change as good as their old pair. Because of the above it is recommended that these lenses are always replaced in pairs to ensure best possible tint match.

TINT OPTIONS IN PHOTOCHROMIC LENSES

Glass photochromic lens usually come in two basic colours – grey and brown. Technically it is possible to obtain other tint also, but demand has to be sufficiently to justify the production of the particular tint. It has been attempted in the past to make pink and green photochromic lens, but it seems to have settled down to a choice between grey and brown.



Fig. 7.9: Photochromatic lenses, Brown and Grey

RESIN PHOTOCHROMIC LENS

Photochromic resin lenses utilize a significantly different photochromic technology than that is used for glass. Photochromic compounds can be incorporated into a resin lens by applying either a photochromatic coating

or dye to the lens or by penetration of the surface, known as imbibitions. Using the imbibing technique it is possible to provide a uniform distribution of millions of photosensitive molecules within the front surface to depths of several microns. They become an integral part of the lens and not a coating that can wear or rub off. The process of imbibing can be illustrated by imaging a piece of standard laboratory filter paper saturated with the photochromic compounds and then allowed to air dry. The result is a paper with a compound evenly dispersed throughout. By placing the paper on the lens surface and heating both lens and paper, the compound will transfer and imbibe into the lens surface. Penetration depth of the compound is in the region of 100-150 microns. The advantage of the system is that no matter what the prescription is, the tint density is uniform. Unlike glass photochromic, resin photochromic lenses, begin activation instantly as they are exposed to sunlight with no break-in period. Over a period of approximately 2 years resin photochromic will degrade due to their exposure to UV radiation, unlike glass where the reaction is locked in permanently, for the life of the lens.

DISPENSING TIPS FOR PHOTOCHROMATIC LENSES

Photochromic lenses are not as effective in hot climate. When temperature increases, the reaction slows. So they are not recommended to replace sunglasses. However, they are useful lens to have, as the variation allows comfortable vision in almost all conditions with one pair of glasses.

Photochromic lenses do not lighten instantaneously when going from a bright to a dim area. For this reason, the elderly often experience problems wearing photochromic as the need for good illumination increases with age. The convenience gained from a darkened lens in a bright environment is offset by the inconvenience experienced when coming into a darker indoor from outside.

Also because the photochromic do not always return to their maximum transmission, the additional reduction in illumination when driving at night may prove hazardous.

No coating that absorbs UV light should ever be used on the front surface of a photochromic lens. Such a coating interferes with the darkening of the lens. Such a coating can, however, be placed on the rear surface without interference.

Anti-reflection coating will not reduce the range of the photochromic cycles but as with any lens, will increase the transmission in both the lightened and darkened status. Theoretically, a multicoated photochromic lens will transmit as much light as an uncoated clear glass lens, in its lightening state.

Photochromic lenses may be treated either through chemtempering for optimum mechanical strength, or air tempering. In the latter case, the treated lenses become lighter a little more slowly and darken rather more in the sun.

When replacing a single lens, the problem of a colour mismatch between the lenses often arises. There are three useful points to remember in order to avoid this problem:

- 1. Always make sure that the new lens is of the same type as the old one, i.e., same brand, same thickness etc.
- 2. If the old lens has been chemtempered, have it re-strengthened along with as the new lens.
- 3. If the old lens has not been treated in anyway, place it with the new lens in boiling water for half an hour (The infrared in the hot water restores original clearness to the old lens).

POLAROID LENSES

Under normal lighting conditions, light waves vibrate and travel in all directions – horizontally, vertically and also everywhere in between. When direct sunlight (which is non-polarized) or artificial light hit a smooth surface at a given angle, it reflects off the smooth surface and travels in the same direction, intensifying their effect on the eyes. This phenomenon produces disturbing optical noise or glare. Glare results in eyestrain, loss of clear vision, poor colour saturation, loss of depth perception, causing discomfort.

The principle of polarized lenses can be best illustrated by observing Venetian blinds. The blinds block lights at certain angles, while allowing lights to transmit through it at certain angles. Polarization implies restricting the light waves to one direction. Polarized lenses block horizontally aligned light which causes glare, while allowing vertically aligned light to transmit.



- 1. Polarizing filter
- 2. UV filters on both sides of the filter
- Support layer laminated to either side of UV absorbers for stability
- Scratch resistant coating applied to both outside surface

Fig. 7.10: Composing of Polaroid lens



Fig. 7.12: Principle of polarized lens is best illustrated by observing Venetian blinds which blocks light at certain angles, while allows light to transmit through it at certain other angle

APPLICATION OF POLARIZED LENSES

Polarizing filters are created by stretching sheets of polyvinyl alcohol (PVA) so that its molecules align in long directional chains. The PVA is then passed through an iodine solution where the light absorbing iodine molecules attach to the molecular chains forming the microscopic blinds. The film so prepared is sandwiched in the lens. The back surface of the lens is cast first and the precurved Polaroid film is placed on the cast part and then liquid material is injected over. Polarizing filters are aligned 90° to the angle of the polarized light.

As spectacle lenses are designed to eliminate the polarized light in the horizontal plane, the filter is placed vertically in the eyewear or eye rim. This means that the filter must be properly aligned during surfacing and edging layout, otherwise filters will not work properly.

ADVANTAGES OF POLAROID LENSES

- 1. Filters glares
- 2. Enhances contrast and depth perception
- 3. Reduces eye strain, greater comfort
- 4. Improves visual acuity, provides safety
- 5. Eyes feel rested
- 6. Realistic perception
- 7. Reduces reflection
- 8. Comfortable and attractive looking sun wear.

TINTS VS. POLARIZED LENSES

Although, darkly tinted sunglasses may reduce brightness, they do not remove glares like polarized lenses. In addition, dark sunglasses without added ultraviolet protection may cause more damage to the patients eyes than not wearing sunglasses at all. The darkness of the lens can cause the pupil to dilate, letting more ultraviolet rays into the inner parts of the eyes. Polarized lenses solve both problems by eliminating glares and filtering out harmful ultraviolet light because the filter reduces the polarized glare and also has UV absorbing properties.



With ordinary sunglasses

With polaroid sunglasses

Fig. 7.13

DISPENSING TIPS FOR POLAROID LENSES

Boaters, fishers and water sports players have used polarized sunglasses to reduce the effect of glare from water surface. In the past few years, the benefits of polarized lenses have been realized by a variety of other outdoor sports enthusiasts as well as by drivers and general use wearers. Besides them, the skiers, golfers, bikers, and joggers can also enjoy a clearer view and elimination of glare from polaroid lenses. It is also suited for patients with eye ailments like cataracts, albinism, aniridia etc.

However, polarized lenses may react adversely with liquid crystal display (LCDs) found on the dash board of some cars or in other places such as digital screen on automatic letter machines. The problem with LCDs is that when viewed through polarized lenses from a certain angle, they can be invisible.

PRESCRIBING TINTS

The scope and application of colour lenses are huge and varied. With usage ranging from pure aesthetics, fashion and sports to medical and safety applications, and with the infinite variety of fixed tints, graduated tints and variable tints, it can be difficult to know which tint can be best suited to the wearer. While cosmetic choice is a primary factor in choosing a colour, there are also many other reasons for the opticians to prescribe tinted lenses. These may include the followings:

Luminous Transmission Factor: Transmission level is specified in terms of luminous transmission as a percentage of the light transmitted. For example, LT 80 brown tint lens transmits 80% of the light averaged over the visible spectrum. The colour of a tinted lens is an indication of its absorption characteristics but the exact transmission can only be found by measuring on a scanning spectrophotometer. By specifying the light transmission factor precisely, corrections can be made easily if the tint is too light or too dark.

Light Sensitivity: Light sensitivity or photophobia is a common eye complaint. It can result from several different conditions. Many a times a patient will complain of light sensitivity, for which no logical explanation can be given. Most of these individual tends to be fair skinned, with blue eyes. The treatment is the judicious use of tinted glasses to relieve their symptoms. Usually those with some light sensitivity will choose grey, green and blue and reject orange and yellow. The reason is likely to be that yellow and orange are at or near the peak spectral sensitivity of the eye. On the scale of light sensitivity, even green can be too bright for some people.

Contrast Enhancement: Contrast filters are generally red, orange, yellow and light green. They tend to allow the transmission of light that is the same as the colour of the filter and promote tonal separation in that colour. At the same time they tend to suppress other colour. The bright contrasting effect is achieved by absorbing blue and UV - both of which contribute to a veiling background haze. Contrast enhancement can be achieved with green, yellow, brown and red tinted lenses – the choice again depends on colour preference and use. Yellow has a limited application in bright sunlight because it transmits visible light at the eyes peak sensitivity.

Reduced Migraines: Patient who experiences migraines may be hypersensitive to the visual stimuli. Colour filters can reduce symptoms caused by these stimuli. The choice of lens colour may also be an important factor to reduce migraines. In one study, children who wore lenses with either pink or a blue tint experience migraines less frequently after 1 month. At 4 months, however children wearing only pink tinted lens continued to experience migraines less frequently.

Reading Comfort and Performance: Tinted lenses may filter out certain light frequencies and reduce the amount of information the eyes absorb. Some researchers believe that by reducing the amount of information, the brain can process better what the eyes see. Another study of children and adults with learning disabilities showed that the rate of reading was significantly faster in the subjects who read with glasses that had a coloured overlay compared with those who read with glasses without a colour overlay. Research by Optometrist Mr. Harold A. Solan from New York, has demonstrated that blue light filters are superior to the other colour filters for this purpose. It caused improvement in the number of fixations and regression and rate of reading in children with learning disabilities.

Driving Factors: Lenses for driving must not be too dark, as they reduce visual acuity. It is essential to offer protection to the eyes while driving in order to see better, react quickly to dangerous conditions and improve safety. A brown tinted lens is ideal for drivers for day time driving as they reduce the transmission of blue light. But it is too dark to use in the night. Night driving lenses would typically have a yellow tint or amber tint with antireflection coating which may improve contrast and reduce glare.

There may be a possibility that the subject may not be very comfortable with any tint and he rejects all the colours. But the normal requirements of protections still apply – everyone should protect their eyes in bright sunlight. In practice, a neutral density grey filter would be used by this group. Contrarily, if all the colours are equally liked, then the tint can be chosen on optical principles, say when required for sunglass, a brown tint which has UV absorption and contrast enhancing properties would be better.

BLUE LIGHT HAZARDS

We know that sunlight is divided into various families by wavelength of light: ultraviolet, visible light and infrared and others. In the atmosphere, the first natural barrier encountered by the sun's radiation is ozone layer. Ozone minimizes the effect of ultraviolet radiations. Infrared radiation is filtered out by water droplets in suspension in the lower levels of



Fig. 7.14: Blue -violet light hazards



Fig. 7.15: Corning CPF lenses

atmosphere. We are left with visible light. In the recent past studies have been done to examine the effect of blue - violet end of the visible spectrum. Although, they do not cause severe damage to the eyes, they do desensitize the eyes to light. The nature of blue light is such that they are randomly diffused, both in the atmosphere and within the human eyes. Rather than reaching to a focus on the retina, blue light spreads in the whole interior of the eye, causing dazzle. This phenomenon may not trouble the normal, healthy eyes, but may affect severely where pathologies like cataracts, diabetic retinopathy, macular degeneration, retinitis pigmentosa, corneal dystrophy, albinism, aniridia and glaucoma are present. The contrast may reduce and the objects may appear flat and washed out. Not only outdoors, blue light is present indoors, in fluorescent tubes, television or computer screens. Specially –designed lenses are needed to combat its adverse effects. Corning has introduced a range of CPF photochromic filters. They include CPF 450, CPF 511, CPF 527, CPF 550 and others. They have varieties of applications and can be used indoors as well as outdoors.

Anti-reflection Coated Lens

The normal eye is easily adapted to different lighting conditions. Thus, the loss of light due to reflection is usually not serious enough to reduce visibility except where poor lighting condition already exist. It is the reflected light which enters the pupil of the eye along the same path as the light used in "seeing" an object that is of primary importance. Whenever light is incident on the boundary between two medium, some light is reflected and some is transmitted, and the transmitted light undergoes refraction into the second medium. Anti-reflection coating are applied on the lens surface to efficiently manipulate the light transmission and reflection through it. It has been seen that the surface reflectance can be reduced by coating the lens with a film of some materials having a lower refractive index than that of the lens. Although, there are now two reflections - one at the exposed surface of the film and another at the lens surface, their combined effect produces less reflection than the uncoated surface. The result is, patient experiences a marked sensation of improved vision. There is no doubt that antireflection coating leads to greater patient comfort.

THE REFLECTION OF LIGHT

Dr Rayton presented some of the problems encountered due to reflections of light in spectacle lenses. There are four definable sources of reflection that can cause annoyance to the spectacle lens wearer:

1. Frontal Reflection: Frontal reflection occurs when some of the light incident on the front surface is reflected back towards an observer as shown in Figure 8.1B. This can be disconcerting for the observer, as the wearer's eyes are difficult to observe. Communications between human relies just not on spoken or written words but also by facial expressions, much of which are centered on the eye's reactions. Inability to see the eyes of a person you are talking to can be rather "off - putting" as one cannot deduce whether what is being said is actually being understood. These reflections are also annoying from purely a cosmetic point of view as they detract from the overall appearance.

- 2. Backward Reflection: Backward reflections occur when some of the light behind the patient is reflected from the back surface of the lens into his eyes as shown in Figure 8.1A. This can be annoying at times when reduced lighting conditions are encountered such as at dusk or while driving at night.
- **3. Internal Reflection:** Internal reflection is caused by light being reflected between the two lens surfaces as shown in Figure 8.1C. The amount of reflection caused in this manner depends upon the power and position of the lens in front of the eyes.
- **4. Corneal Reflection:** Corneal reflection is caused by light being reflected from the corneal surface and then interacting with the lens surfaces as shown in Figures 8.1D and E.



Fig. 8.1

- A. Light reflected from the rear lens surface into the eye
- B. Light reflected from the front lens surface into the eye
- C. Light entering the eye after double reflection within lens
- D. Light reflected by cornea to rear lens surface and back into the eye
- E. Light reflected by cornea to front lens surface and back into the eye

While frontal reflections would appear only to be a cosmetic problem they do reduce the amount of light transmitted through to the eyes. Backward, internal and corneal reflections all cause ghost imaging that in turn can lead to reduce visual acuity due to blurring and reduced contrast, which overall reduces the effectiveness of the prescription lens and thereby reduces its efficiency.

PRINCIPLE OF ANTI-REFLECTION COATING

Anti-reflection coating is applied on the lens surface to reduce the loss of light due to reflection and increase the light transmittance through the lens to the eyes. To understand how it is achieved, we need to remember "Quantum theory" that tells that the light travels in waves similar to those in the ocean.



The "Principle of Optical Interference" explains that there are two types of optical interference:

- Destructive Interference, and
- Constructive Interference.

Destructive interference occurs when the light waves are traveling out of phase with each other. When this occurs the peak of the wave is lined up with the trough of another wave and they virtually cancel each other out.



Fig. 8.3: Destructive interference

With constructive interference we have the opposite effect happening. In this case the light waves are traveling in phase with each other so that the peaks and troughs of one wave line up with the peaks and troughs of another wave. They are now working together creating one larger wave.

Anti-reflection Coated Lens 87



Fig. 8.4: Constructive interference

With anti-reflection coating the optical effect that is used to reduce the surface reflection is based on destructive interference. It works by interposing a transparent layer, i.e. the coating; we cause two reflections – the first from the surface layer itself and the second from the lens surface. If the thickness of the layer is made a quarter of a wavelength thick, the two reflected rays will be out of the phase with one another by half a wavelength. This is because the rays reflected from the lens surface have to travel through the layer and then back again. Being out of phase with one another they effectively cancel or eliminate each other, thus destroying the reflection.

SINGLE LAYER ANTI-REFLECTION COATING

The simple principle of single layer anti-reflection coating is that the substrate (lens) is coated with a thin layer of material so that reflection from the outer surface of the film and the outer surface of the substrate cancel each other by destructive interference. To achieve this we take the advantage of the undulatory nature of light by creating opposition of phases between reflected waves.

If we place a thin coating on the lens, the light beam, which is a series of waves, hits the coating and breaks up into reflected waves and refracted waves. The refracted waves then hit the lens and split second time into reflected and refracted waves. By a careful calculation of the thickness and index, in such a way that the first series of reflected waves and the second are super imposed while being out of the phase by half a wavelength, we obtain mutual cancellation. Light which is not reflected is refracted.



Fig. 8.5: Principle of anti-reflection coating

However, in practice it is impossible to attain total extinction of reflection just by depositing a single layer of coating on the lens. In fact, the reflection could be almost eliminated by meeting two conditions:

1. The refractive index of the coating is the square root of that of the lens material.

ⁿ film =
$$\sqrt{{}^{n}Substrate}$$

 The thickness of the coating, multiplied by its refractive index, is exactly one – quarter of a wavelength of light or any odd number of quarter wavelengths.

Unfortunately, this is not always obtainable. Crown glass with a refractive index of 1.523 would need a material with an index of 1.234, whereas the most suitable material available for glass is Magnesium Fluoride which has a refractive index of around 1.38. So it is not very well suited for crown glasses but its performance is better on higher index materials. Also the two necessary conditions can be met for only one wavelength. This is the reason why single layer anti-reflection coating cannot reduce the reflectance in the entire range of visible spectrum. Single layer coatings are designed to give their maximum effect in the middle and brightest region of the visible spectrum. The reflectance gradually increases towards both violet and red ends of the spectrum. As a result, the coated surface presents the characteristics of purplish appearance which is described as bloom.

MULTILAYER ANTI-REFLECTION COATING

The limitations of the single layer antireflection coating can be overcome by multilayer coating which are now capable of almost extinguishing surface reflections from one end of the visible spectrum to the other. The coating may be two layers or more. The basic problem of a single layer antireflection coating is that the refractive index of the coating material is too high, resulting in too strong reflection from the first surface which cannot be cancelled completely by the comparatively weaker reflection from the substrate surface. In a two layer coating, the first surface reflection is cancelled by interference with two weaker reflections.



In a two layer coating, the outer layer is made of a low refractive index and the inner layer is made of a high refractive index material compared to the substrate.



On crown glass with refractive index of 1.523, the first layer of coating is applied with the material which has a refractive index of 1.70. Either beryllium oxide or magnesium oxide is used for this layer. And the top layer is coated with magnesium fluoride which has a refractive index of 1.38. Both beryllium oxide and magnesium oxide are soft materials and will not produce very durable coating. Although, it allows some freedom in the choice of coating materials and can give very low reflectance, the two layer coating is very restrictive in its design. As a consequence multilayer antireflection coatings have been developed to allow the refractive index of each layer to be chosen. The complex computer design techniques were developed to make multilayer coating based on the simple principles of interference and phase shifts. All methods consider the combined effect of various film elements. Each layer is influenced by the optical properties of the layer next to it. The properties of that layer are influenced by its environment. Clearly this represents at least a complex series of matrix multiplication where each matrix corresponds to a single layer. The efficiency is not necessarily directly related to the number of layers used, rather on correct selection of coating materials for refractive index, the thickness with which the layers are applied, and the adherence to the previous layer of the materials are all qualifications for an efficient multiple coating.

ADVANTAGES OF ANTI-REFLECTION COATING

Primarily reasons for recommending anti-reflection coating to the eyewear consumer are:

- People see better with anti-reflection coated lenses as anti-reflection coated lenses transmit more lights. Conventional glass or plastic gains 8% in light transmission. High index lenses gain even more 11% to 16% depending on the materials. Increased light means wearer sees things brighter and clearer, with crisper details.
- 2. While looking at a person wearing uncoated lenses, we see reflection of light that is actually coming from the front surface of the lenses. This can be disconcerting for the observer, as the wearer's eyes are difficult to observe, creating a barrier between the observer and the wearer. By getting rid of the reflections, the lenses seem to "disappear" into the frame.
- 3. Ghost images are a common experience with uncoated lenses, particularly while driving at night. These visual annoyances appear as dull images created by reflections coming from the internal lens surfaces. With minus correction, ghost images are crisp and reflected on the side of the light image towards the optical centre. With plus lenses, ghost images are larger, less distinct and appear away from the optical centre.

Most patients drive vehicles and understand the advantage of antireflection coating eliminating ghost images.

- 4. Reflections from back lens surfaces can also be annoying. This is most noticeable with sun lenses because the dark lens acts like a mirror. Backside reflections are also more prominent with aspheric lenses as their flatter inside surface reflects more light.
- Strong minus lenses can produce a "Coke bottle" look caused by light reflecting from thick lens edges. The reflection appears as a series of concentric rings. Modern anti-reflection coatings virtually eliminate these unsightly rings.
- 6. Anti-reflection coating has become popular in recent years. As a result, there is a growing perception among consumers that, quality eyewear include anti-reflection coating. Offices that do not routinely recommend anti-reflection coated lenses, risk having patient learn about it from a friend, neighbour or a competitors advertising.

ANTI-REFLECTION COATING OF PRETINTED LENSES

Glass lenses in which the tint is in the lens material itself, may also be antireflection coated. This is quite advantageous in several situations:

- 1. If a person desires a light tint in his lenses and yet it is felt that night vision is hindered by it, anti-reflection coating may return the glass to its previous non-tinted transmission. For example, pink tint may reduce the lens transmission from 92% to 88%. Anti-reflection coating on the lens will bring the transmission back to at least 92%, while multi-layer coating may increase the transmission to above 92%. In spite of the increased transmission, the pink lens maintains its characteristic of light coloured appearance.
- 2. Sun lenses may be antireflection coated to advantage as well. For example, the patient may find reflections from the back surface of the sun lens disturbing. This is a genuine complaint because of the reflection coming from behind. An anti-reflection coating allows majority of light coming from behind the wearer to pass on through the lens without being reflected back into the eyes.
- 3. Photochromatic lenses may be anti-reflection coated. This will increase both maximum and minimum transmission by a certain amount. The lens will transmit more light in both the lightened and the darkened state. It also helps when lenses are dark by reducing backside reflections from dark lenses.

DISPENSING TIPS

In dispensing anti-reflection coated lenses, always remember not to sell half pair lens. Whenever only one lens is required, most laboratories will

strip anti-reflection coating from the old lens and recoat both lenses together for an exact colour match. Never use a stock anti-reflection coated lens for one eye and order custom anti-reflection coating for the other. Inevitably, there will be a slight colour difference in the anti-reflection coating. The difference in colour has no effect on vision but is always noticed by the patient.

Be sure to explain that anti-reflection lenses must never be cleaned dry, as this can scratch the coating. The best cleaner is one that is made especially for anti-reflection coated lenses. Patient should not use acetone, windex, caustic solution or soaps to clean the anti-reflection coated lenses. Make sure that every eyewear patient going through the office gets an explanation and demonstration of anti-reflection coatings benefits. This ensures that every patient understands you are trained and skilled in dispensing what has become accepted as the most advanced modern eye wear available.

TECHNOLOGY OF ANTI-REFLECTION COATING

Anti-reflection coating requires great technical expertise and very high quality pure coating material. The technology consists of stacking thin layers with specific characteristics to achieve overall result and is done inside a vacuum chamber. The lens to be coated must be absolutely free of surface defects, perfectly cleaned and rid of dust or any other impurities before they are placed in the vacuum chamber. Extremely low pressure is created inside the chamber by removing the air from it and a very high temperature has to be ensured which is fine for mineral glass lens but not for resin lens. Material used for coating must be heated to 1000 deg C/1800 deg F to 2200 deg C/4000 deg F to bring it to gaseous state. The several layers of transparent materials are evaporated by a very high energy evaporator. The lens surfaces are charged electrically to create an attraction between the lens surface and the material. Coupled with the use of sophisticated microprocessor controls of pressure, temperature and evaporation rate and other technological advances with regard to adhesion of coating to lens surface has allowed the application of very durable coating to most lens types. The end result is lenses that provide enhanced cosmetic appeal, fewer ghost images, improved contrast and therefore, improved optical performances.

However, glass lenses can be heated up to 300 deg C/570 deg F, but plastics heated above 100 deg C/210 deg F turn yellow and then decompose very fast. Magnesium fluoride used to coat glass lens has no adhesion, if applied below 200 deg C/400 deg F. Hence, plastic lens coating requires more complex stacking procedure with low index layers made of silica.

Aspheric Lenses

The term "aspheric" has been widely used in recent years to describe the surfaces of the various lens designs. The literal meaning of "aspheric" is simply "not spherical", which means cylinder surfaces or toroidal surfaces used for astigmatic correction. Quite often progressive addition lens surface is also described as "aspheric". In terms of "lens designing" the term "aspherical" usually refers to a surface that is rotationally symmetrical, but at the same time not spherical. A change in curvature is noticed over the lens surface, rather than constant curvature like a spherical surface. The change is the same in all direction or meridians of the lens. The "asphericity" is achieved by flattening the periphery of the front surface in plus lens and by steepening the periphery of the front surface in minus lens and/or by flattening the periphery of the back surface to reduce the edge thickness. Using the "asphericity" the lens designers are able to produce thinner and flatter lens that also provide peripheral vision comparable to the best form lens. The off-axis performance of the lens improves considerably. The lens looks flatter which makes the eyes look more natural due to reduced magnification or minification. Also flatter lens fits better ensuring the attractive look of the spectacles, thereby, offering the subjects a wider variety of frames to choose from. If the aspheric lens design is coupled with high index material, it will definitely provide thinner, lighter and flatter lens that looks cosmetically the best.



Fig. 9.1: Comparison between aspheric and spheric surface

WHY ASPHERIC?

Unfortunately several lens aberrations affect the quality of peripheral vision through a spectacle lens. Oblique astigmatism is the principal lens aberration that is considered to be the most serious defect in designing the

ophthalmic lens. When the rays of light strike the periphery of the lens obliquely, two focal lines are produced from each single object point. The dioptric difference between these two focal lines is known as the astigmatic error of the lens. The effect of this aberration is the reduction in wearer's field of clear vision through the lens. For conventional lens, front surface base curve selection is one of the primary tools used to reduce the lens aberrations. Flatter base curves produce cosmetically appealing lenses that are flatter, thinner and lighter in weight. They are easily retained in the frames as well. However, flattening the base curves introduces significant aberrations in the periphery of the lens as shown in Figure 9.2.



Fig. 9.2: A comparison between steeper and flatter lenses. The steeper lens provides better off- axis optics, while the flatter lens provides better cosmetics

So it is established that while the best form lens gives the least oblique astigmatism, the flat lens gives the least bulbous appearance. The solution, therefore, is one of the many aspheric design lenses available in the market today.

ASPHERIC LENS DESIGN

Three dimensional aspheric surfaces are produced by rotating non-circular curves about an axis of symmetry. The central curvature or vertex curvature of an aspheric surface is nearly spherical which is the front curve value utilized for lens power and surfacing calculations. Away from the vertex curvature, the amount of surface astigmatism smoothly increases. The rate of increase in surface astigmatism depends upon the degree or type of asphericity. Figure 9.3 demonstrates the surface created by rotating an ellipse about an axis of symmetry. We can notice the changing radii of curvature in both the tangential and sagittal planes of the lens. This surface astigmatism is designed to neutralize the oblique astigmatism produced as the wearer looks away from the centre of the lens. Original aspheric designs utilized conicoid surfaces, which are produced by rotating a conic section about an axis of symmetry to produce a three dimensional surface. Modern aspheric lenses, however, often employ higher order surfaces that allow for more complex shapes than the simple conic sections.



Fig. 9.3: Anatomy of an aspheric surface. This elliptical curve has a radius of curvature that gradually changes away from the centre. When the ellipse is being rotated about the axis of symmetry, it produces a three-dimensional conicoid surface



Since, flattening a lens introduces astigmatic and power error, the peripheral curvature of the aspheric surface should change in a manner that neutralizes this effect. For example, plus lenses with asphericity on the front surface requires a flattening of curvature away from the centre of the lens to reduce the effective gain in oblique power and astigmatic error. Asphericity on the back surface will require steepening of curvature away from the centre of the lens. The opposite holds true for minus lenses, which can also benefit from asphericity.



Fig. 9.5: Aspheric versus spherical surface

Proper base curve selection as recommended by the manufacturer is critical for an aspheric surface. Even the smaller increments of surface power affect the base curve selection quite considerably. Consequently, aspheric lenses have more base curves options. Substituting aspheric base curves can often have a negative impact on the off-axis performance of the lens. Flatter base curves produce thinner lenses. It is interesting to note that the actual geometry of an aspheric surface helps reduce lens thickness also. This is a consequence of the fact that the sag of an aspheric surface differs from the sag of a spherical surface. Consider the comparison made in Figure 9.5. At a given diameter; the aspheric surface has shallower sag than the spherical surface.



Fig. 9.6: Sagittal depth, conventional versus aspheric lens design

MEASURING AN ASPHERIC SURFACE

Since the curvature of an aspheric surface varies from the centre to the periphery, normal measuring instruments cannot measure the front curve value or vertex curvature of an aspheric lens accurately. The manufacturers occasionally publish the design of their lenses, which enables to determine



whether the correct design has been supplied. The most common qualitative test to detect whether or not a lens is spherical is to use a lens measure in a sagittal section across the front surface. Spherical or toroidal surface will give a constant reading, whereas aspheric surface will vary in power from the centre to periphery. However, in low power the change in surface curvature towards the edge of the lens is so subtle that it becomes difficult to verify with the instrument.

PRISM IN ASPHERIC LENSES

The geometric centre of the aspheric lens is to be aligned with the optical centre of the patient's eyes. This accurate centering of the aspheric lens, throws up an issue with the prescribed prism. Some optical dispensers like to achieve prismatic effect by decentring the lens. Clearly this will move the geometric centre of the lens away from the optical axis of the eye which will cause unwanted optical problems for the patient. In order to maintain the alignment of the aspheric geometrical centre with the pupil and also have prism in the lens, we need to order the lens with surfaced prism. Typically the lens will have aspheric front side and the rear surface with prism and cylinder surfaced in it. However, the true benefit of aspheric lens is achieved only when the optical centre of the eye is in alignment with geometric centre of the aspheric lens, which is also the pole of the aspheric surface. In a true aspheric lens, asphericity begins right near the centre of the lens which also prevents shifting of centre to create prism. This suggests grinding prism to decentre the lens is also not the right practice in aspheric lens.

ASPHERIC LENSES FOR APHAKIC PATIENTS

Aphakic spectacle correction requires powers of + 8.00D to + 15.00D. Such a high power correction produces a number of difficulties like:

- Magnification
- Decreased field of view
- · Aberration and swimming of object in the field of view
- "Popeye" appearance of patients
- Sensitivity to exact position of the lenses.
- Lens weight and thickness.

Various design approaches have been applied to cataract lenses. There are two main approaches the "foveal philosophy" and the "peripheral philosophy". Both use the aspheric curve designing. Foveal philosophy parallels the standard lens design philosophy, trying to give the patient the largest possible dynamic field of view, which is not possible with the spherical curves. Therefore, aspheric curves are used. Peripheral philosophy assumes that aphakics are more of head turner than eye turner. Therefore it uses the front surface curves of diminishing power away from the centre to reduce the lens thickness and weight of the lens.

Most of the lens manufacturer offer CR₃₉ aspheric lens with convex prolate ellipsoidal surfaces. These series are available in both full aperture and lenticular form, usually with a forty millimetre diameter. They can also be obtained in bifocal forms with round segment and 'D' shapes segment. However, the segment surface itself is not aspherical and since it is cast on ellipsoidal distance portion, the segment tends to be oval shape rather than circular. It is very important while dispensing these high power aspheric lenses that they are carefully centred both vertically and horizontally, as incorrect centration may well obviate the advantage of the ellipsoidal surface.



Fig. 9.8: Postcataract aspheric lenses
Mostly aphakic lenses are made in lenticular design in which central aperture incorporates the optical correction, and is surrounded by a carrier or margin of lower power or even afocal. Natural, sharp and foveal vision is only possible when the wearer views through the aperture. During 1970 aspheric lenses was introduced in which the dividing line between the aperture and margin was blended to make it invisible, Removal of dividing line both improved the appearance of the lenses as well as field of vision by removing the ring scotoma associated with the abrupt change in power at the edge of the aperture.

With the advent of CNC grinding technology, it became possible to design and manufacture surfaces of almost any complexities. This led the introduction of convex surface that is polynomial form.

For example, in the Figure 9.9 the zone ab is having the same optical properties on aspheric lens that employs an ellipsoidal surface. It could be free from aberrational astigmatism. Zone bc is seen to be concave in its tangential section. The surface flexes backwards in this region. Since the surface is continuous, there is no annular scotoma between the central ellipsoidal zone and the margin. Zone cd has the same purpose as that of the margin of the lenticular design, i.e. supporting the central aperture.

There are two important advantages:

Firstly, the aspheric zone has excellent optical properties, and does not have any aberrational astigmatism of spherical surface.

Secondly, the blending is concave which eliminates the ring scotoma that exists at the edges of every plus lens, which is so annoying.



Fig. 9.9: Cataract lens design with convex polynomial surface

However, today's fact is the aphakic lenses are not much used any more. Implants are almost universal and they allow the use of ordinary correction. A great number of patients go for contact lenses. They need glasses for part time use. A few still have true aphakia, which may take advantage of these lenses.

CHECKING LENS POWER IN ASPHERIC LENS

The lens power in case of aspheric lenses can be measured on the focimeter so that it is aligned through the geometric centre or middle of aspheric side of the lens. In this area of the lens, the correct power as per the prescription can be seen. As we move away from the geometric centre of aspheric surface, the prescription alters- incline with the way the lens surface changes power. The aspheric lens designer specifies a portion, which will be the central region of aspheric side of the lens to be assured of 100% full prescription; the rest of the lens will have a different prescription. The size of this portion depends on the formula, the designer used to formulate the shape of the curves.

DISPENSING TIPS

Aspheric lenses represent the ultimate in optics . Using the aspheric curves in a lens produces two benefits: better vision and improved cosmetics. This immediately places the lens into the premium category, providing better profits for every one. This imposes an additional responsibility on dispenser because aspheric can be less forgiving than conventional lenses and requires more precise positioning by the dispenser. A poorly fitted aspheric lens



Fig. 9.10: Aspheric fitting guide

can adversely affect its all benefits. Fitting of aspheric lenses is somewhat similar to the way progressive lenses are fitted.

Pupillary distance: Precise monocular PD measurements position is essential to point the pole of the lens in front of pupil.

Vertical height: The vertical height of each pupil centre is marked on the dummy lens of the selected frame.

Rotation: Rotation of the eye must be considered. This requires lowering the optical centre based on the pantoscopic angle of the frame. The rule is to lower the optical centre 1 mm for every 2 degrees of pantoscopic tilt. However, the maximum drop is 5 mm.

SUMMARY

Aspheric lenses have really changed the trend in the ophthalmic lens designing. The research is still on to make the lens thinner and to improve the optics. But whatever development occurs, it must be correctly fitted to really get their advantage.

Bifocal Lenses

Eyes age along with rest of us and vision stealing problem becomes more troublesome beginning in the middle age. Usually around the age of 40 years, when a person is found squinting at the newsprint held at the arm's length, he has achieved the middle age milestone: *the arrival of presbyopia*. A presbyopic subject requires a separate correction for distance and near vision, the two prescriptions may be provided as one pair of spectacle in the form of a bifocal lens. A bifocal lens is defined as having two portions of different focal power. The area of the lens used for distance vision is called Distance portion or DP and the area used for near vision is called the Near Portion or Reading Portion or NP. The larger of these two portions is referred to as the main lens (the exception being the up curve bifocal).

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The first recorded mention of bifocal spectacle lens is a letter written by Benjamin Franklin in 1784 in which he described a pair of spectacles incorporating such lenses. These were made by the relatively crude method of splitting a distance and a near lens, then mounting the top half of the distance and the bottom half of the near together and were fitted edge-toedge in a single rim as shown in Figure 10.1.



Fig. 10.1: Split bifocal (Franklin design)

This approach is still in use for prescriptions that cannot be manufactured using mass production technique, an example being where a large amount of prism is required at near but not at distance. Following Franklin's invention, the bifocal lens evolved through a number of stages before the development of modern fused and one-piece bifocal lenses early in this century. Modern version is cosmetically and mechanically improved to suit the mass production also.

TYPES OF BIFOCAL LENSES

Bifocal lenses can be obtained in four basic constructional types: Fused bifocals, Solid bifocal, Cemented bifocal and Split bifocal.

FUSED BIFOCAL

The first fused bifocal was the fused kryptok invented by Borsch in the year 1908. In countries, where glass lens still represent a sizeable section of the market, the fused bifocal remains the most common form of bifocal design. The round segment is still in production for some markets but no doubt, the most commonly used segments are D-shaped flat top or the C-shaped curved top as shown in Figure 10.2.



Fig. 10.2: Fused bifocal design (A) Round segment (B) D segment flat top (C) C segment curved top

The segment is permanently bonded onto the convex surface of the lens by heat fusion process and the required addition depends upon:

- 1. The refractive indices of the two glass materials.
- 2. The depression curve.
- 3. The curve worked on the segment side of the lens.

To fuse a segmented bifocal, a countersink cavity is produced on the front surface or the convex side of the crown lens having a refractive index of 1.523. A flint glass of high refractive index usually of 1.654 is taken. The front surface of the flint button is simply left and a predetermined contact surface is worked on the rear surface of the button to match the curve on the crown blank.



Fig. 10.3: Construction of fused bifocal: (A) Components prior to fusing, (B) Rough fused blank (C) Semi-finished fused blank

The curve on the contact surface of the button is deliberately made some 0.25D to 0.50D steeper than the depression curve on the corresponding crown blanks so that initially, contact is only made at the centre of the curves. The button is placed on the depressed crown portion and the assembled components are then placed on a carborundom block, the surface of which has been molded to match the curve on the back of the crown glass major and the blocks are then kept into the furnace. At around 640°C the button softens and sags under its own weight, gradually expelling air towards the wire feeler. The steeper curve on the button aids this procedure by tending to unroll the depression curve towards the feeler. Eventually, the whole surface of the button is in contact with the depression curve except for two very small areas around the supporting wires. The resultant fused blanks are then put into rigorous inspection. If, by chance, some dust has remained between the surfaces, a bubble is formed, which may result in rejection of the blank. Since, the front curve is continuous over the distance and near portion; the dividing line of the fused bifocal segment cannot be felt.

Shaped bifocals like D segments, B segments, C segments and curve top bifocals can be produced by means of composite buttons, made up of two or three different glasses. In each of these cases the composite button consists of a crown component and a flint component. The crown portion must have exact refractive index as the main crown glasses. In case of shaped bifocal, the shape of the segment must be checked and if necessary it must be corrected so that it has the required segment diameter and segment depth. This can be achieved by grinding a small amount of vertical prism relative to the segment side surface.



Fig. 10.4: Composite buttons for different bifocal shapes (A) D – Segment flat top bifocal. (B) B – Segment

Reading Addition of a Fused Bifocal

The fused bifocal is produced by fusing a higher index flint to the main crown glass. A countersink cavity having a specific depression curve is made onto the convex side of the crown glass whereon the flint is fused at a high temperature. If we can find out the curvature required for the countersink cavity, we can determine the resultant addition. Therefore, the following factors determine the addition:

- The refractive index of the crown glass, denoted by n and the refractive index of the flint glass denoted by n_f.
- 2. The front surface power of the distance portion of the crown glass, say F_{1} .
- 3. The front surface power over the segment area, say F₃ which is greater owing to the higher refractive index of the glass of the segment.
- 4. The depression curve to which the flint button is fused has a power in air, say Fc.
- 5. The power of the contact surface of the button in situ denoted by $F_{con'}$ which also forms the part of the total addition.

Therefore, the addition from the front surface would be $(F_3 - F_1)$. But the total addition would also be affected by the contact surface of the button in situ, i.e., F_{con} . The total addition for near A, therefore, would be the sum of these two components:

$$\mathbf{A} = (\mathbf{F}_3 - \mathbf{F}_1) + \mathbf{F}_{con}$$





Fig. 10.5: Stages to manufacture round segment bifocal

The quantity $(F_3 - F_1)$ is the function of the refractive indices of the respective materials and hence can be shown to be equal to $F_1 (n_f - n) / (n - 1)$. Similarly, F_{con} can be shown to be equal to $-Fc (n_f - n) / (n - 1)$. Substituting the values:

	А	=	$F_1\left(\frac{n_f-n}{n-1}\right) - F_c\left(\frac{n_f-n}{n-1}\right)$
Or,	А	=	$F_1(K) - F_c(K)_{n-1}$
Or,	А	=	$K(F_1 - F_c) = \left\lfloor \frac{n-1}{n_c - n} \right\rfloor$
Or,	A/K	=	$F_1 - F_c$
Or,	F _c	=	$F_1 - A/K$
<i>.</i>	F _c	=	$F_1 - A$

Example:

(1) Consider a lens with F_1 of + 6.00D and refractive index of 1.523 and 1.654 for n and n_f respectively. If required addition is + 2.00, then

$$F_{\rm c} = 6 - (0.523/0.131) 2$$

$$= -1.98D$$

SOLID BIFOCAL

Solid bifocal can be considered as one piece bifocal, made from single piece of material. They can be made by molding or casting one surface and working the other (usually plastics), by molding or casting both the surfaces (almost always plastics) or by working both the surfaces (almost always glass). Most segment shapes and sizes, from E style to round are available as solid plastic bifocals. Blended bifocals are solid, usually round segment bifocals in which the segment edge blends into the distance portion.



Fig. 10.6: The solid bifocal in which the reading addition is the difference between the RP curve and the DP curve. (A) segment on the concave surface. (B) segment on the convex surface

The reading addition of a solid bifocal is obtained by raising a second curve on one surface of the lens to form the segment. The segment can be worked on either side of the lens. The surface on the segment side of the lens that forms the part of the distance power is called the DP surface and the power of this surface is referred to as the DP curve. The raised curve on the segment side that forms the near power is called the segment surface and its power is known as RP curve. The reading addition is the difference between the RP curve and the DP curve. Thus, if the segment is on the convex surface of the lens and the DP curve is + 6.00D and the RP curve is + 8.00D, the reading addition would be + 2.00D. Alternatively, if the segment is situated on the concave side of the lens and the DP curve is -6.00D, then to produce a reading addition of + 2.00D, the RP curve would have to be - 4.00D.

CEMENTED BIFOCAL

A segment is glued onto the surface of a single vision lens. Theoretically, almost any prescription can be obtained and it is also possible to get almost any shape of segment, in any position on the main lens. Traditionally they are made from glasses but they can be made from plastic materials too. Until about 1960, the adhesive in common use was Canada balsam – a resin exuded by the balsam fir tree. Canada balsam was easy to apply and reapply, but its adhesive is deteriorated after being subjected to mechanical, thermal or chemical shock. More recently, ultraviolet cured epoxy resins have replaced Canada balsam and provide excellent long-term adhesion of glass components.





Fig.10.7: Cemented bifocal

FRANKLIN BIFOCAL

Also known as split bifocal is made of two separate lenses held together by the frame. They are almost invariably an E-style bifocal, although very rarely they are made as very large segment diameter in down curve forms. They sometimes have their two sections bonded together and they can be made in either glass or plastic materials. Unfortunately, dirt tends to accumulate in the joint between the lenses, however well made they are and no matter how careful the subject is in cleaning them.

BIFOCAL SEGMENT SHAPES

Segments vary from tiny "B segment" to "E-style" in which the whole bottom half of the lens is used for near portion. Historically, there were huge number of segment shapes with minor variations and corresponding number of descriptions used for them. But now the apparent choice has reduced, so that a small number of terms can be used to cover all multifocals. The most popular bifocal shape at present in common use is probably Dsegment, E-style and round segment bifocal. B-segment and C-segment are relatively rare, while any other shape is almost unheard of.

ROUND SHAPED BIFOCAL

Round segment bifocal have a segment with a dividing line that is a single circular arc which is least visible compared to the other bifocals. When placed at the bottom half of the lens, they are often called "down curve" bifocal. The centre of the segment in round shape bifocal fall much below from the top, so they must be fitted a little higher than the other bifocals.



Fig. 10.8: Round segment bifocal

This gives rise to "jump" at the edge of the segment when the line of gaze passes from distance to near.

The kryptok bifocal is one of the most popular round bifocals. The design as developed by John L Borsch Jr, in 1908 made use of distance lens of crown and a segment lens of flint glass. The process involved fusing of flint glass into a countersink curve made on the convex side of the crown lens under a high temperature. If the heat is not carefully controlled during the fusing operation, the countersink curve will warp and will produce unwanted optical aberration.

The round Barium (Nokrome) bifocal differs from the kryptok bifocal in the use of high index barium glass for the segment instead of flint glass and in the close matching of the countersink curve and the rear surface of the button. Close matching of curves cuts down on the heat required for fusing process. This in turn results in more accurate curves and better lenses.

Round segment bifocal, especially those with low power having small segments are among the least conspicuous of conventional bifocals. Only the cosmetic or blended bifocals and the progressive addition lenses are less conspicuous multifocals.

D-SHAPED BIFOCAL

D segment bifocals are available in solid plastics and fused glass forms. They are a nice compromise lens, giving a relatively wide reading area at the point of visual entry into the segment, with less of a thickness problem than E-style. Cosmetically, the straight edge of D segment is little more noticeable and therefore cosmetically less attractive to many patients, than edge of round segment. There is still some jump at the edge of most D



Fig. 10.9: (A) Straight top D bifocal. (B) Curve top bifocal. (C) B segment bifocal. The dot indicates the geometric centre of the segment

segments, although it is less than round segments. A modified shape of D shape bifocal is C segments which are also available with a slight rounded top instead of flat tops. The principle advantage of C segments over D segments is probably in glazing and surfacing. Minor errors made in the cylinder axis during surfacing can be glazed to the correct axis and they can be far less noticeable. B segments are like a D bifocal with the bottom chopped off. Losing the top of the circle, as with the D-shaped bifocal, reduces the jump at the edge of the segment and losing the bottom gets rid of the area which is potentially the worst optically and thereby allows a clear view of the feet through the bottom.

E-STYLE BIFOCAL

E- Style Bifocal is one piece bifocal lens with two different curves ground usually on the front surface. The optical centre of both the distance and the near lens lie on the dividing line. It is, therefore, classified as monocentric bifocal. The difference in curves between the distance and the near portion of the lens produces a ledge that is most prominent towards the outer edge of the lens. E-style bifocals, popularly known as Executive bifocal are invariably solid bifocal. Most of optical centre of the distance and near portion on the dividing line gets rid of vertical image jump.



Fig. 10.10: E-style bifocal. The cross shows the position of optical centre

To locate the segment centre, hold the lens 4 to 5 inches away from a straight line and move the lens from left to right, the straight line will break as it passes from the upper portion of the lens to the segment. At the segment centre point, the straight line will have the continuity as shown in the Figure 10.11.



The big advantage of E-style bifocal is that the entire bottom half of the lens is for near vision. Thickness can be a problem in hypermetropic prescription. Because of the fact that both distance and near optical centre fall on the dividing line, the thickness of the finished lens is largely controlled by the resultant near prescription rather than the distance prescription. Hence, + 3.00D with + 3.00D addition would have a centre thickness is equivalent to + 6.00D, i.e. for a plus prescription the centre thickness can be comparable to -3.00D, i.e. the difference between distance prescription and the resultant near prescription. Prism thinning can reduce but can never eliminate the effect.



Fig. 10.12: Section through the common optical centres of distance and near areas of an E-style bifocal in case of plus prescription

Contrarily, in minus lens the centre thickness is affected by less power than the distance prescription, i.e. if the distance prescription is -4.00D and the near addition is +2.00D, then the sum of distance power and the near addition is -2.00D. So, the centre thickness can be comparable to -2.00D. Prism thinning can improve the appearance of the top edge.



Fig. 10.13: Section through the common optical centres of distance and near areas of an E-style bifocal in case of minus prescription

Another problem associated with the type of bifocal lens is the reflection from the top edge of the straight top bifocal which can be annoying to the patient. Reflection from this edge can often be seen by others, making the segment more obvious to others.



Fig. 10.14: Reflection from the top edge of straight top bifocals can be annoying to the patient. It can also be seen by others

OPTICAL CHARACTERISTICS OF BIFOCAL LENSES

Optical characteristics of bifocal lenses vary widely from one bifocal style to other, so they should be taken into consideration when selecting a bifocal segment style for a given patient.

IMAGE JUMP

When looking from distance portion to the near portion of a bifocal lens, the sudden change in the prismatic effect because of the introduction of the base down prism by the segment causes the world to "jump". This displacement of the patient's visual world can be very disturbing and often dangerous particularly with steps and kerbs. It has both vertical and horizontal element. Jump occurs all around the edge of the bifocal segment, although it is at the top part which is most frequently noticed.



Fig. 10.15: Jump at the bifocal dividing line

The base of the prism lies at the optical centre of the segment Os. Consider the eye viewing through the distance portion. As the gaze is lowered, the eye encounters an ever increasing prismatic effect as it rotates away from the optical centre of the distance portion. When the eye enters the near portion, it suddenly encounters the base down prism exerted by the segment at the segment top. The effect is twofold. Firstly, object that lies in the direction of AT, appears to lie in the direction BT. Apparently, they have jumped to a new position. Secondly, light from the angular zone BTA, around the edge of the segment, cannot enter the eye. The segment dividing line causes an annular scotoma within which the object is completely hidden until the wearer moves his head to shift the zone in which jump occurs.

The amount of jump is simply the magnitude of the prismatic effect exerted by the segment at its dividing line that is the product of the distance from the segment top to the segment optical centre, in centimeters and the power of the reading addition. For a round bifocal the distance from the segment top to the optical centre of the segment is simply the segment radius and therefore, for circular segments:

Jump = Segment radius in cms × reading addition.

But for shaped bifocal like B, C or D segments, the jump will be less as it is:

Jump = Reading addition × Distance to the centre of the circle of which the segment is part from the top edge.

For most of the E-style bifocal, with their distance and near optical centres coinciding at the dividing line, the jump is purely horizontal at points away from the common centre.

Clearly the jump is completely independent of the power of the main lens and the position of the distance optical centre. Jump increases as the distance from the segment top to the segment optical centre increases, i.e. in case of round segments as the segment diameter increases.





Fig. 10.16: Image jump at the top of round segment due to the segment alone is the product of the addition power and the radius of the segment in centimeters. For a shaped bifocal, say 'D' segment the prismatic effect at the top edge is the distance of the top edge from the centre of the circle of which the segment is the part multiplied by the addition





For example, if the reading addition is + 2.00D, the jump exerted by a 24 mm segment is 2.4 Δ BD in case of round segment bifocal.

But in case of D segment where segment size is, say, 28 x 19 and the segment centre lies just 5 mm below the segment top, the jump will be only 1.00Δ BD. Reduced jump is probably the one reason why shaped bifocal have proved to be so popular.

To eliminate the jump effect in a bifocal lens, it is necessary to work the segment in such a fashion that its optical centre coincides with the segment top.

PRISMATIC EFFECT

When a wearer uses single vision lens and he gazes downward to read through the lens, he encounters a prismatic effect. The prismatic effect will change in the near visual zone when he wears a bifocal lens. While determining the prismatic effect in the near portion, it is to be understood that bifocal lenses are made of two separate components – a main lens with a distance prescription and a supplementary segment lens with a power equal to reading addition.

The optical centre of the main lens, i.e., distance optical centre is referred to as O_D and the optical centre of the segment lens as O_s . The total power of the near portion is the sum of the distance portion power and the reading addition of the lens and the prismatic effect at some point in the near portion is given by the sum of the prismatic effect of the distance portion and the prismatic effect of the segment lens.

Consider a case of round shape bifocal lens as depicted in Figure 10.18 the prismatic effect at the NVP, 8 mm below the distance optical centre and 5 mm below the segment top can be determined as follows:

The prismatic effect at 8 mm below the optical centre in + 3.00D lens can be found out from the decent ration relationship P = cf, where C is the decent ration in centimeters and F is the power of the lens.

Hence, P = 0.8×3.00 = 2.4Δ BU

The segment would exert base down prism at the NVP which can be deduced as follows:

Suppose the segment diameter is 38 mm. The distance from the dividing line to the optical centre of the segment is 38/2 or 19 mm. Since, NVP lies 5 mm below the segment top, it must lie 14 mm above the segment centre. Hence, the prism from segment is:



Fig. 10.18: Prismatic effects at the near visual point (NVP) of a bifocal lens. O_{D} is the optical centre of the distance portion. O_{s} is the optical centre of the segment lens

The total prismatic effect at the NVP is the sum of 2.4Δ BU and 2.8Δ BD, which is 0.4Δ BD.

Now, consider a case of D-shape bifocal as shown in Figure 10.19. In this case D shape segment size of 28 x 19 mm has been prescribed. If we assume that NVP is located in exactly the same position 8 mm below the O_D and 5 mm below the segment top. The optical centre of the segment O_s now coincides with the NVP, so segment adds no prism at this point. So the net prismatic effect would be only 2.4 Δ BU, what is exerted by distance portion. This is an important advantage of the shaped bifocal.



Fig. 10.19: D-shaped segment of 28 × 19. Os is the optical centre of segment which lies 5 mm below the segment top and coincides with NVP





In case of E-style bifocal, the optical centre of the segment is positioned on the dividing line which is above the NVP and since the power of the segment is positive, the segment will exert base up prism. If we assume that NVP is located at the same position, i.e. 5 mm below the optical centre of the segment or the segment top, the prismatic effect would be:

$$P = 0.5 \times 2.00$$

= 1.0\Delta BU

The prismatic effect due to the distance lens would be:

$$P = 0.5 \times 3.00$$
$$= 1.5\Delta BU$$

The total prismatic effect would be 2.5Δ BU.

In case of minus power, the distance portion will exert base down prism. Consequently the prismatic effect will change depending upon the type of the segment shape. E-style bifocal will exert least prismatic effect in minus power. In case of straight top D shape bifocal which has an optical centre coinciding with the NVP, the vertical prismatic effect at reading level is due to the distance power only. Therefore, it does not change when the wearer switches from single vision to bifocal lens. The total vertical prismatic effect at the reading level is of practical importance as it determines the amount of transverse chromatic aberration the wearer will be subjected to.

CHROMATIC ABERRATION

Transverse Chromatic Aberration (TCA) arising out of the oblique rays is the potential problem for the wearer of the single vision lenses as well as bifocal lenses. The effect of TCA is the colour fringes to be seen surrounding the image of the high contrast targets, while looking through a point in the lens away from its optical centre. As a result of the fact that bifocal segment is viewed through the edge of the distance lens, problems can arise due to TCA arising from the distance vision prismatic effect. When the prismatic effect at a point is known, the TCA at that point can be found by dividing the prismatic effect by the Abbe Number for the material which is denoted by V, i.e.

TCA = P/V

(Where, P stands for the prismatic effect).

This paraxial relationship expresses the chromatism in prism dioptres and the average threshold value is in order of 0.1Δ . Chromatism less than this value are unlikely to give rise to complaints. In case of solid bifocals including both glass and plastic, the chromatism can be found simply by dividing the total prismatic effect at the point in question by the Abbe Number for the material. Thus, in case of solid bifocal of + 5.00D with reading addition + 2.00D, made with a 24mm diameter segment and a segment drop of 2mm, the vertical prismatic effect at a point 6 mm below the segment top is given by:

$$P = cf$$
Or,
$$P = 0.8 \times 5$$
Or,
$$P = 4.00\Delta BU$$

The prismatic effect due to segment is:

$$P = cf$$
Or,
$$P = 0.6 \times 2$$
Or,
$$P = 1.2\Delta BD$$

So, the total prismatic effect would be 2.8" Base Up, the horizontal prismatic effect being ignored. Therefore, TCA at this point would be, if the material is CR_{39} with Abbe number 58:

$$TCA = P/V$$

= 2.8 / 58
= 0.05 Δ

This value at the centre of the near visual zone is unlikely to cause any complaints.

In case of fused bifocal in which the near portion combines a crown glass element with a flint glass element of lower abbe value, the chromatism is the sum of three components – distance element, chromatism because of depression curve and chromatism due to segment element. The distance element of crown glass represents the power of the distance portion and is denoted by F, the centered depression curve, also a part of crown glass, is denoted by – Ak, where A is the reading addition and k is the blank ratio $(n - 1) / (n_s - n)$. The power of the segment element is given by A (k + 1).

At a point N, in the near portion, three components contribute to the prismatic effect and hence to the chromatism at that point. Two components are made from crown glass and the third is the flint glass element of the near portion. If the distance from the distance optical centre to the point N is denoted by Y and the distance from N to segment optical centre to N by Ys which must be given a minus sign when Os lies below N. Then chromatism at point N is given by:

$$TCA = y (F/V) - \left\{ (-ys) (AK/V) \right\} + \left\{ (-ys) \left(\frac{A[K+1]}{Vs} \right) \right\}$$

Where V = Abbe value of crown glass Vs = Abbe value of flint segment $k = (n-1) / (n_s - n)$

So, in our above example:

Y = 0.8 Ys = 0.6
F = 5.00 A = 2.0
V = 58 Vs = 36 (say).
K =
$$(n-1) / (n_s - n) = 1.523 - 1 / 1.654 - 1.523 = 4.$$

Putting up the values:

$$TCA = 0.8 \left(\frac{5}{58}\right) - \left\{ (-06) \left(\frac{2 \times 4}{58}\right) \right\} + \left\{ (-0.6) \left(\frac{2 \left[4 + 1\right]}{36}\right) \right\}$$

= (0.8 × 0.086) - {(0.6) (0.38)} + {(-0.8) (0.278)}
= (0.0688) - (-0.0828) + (-0.167)
= -0.02\Delta

This is negligible.

Once again the flat top fused bifocal demonstrates its superiority over round segment, since the distance Ys is negligible in case of most shaped bifocal.

MAGNIFICATION

Another consequence of the reading addition is the small magnification difference between the distance and the reading portion. Patient may be aware of this, although it is unlikely to cause serious problems as the size change occurs in both eyes. This may give rise to change in perceived distance rather than aniseikonia.

We have seen that a bifocal free of jump (executive type) will induce a certain amount of prismatic effect at the reading level; while the bifocal that induces no prismatic effect at the reading level (straight top shaped bifocal) is subject to a certain amount of jump. For the long term spectacle wearer who is already accustomed to a certain amount of prismatic effect, this will change when bifocal lenses are first worn. Adaptation to this new type of prismatic effect should not be difficult. However, jump manifests itself each time the wearer directs his line of vision downwards across the dividing line. Even if the patient will learn to ignore the displacement of his environment, it will never cease to occur. Consequently, we should expect jump to be a greater problem for the wearer than the segment induced prismatic effect.

PRISM CONTROLLED BIFOCALS

Bifocal designs that permit control of the prismatic effects in the near portion by the incorporation of prism in the segment are known as prism controlled bifocals. Prismatic effect at any point in the near portion depends upon the power of the main lens and the power of the segment lens, and the positions of their individual optical centres in relation to the visual point at which we wish to find the prismatic effect. Sometimes it is necessary to alter the prismatic effect at the NVP, for example to balance the vertical prismatic effects at the NVP or to provide horizontal prism correction in the reading portion only. This can be achieved by using a bifocal design for which the method of construction allows independent centration of the reading

portion. Such a design is called a Prism controlled bifocals. This kind of bifocal design is constructed to incorporate the prism in the segment and is totally independent of any prism included in the main lens. There are several methods by which prism may be incorporated in the near segment only. They are:

SPLIT BIFOCAL

Two half lenses – one for distance and another for reading are made from two separate lenses for which the power and centration may be chosen at will. Reading portion carries the corrective vertical prism. Full prism control is possible in Split bifocals.

CEMENTED BIFOCALS

A separate prism segment is attached to the main lens using permanent epoxy resin adhesives.

UNEQUAL SEGMENT SIZES

Although, visually a little strange for beholders of those wearing a combination of unequal segment sizes in two eyes, vertical prismatic effect due to anisometropia can be controlled by unequal sizes of the round segment in both the eyes. The heights of top of the segment must be at the same, as when the eyes are depressed from the line of distance vision they must meet the upper margin of the reading portion simultaneously. From Prentice rule, the following expression can be deduced for round segment down curve bifocal:

Difference in segment radii (in cms) x near addition = Amount of relative vertical prism overcome.

Example – RE + 3.00 Dsph

LE + 4.00 Dsph BE Near Add + 3.00 Dsph Round bifocal 20 mm segment size. Upper margin 2 mm below optical centre. Reading point 6 mm below the top edge of segment.

The reading point in the above case is 8 mm below the distance centre and 4 mm above the centre of the segment.

In the RE, prismatic effect produced by distance correction at this point will be:

$$3 \ge 0.8 = 2.4\Delta$$
 BU.

The prismatic effect produced by the segment at this point is:

 $3 \ge 0.4 = 1.2\Delta$ BD.

Therefore, the resultant prism at this reading point in RE is:

1.2∆ BU.

Similarly, in LE, the resultant prism is 2.0Δ BU, makes a difference of 0.8Δ BU in LE, which may produce discomfort. To overcome this we have to move the centre of the reading segment in the right eye up, to reduce the base down effect and in the left eye, we have to move the centre of the reading segment down to increase the base down effect. The difference to be eliminated is 0.8Δ , i.e., 0.4Δ in each eye. The amount, therefore, by which the position of the centres of the segments is to be moved is given by:

A x 3 =
$$0.4\Delta$$

Therefore, A = 0.4 / 3 = 0.133 cms Or, A = 1.33 mm

Hence, RE segment will be 17.34 mm diameter and LE segment will be 22.66 mm. A 17 mm segment in right eye and a 23 mm segment in left eye will practically balance the vertical prism at the NVP. Bigger segment will be placed in front of more hyperopic eye or least myopic eye.

In case of shaped segment bifocal, prism control by unequal segment sizes are not useful due to their construction as the optical centre of the segment is just around the NVP at which we consider the prismatic effect.

BI-PRISM BIFOCALS

A bi-prism is achieved by surfacing the concave rear surface with the base up prism of equal value to the imbalance between the right and left prescriptions over the entire lens, i.e., distance and reading. Next base down prism with the same amount is worked on the distance curve of the front surface, i.e. on the top part of the lens only. This leaves a lens with zero prisms at distance and base up prism at near.

The result of this entire process creates a horizontal dividing line between the two portions of the lens. For this reason, bi-prism technique is applied to flat top D segments and E-style segments as the bi-prism dividing line can be made to coincide with exactly the top line of the segment. It is usually recommended that the minimum prism worked is 2Δ in order to obtain a clear dividing line between the two zones. Slab off can only provide a variation in vertical prism and special skill is needed to achieve a neat, straight slab line coinciding with the segment line. Some higher index resins are too soft to produce a clean line, the reason why polycarbonate cannot be slabbed.



Figs 10.21A to E: Stages in the production of an E-style bi-prism bifocal from the semi-finished lens

- (a) Semi-finished lens
- (b) Front view
- (c) Base up prism is applied across whole of the rear surface
- (d) Lens with base up prism
- (e) Base down prism is applied to front surface, distance only

PRISM CONTROLLED SOLID BIFOCAL

Prism controlled solid bifocal lenses, surely are the most versatile prism segment lens of all, allows to achieve separate control of prismatic elements in both the distance and near portions. Unlike lenses for the control of anisometropia whose correction is only for the vertical prismatic element, a prism controlled solid bifocal lens can correct vertically, horizontally and any oblique angle.

The segment surface of this bifocal saucer blank shows the same axis of revolution as the DP surface, the centration of the reading portion is dependent upon the segment diameter and the prescription of the lens. The segment does not incorporate a separate prismatic effect and is constructed by depressing the reading portion surface below the level of the DP surface and dropping a prism into the depression. The apical angle of this prism is the same angle as that which the blank must rotate through to obtain the prescribed prism in the segment.

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Bifocal Lenses 123





Truly this is very interesting lens which provides a comfortable binocular vision to many who otherwise would only achieve monocular vision or revert to two pairs of single vision lenses.

INVISIBLE BIFOCALS

Invisible bifocals are one-piece bifocal lenses having round segment, in which the line of demarcation between the distance portion of the lens and the bifocal segment has been obliterated by a polishing process. The result is an invisible bifocal segment. Optically the lens performs the same as a standard round shaped bifocal, as only two actual zones of focus exist – one for distance and one for near. The obliteration process produces distortion around the bifocal segment which varies in width from less than 3 mm to just under 5 mm, depending on the power of the near addition and the base curve. This area serves as the boundary of the segment and permits the lens to be fitted according to the same provisions that affect an



Fig. 10.23: Invisible bifocal-round shape

ordinary round bifocal. Since the blending is wider than the actual demarcation line, the bifocal may require either slightly higher placement of the top of the segment or greater depression of the gaze for reading. The manufacturer recommends fitting this bifocal 1 mm higher than other types of bifocals. The invisible bifocals only cater to the wearer's vanity. Some bifocal wearers are ready to accept the blurred area and the comparatively small reading field in order to avoid the stigma of wearing bifocals.

BIFOCAL FITTING

Bifocal segments must be positioned so that the distance and near positions of the lens provide adequate fields of view for distance and near vision respectively. The fitting position of the bifocal segments should be decided according to the purpose for which they are to be worn. However, it is necessary to consider the positioning of segments in vertical and horizontal meridians. So while fitting the bifocal into a spectacle frame three factors must be considered:

- 1. Segment Inset
- 2. Segment Width, and
- 3. Segment Height.

Segment Inset

Segment inset is specified as the difference between the subjects distance PD and near PD. In the normal range of PDs, the near PD for a reading distance of 40cms is 4mm less than the distance PD. Segment inset, therefore, is usually specified as 2mm for each lens. There are two reasons for insetting bifocal segment – to ensure that the subject's line of sight will go through the segment at its optical centre and to ensure that the reading fields for the two segments will coincide with one another.

Segment Width

Different segment widths are usually available for straight top shaped segments in 22, 25, 28 and 35 mm widths. Some manufacturers also provide this option in round shaped segments. E-style bifocal encompasses the full width of the lens, so it is obvious not to specify segment width when this lens is prescribed. Given a choice wider segment widths are preferred.

Segment Height

In the vertical meridian, bifocal lenses prescribed for general purpose use are usually mounted before the eyes so that the segment top is tangential to the lower edge of the iris (Fig. 10.24A). In most cases the position of the lower edge of the iris also corresponds with the line of the lower eyelid when the head is held in the primary position. This is usually normal for great majority of bifocal wearers and is certainly the safest position for the segment top in case of first time wearers. However, if the bifocal prescribed is mainly for near vision, then the segment top might be fitted little higher, say, midway between the lower edge of the iris and the lower edge of the pupil (Fig. 10.24B). If the lenses have been prescribed for some vocational purpose and are to be designed for only occasional near vision use, then the segment top might be fitted 2-3 mm lower than the normal (Fig. 10.24C) These suggested positions of the segment top assume that the head is held in the subjects primary position with the eyes viewing a distant object. But if a person who habitually holds his head high will need a lower segment height than a person who slouches a bit and keeps his head downward. A tall person who habitually keeps his head down may need a little higher segment top whereas a short height person who has to keep his head up may prefer a little down segment top. Past wearing habit of the subject should also be given importance while positioning the segment top. If a wearer is used to wearing bifocal segment up, fitting a lower segment in the new spectacle will create trouble for him to adjust immediately.



Figs 10.24A to C

Various kinds of dispensing aids have been proposed from time to time to assist in the fitting of bifocal lenses, but most practitioners obtain excellent and consistent results by simply measuring the segment height with a millimeter ruler. Ideally the segment height should be converted into a segment top position in relation to the horizontal centre line of the frame. A typical routine procedure for taking the measurement is:

1. Choose the final frame and adjust it to fit the subject correctly (Fig. 10.25).



Fig. 10.25

2. If the frame is without demonstration lens, attach a vertical strip of transparent adhesive tape to each eye of the frame to enable reference points to be marked (Fig. 10.26).



Fig. 10.26

3. Replace the frame on the subjects face and direct the subject to look straight into your eyes. If necessary, adjust the height of your chair so that your eyes are on exactly the same level as those of the subject (Fig. 10.27).



Fig. 10.27

4. Direct the subject to look straight into your open left eyes and using a fine tip marking pen, place dots at the same height as the lower edge of the subject's right iris. This point often coincides with the line of the lower lid. Similarly, without moving his head, place a second mark in front of the subjects left lower iris margin (Fig. 10.28).

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Fig. 10.28

5. Remove the frame and put the frame face down with dots coinciding with a straight line. Draw a straight line from one dot to another (Fig. 10.29).



Fig. 10.29

6. Put back the frame on the face and verify (Fig. 10.30).



Fig. 10.30

7. The position of the segment top is usually specified in millimeter from the marked straight line to the lower eye wire of the frame where the bevel of the lens will fit into the groove (Fig. 10.31).



Fig. 10.31

VERIFICATION OF SEGMENT HEIGHT

Subjective determination is the most accurate means of determining the segment height and of assuring the wearer that the bifocal segment will be positioned properly (Fig. 10.32).

- 1. Ask the subject to stand and look straight ahead.
- 2. A card is held over the lower half of the frame with its upper border coinciding with the proposed segment position.
- 3. The subject should be able to see the floor over the top of the card at a distance of 15 feet.
- 4. Now ask the subject to look down at the reading material. The card is held over the upper portion of the frame with its lower border at the level of the proposed bifocal segment.
- 5. The reading material should be visible without major readjustments of the subject's posture or reading material.



Fig. 10.32

Progressive Addition Lenses

The concept of progressive addition lens has been around since 1907 when the first patent on progressive power lens was published by Owen Ave. The early progressive lenses were rather crude in design. Varilux 1 was introduced by Essilor in France in the year 1959 and since then progressive addition lens have gained worldwide acceptance as the most performing ophthalmic lens for the correction of presbyopia because they provide comfortable vision at all distances. They are successfully and advantageously replacing single vision and bifocal lenses. Growing popularity of progressive addition lenses has stimulated the search for advances in design and manufacturing technology of the progressive lenses. This has enabled progressive addition lenses to develop from the early "hard" designs requiring extended patient adaptation time to current "state of the art" softer asymmetric design to the individually customized progressive lenses. Today over 150 progressive addition lens designs are in the market.

Progressive addition lenses (Fig. 11.1) are one piece lenses that vary gradually in surface curvature from a minimum value in the upper distance



Fig. 11.1: Progressive addition lens

portion to a maximum value in the lower near portion. Unlike bifocal or trifocal lenses, progressive lenses ensure that the presbyopic spectacle wearer finds the right dioptric power for every distance, guaranteeing smooth and uninterrupted vision without any visible line of demarcation. The power increase is achieved by constantly decreasing the radii of curvature in the vertical and horizontal directions. Figure 11.2 demonstrates the gradual increase in curvature and surface power towards the lower, near portion of the lens.



Fig. 11.2: Cross-sectional view of progressive addition lens surface. The shorter radius of curvature in near portion provides a stronger surface power than the longer radius of curvature in the distance portion

In the most used zones of vision, virtually aberration-free vision is possible, as here the radii of curvature are almost identical in the vertical and horizontal directions.

A typical, general-purpose progressive lens will have three district zones of vision as shown in Figure 11.3.



Fig. 11.3: Distance, intermediate and near zones of a typical progressive lens

Distance

A designated zones located in the upper portion of the lens, which provides the necessary distance correction.

Near

A designated zone in the lower portion of the lens, which provides the necessary near addition or near power.

Intermediate

A corridor in the central portion of the lens connects these two zones, which increases progressively in plus power from the distance to near. This zone is also known as "progressive zone".

These three zones of vision blend together seamlessly, providing the wearer with a continuous depth of field from near to far.



Fig. 11.4: Typical progressive lens

BASIC DESIGN DIFFERENCE BETWEEN PROGRESSIVE, SINGLE VISION, BIFOCAL AND TRIFOCAL LENSES

A single vision reading lens consists of a single sphere of appropriate radius providing correction for near vision only. Distance vision through the lens is blurred and there is no specific correction for the intermediate vision. (Fig. 11.5).



Fig. 11.5: Basic design principle of single vision lens

They provide larger field of view for the reading and they are readily available at low cost. But they are inconvenient to use as they correct only one particular distance at a time.

Bifocal, trifocal and progressive lens designs combine areas of correction for both distance and near vision in a single lens and link them in different ways:

In a bifocal lens, a distance vision sphere is placed above a near vision sphere and is linked by a single "step" creating a visible segment line. They offer convenience of distance and near in the same spectacle and are available at lower cost. But they are unappealing cosmetically as there is a visible demarcation between zones. Intermediate is blurred and the subject have prismatic image jump (Fig. 11.6).



Fig. 11.6: Design principle of bifocal lens

In a trifocal lens, a third sphere is added between the distance and near vision sphere to produce an intermediate power. This gives rise to two segment lines on the lens surface (Fig. 11.7).



Fig. 11.7: Trifocal lens design principle

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In a progressive lens, an uninterrupted series of horizontal curves link distance vision zone, intermediate vision zone and near vision with no visible separation. Lens power increases smoothly from distance vision area at the top of the lens, through an intermediate vision area in the middle, to the near vision area at the bottom of the lens. They provide convenience of use with no prismatic image jump. The subject feels confidence in negotiating stairs; gutters etc., besides progressive addition lenses are under constant research and development, providing us a newer and better design to adapt faster (Fig. 11.8).



Fig.11.8: Progressive lens design principle

ADVANTAGES OF PROGRESSIVE ADDITION LENSES

Most eyewear professionals are aware of the product benefits afforded by the optical features of a progressive addition lens:

No Visible Segments

No line of demarcation provides more cosmetically appealing lenses with continuous vision, free from visually distracting borders. The lens looks like a single vision lens (Fig. 11.9).

Continuous Field of Clear Vision

Progressive addition lens offers a greater visual flexibility with uninterrupted clear vision from distance to near. Single vision reading lens offers a field of clear vision limited to the near area only, while the abrupt change of power in a bifocal creates completely divided fields for distance and near vision with no specific correction for intermediate vision. At virtually every point in the progressive lens, the eye finds the power in the perfect agreement with the distance at which it is focusing (Fig. 11.10).



Fig. 11.9: No line progressive lens



Fig. 11.10: Progressive lens provides clear vision from far to near

Comfortable Intermediate Vision

The progressive zone of the progressive addition lens gives rise to an area, which provides the clear vision for the intermediate correction. Only in the early stage of presbyopia, can single vision and bifocal wearer enjoy clear intermediate vision, as they can still accommodate and adjust their head position. But for higher additions, progressive addition lens continues to offer clear vision at intermediate distance also. Trifocal lens, despite their clear intermediate field of vision, is not ideal, as the wearer must cope with the image jump at the two segment lenses (Fig. 11.10).

Continuous Support to the Eyes Accommodation

In a single vision-reading lens, the eyes accommodation is supported for near vision only. In a bifocal lens, the eyes accommodation experiences abrupt changes when the gaze shifts from distance to near vision across the segment lines, because the wearer must constantly choose between distance and near vision power and switch from maximum to minimum amplitude of accommodation. For example, consider an eye focusing
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Fig. 11.11: Extreme right picture shows clear intermediate vision through progressive lens

through a bifocal lens at an object moving towards it from a reasonable distance. The eye first uses the distance power, accommodating to its maximum amplitude to focus as the object is drawn within arm's length. The eye then switches to the near segment where it must totally relax its accommodation for intermediate viewing, before again increasing to its maximum amplitude of accommodation as the object is drawn closer. Thus, the eye varies its amplitude of accommodation twice from minimum to maximum. This adjustment in accommodation would occur only once with a progressive lens, just as it would with natural, non-presbyopic accommodation.

Continuous Perception of Space

Progressive lens also offers continuous perception of space. When an eye looks through a progressive lens, its perception of spatial relationship is uninterrupted. Changes of power are gradual and continuous in all direction with minimum distortion. Single vision reading lenses do not allow real spatial perception. The two portions of bifocal lenses split and alter spatial relationship. Vertical and horizontal lines appear broken and image jump hampers wearer's vision (Fig. 11.11).



Fig. 11.12: Perception of form and movement through a progressive lens

PROGRESSIVE ADDITION LENS MARKINGS

All the progressive addition lenses contain important markings, which are used to identify lenses and to assist in their fitting and verification. The important markings are explained below (Fig. 11.13):



Fig. 11.13: Left eye progressive lens

- A and A1: They are two hidden circles, which are permanently etched on the lens at 34 mm apart. When the ink marking is removed, they are made visible by fogging.
 - B: This point is the distance optical centre (DOC) of the lens and is also known as Prism Reference Point.
 - C: Hidden addition power situated at the temporal side and is made visible by fogging.
 - D: 0-180° axis line passing through the DOC.
 - E: Fitting cross lies above the DOC.
 - F: This is the Distance Power (DP) circle to check the exact distance power with the help of lensometer.
 - G: Hidden logo situated nasally and is made visible by fogging when the ink marking is removed.
 - H: 7mm to 9 mm circle is the centre of the near vision area and is inset by 2.5 mm.

PROGRESSIVE ADDITION LENS OPTICAL DESIGN

Every progressive lens design requires a globally smooth surface that provides a gradual transition in curvature from the distance portion down into the near portion. This gradual blending of curvature means that the addition power is gradually changing across a large area of the lens. Unfortunately, the superior optics and line free nature of progressive addition lens does have a bit of a price to pay, i.e., the change in curvature

Distance zone Peripheral zone Near zone

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Fig. 11.14: Progressive addition lens design

results in an inevitable consequence in the form of surface astigmatism at the temporal and nasal side. Surface astigmatism produces an unwanted astigmatic error or cylinder error that can blur vision and limit the wearers field of clear vision. Therefore, this astigmatic error essentially serves as a boundary for the various zones on the progressive lens surface. Unwanted cylinder which is the consequence of the lens design is influenced by:

Add Power

The amount of astigmatism will be directly proportional to the add power of the lens. A + 2.00D addition, for example, will generally produce twice as much cylinder error as + 1.00 D addition.

Length of the Progressive Corridor

Shorter corridors produce more rapid power change and higher levels of astigmatism, but reduce the eye movement required to reach the near zone. Larger corridors provide more subtle power changes and lower levels of astigmatism, but increase the eye movement required to reach the near zone of the lens.

Width of Distance and Near Zone

Wider distance and near zones confine the astigmatism to smaller regions of the lens surface, which produces higher levels of astigmatism. However, wider zones do provide larger areas of clear vision. The location of the near zone, which is offset nasally to account for convergence in down gaze, is critical to wearer's comfort and its position varies between designs.

To understand how the length of the progressive corridor and the add power can affect the rate of change and magnitude of the astigmatic error, consider a progressive lens with a + 2.50 D addition, which has a 17 mm progressive corridor. This lens will have to change by 2.50 over a distance of 17 mm. This implies plus power represents an average change of roughly 2.50/17 = 0.15 D per millimeter. Therefore, the power of a progressive lens changes more rapidly down the progressive corridor as the addition power increases or the length of the corridor decreases.

A well designed progressive lens will reduce the amount of astigmatic error to its mathematical limits for a given design. During the design and optimization process, various parameters are adjusted to control and manipulate the distribution and magnitude of this astigmatic error across the progressive lens surface. The width of the near and distance zones, and the length of the progressive corridor are the chief parameters that are altered.

The magnitude, distribution and the rate of change (or gradient) of this astigmatism error are all performance factors that can affect the wearers acceptance of the lens. The amount and gradient of peripheral lens aberration determines the field of view, while the gradient and type of aberration primarily influence adaptation time. A steeper gradient concentrates the change in aberrations over a smaller distance and provides wider distance and near zones free of aberration. Astigmatic aberration is generally perceived as distortion or blur while prismatic aberration is perceived as "swim" or "waviness" with head movement.



Fig. 11.15: Power profile for a progressive lens

PROGRESSIVE ADDITION LENS DESIGNS

Basically we can categorize the progressive addition lens design into three groups:

- Mono design and multidesign
- Asymmetry and symmetry design
- Hard and soft design.

Mono Design and Multidesign

In case of mono design progressive addition lens, a single design is used for all addition powers, i.e. the position for the near vision does not change with the change in near addition power causing difficulties while viewing near objects as the wearer holds reading material closer to him with the increase in his near addition power. Hence, it can never offer optimum comfort to both emerging presbyopes and matured presbyopes, as their needs are different.

In multidesign the position for near vision changes with the addition power change, i.e., the near area goes up with the increase in the addition. All the twelve additions from 0.75D to 3.50D have been studied separately to define the ideal design for each stage of presbyopes.

Image: constraint of the second sec

Asymmetry and Symmetry Design

Fig. 11.16

In case of symmetrical progressive addition lens design, the right and the left lenses are identical. To achieve the desired inset for the near zone, they are simply rotated by an equal and opposite amount in the two lenses, i.e., 10° anti-clockwise in the right lens and clockwise in the left lens. The principal drawback of this design is the disruption of binocular vision as the wearer gazes laterally across the lens, since the astigmatism differed between the nasal and temporal sides of the distance zone.

Asymmetric progressive addition lens design incorporates a nasal offset of the near zone and has separate design for right and left lens. So, there is no need of lens rotation in this case. This results in same peripheral optical characteristics and better adaptation, improved binocular vision, more visual comfort and better convergence.

Image: Hard designEarly soft designCurrent soft design

Hard and Soft Design

Fig. 11.17

A harder progressive addition lens design concentrates the astigmatic error into smaller areas of the lens surface, thereby expanding the areas of perfectly clear vision at the expense of higher levels of blur and distortion. Consequently, harder progressive addition lens generally exhibits four characteristics when compared to softer designs:

- 1. Wider distance zones
- 2. Wider near zones
- 3. More narrow and shorter progressive corridors
- 4. More rapidly increasing levels of astigmatic error.

A softer progressive addition lens design spreads the astigmatic error across larger areas of the surface, thereby reducing the overall magnitude of blur at the expense of narrowing the zones of perfectly clear vision. The astigmatic error may even encroach well into the distance zone. Consequently softer progressive addition lens generally exhibits four characteristics when compared to harder designs:

- 1. Narrower distance zones
- 2. Narrower near zones

- 3. Longer and wider progressive corridors
- 4. More slowly increasing levels of astigmatic error.

In general, harder progressive addition lens designs will provide wider fields of view, and will require less head and eye movement, at the expense of more swim and blur. Softer progressive addition lens designs provide reduced levels of astigmatism and swim while limiting the size of the zones of clear vision and requiring more head and eye movement.

However, modern progressive addition lenses are seldom absolutely "hard" or absolutely "soft". Unfortunately such terms do not accurately describe modern lenses. Many of the recent progressive addition lens design incorporates the best balance of these two design philosophies to show following characteristics:

- 1. Larger effective distance and near zones
- 2. Peripheral aberrations are well controlled to enable the wearer to adapt easily.
- 3. Combination of hard and soft design.

Recently, SOLA optical introduced another concept i.e. DESIGN BY PRESCRIPTION the use of different distance designs for different distance refractive errors. For example, the design employed for the 7.25 base curves varies slightly from the design employed for the 5.25 base.

OPTICAL DESCRIPTION OF PROGRESSIVE ADDITION LENS

Manufacturers have made various attempts to represent the size and location of the optical zones and peripheral aberrations of the progressive lens. Graphically, there are four common ways of progressive addition lens design representation:

Power Progressive Profile

The primary function of a progressive addition lens is to restore near and intermediate vision while maintaining clear distance vision. While distance power and the near vision power in any given lens are fixed parameters, the lens design must define the progression of power change from one to the other. Physiological considerations favor a high location of the near vision zone; however, a short abrupt power progression from distance zone to near zone will usually create the rapidly varying aberrations in the lens periphery that cause discomfort. The great challenge for the designer is to manage both the length of the power progression and the rate of power change in order to create comfortable exploration of distance, intermediate and near visual fields without excessive, and tiring vertical head movements and ocular effort. The rate at which the power increases over the progressive zone is governed by the power law for the design. The power law may be

linear as assumed in Figure 11.18 or it may be more complex to provide a greater or less increase in power at the start of the progression as assumed in the Figure 11.19.

The curve so drawn represents the power progression of the lens along its meridional line from distance to near vision. The power progression is the result of a continuous shortening of the radius of curvature of the front surface.



Fig. 11.18: Power profile for a progressive lens with a linear power law



Fig. 11.19: Comparison of isocylinder lines for hard and soft design of power, plano add + 2.00D

Contour Plots

The contour plot is the most common method used to represent progressive addition lens designs. It describes the surface power of the front surface of the lens and identifies zones of constant surface power indicated by contour lines. Contour Plots also attempt to show the size of the distance, intermediate and near zones as well as the extent and gradient of peripheral aberrations. There are two types of contour plots:

- Isosphere contour plots
- Isocylinder contour plots

Isosphere Contour Plots

This is a two dimensional map of the lens representing the distribution of spherical power across the lens. This form of graphical representation divides the lens along lines of equal dioptric values. Each contour line/ shade represents an increasing level of power at given interval. The value of this line/shade is chosen arbitrarily, usually at the increments of 0.25D or 0.50D to 1.00D. Between two consecutive lines, sphere value varies by a relatively constant rate. Figure 11.20 shows isosphere contour plot of a progressive addition lens. In addition to describing sphere distribution the lens designer may communicate information about the location and size of the near vision zone using an isosphere contour plot.



Fig. 11.20: Power contour plot of a PAL (+ 2.00 with a addition + 2.50D)

Isocylinder Contour Plots

Isocylinder contour plots are two-dimensional map that divides the lens design into ranges of cylinder levels through out the lens. Most of the time isocylinder plot is misused by the lens designer in the promotion of their progressive addition lenses. It is routinely misapplied by some lens marketer seeking to establish competitive claims such as "a larger reading zone" or "less unwanted astigmatism". Since induced cylinder is disturbing but



Fig. 11.21: Astigmatic contour plot of a PAL (+ 2.50 add)

unavoidable by progressive addition lens design process, it is legitimate for the lens designers to map the location and degree of cylinder with each design interaction. "Soft" design have fewer zones of induced cylinder, represented by fewer lines on the isocylinder contour plots, located further apart than in "hard" design. Hard designs, on the other hand, have a greater number of lines located closer together. To the untrained observer, the hard design may appear superior because of the longer areas free of induced cylinder. However, clinical experience has shown that wearers perceive soft design as more comfortable in dynamic and peripheral vision as they do not have a high concentration of cylinder in areas critical to peripheral and dynamic vision, as in the case with hard designs.

Lens designers also use isocylinder contour plots to depict the presence or absence of asymmetry in the progressive addition lens design by comparing the nasal and temporal aspects on either side of the oblique path of power progression. An asymmetric design produces identical optical characteristics on both sides and thus, sphere power cylinder, and vertical prism are almost identical for both eyes in any direction of gaze, promoting binocularity and comfort. A symmetric design employs a single design that is rotated about 10 degrees in one direction to create a "right" lens and about 10 degrees in the opposite direction to create a left lens. In a hybrid of these two approaches, referred to as dissymmetric design, separate designs are used for right and left lenses. However, since the entire unwanted cylinder has been pushed from the temporal to the nasal side, different optical characteristics are present on either side of the lens.

Grid Plot (Fig. 11.22)

The grid highlights the distribution of the prismatic effects of the lens by showing how they alter a regular rectangular grid.





Rate of Change Plot (Fig. 11.23)



Figs 11.23A to C: (A) 3D power plot of a PAL (+ 2.50 ADD), (B) 3D astigmatism plot of PAL (+ 2.50 ADD), (C) 3D power gradients plot of PAL (2.50 ADD)

Rate of change plots are the three dimensional graphical representation of the variation in the optical characteristics of progressive addition lenses, which plots vertically the value of a given optical characteristics at each point of the lens in relation to a reference plane. It may be used to show:

- a. Distribution of power
- b. Astigmatism
- c. Gradients of power variation

Rate of change plot is a better way to visualize the softness or hardness of a lens design. They represent the rate of change in the sphere value between two given points on the lens surface. The lower the difference in the sphere power between two points, the lower the plotted altitudes. Thus, threedimensional plots are more demonstrative of lens characteristics than contour plots. Flatter plots indicate softer design. The lens designer can manage the softness in one of the two ways.

- 1. By lengthening the progression. Or
- 2. By carefully controlling the rate of change of the optical characteristics between all points on the lens surface.

Since the length of the power progression is not easily demonstrated on the rate of change plots, they give incomplete picture of the overall lens design. Otherwise this is a more demonstrative procedure.

The graphical representations are useful tools to communicate the geometrical features of PAL design to a trained observer. However, they do not really correlate with wearer's acceptance, as this is dependent on the sum total of many different factors - astigmatic error, the power rise, prismatic effects, distortions, the required dioptric power, cent ration, the frame fit, vertex distance and the subjective impression of the wearer. So the success of a progressive addition lens design should be judged on extensive wearing trials rather than studying as these plots.

DESIGNING PROGRESSIVE ADDITION LENS

A progressive addition lens is designed not only to provide a presbyope – an ability to see clearly at all distances but also to respect all the physiological visual functions like foveal vision, extra foveal vision, binocular vision, etc. The foveal area of the retina permits sharp vision at any distance within a small field which follows the eyes rotation which is usually within 30° angle.

Within this end the lens areas used for foveal vision must provide for perfect retinal images. The wearers natural body and head positions determine the vertical rotation of the eye for near and distance vision, and therefore the optimal length of the lens power progression. The coordination of the body, head and eye movements in relation to the objects location in the vision field defines the power value needed at each point of the progression. The horizontal eye and head movements determine the field of gaze and defines the width of the lens zone used for foveal vision. And to maximize wearers visual acuity in the lens central area, the unwanted induced cylinder of the progressive lens must be kept to a minimum and be pushed to the periphery of the lens.

Although, extra-foveal vision do not provide sharp vision but the wearer do locate the object in space, perceive their forms and detect their movements through extra-foveal vision. The prismatic distribution on the progressive addition lens surface and its magnitude introduces slight deformation of horizontal and vertical lines, thus altering the wearers visual comfort. The whole of the retina is almost homogeneously sensitive to motion. The variation of prismatic effects plays a role in the wearer's comfort where it must be slow and smooth across the whole lens to ensure comfortable dynamic vision (Fig. 11.24).



Fig. 11.24: Horizontal eye/ head movement coordination and width of field

Binocular vision refers to the simultaneous perception of the two eyes (Fig. 11.25). For perfect fusion, the image produced by the right and left lenses must be formed as corresponding retinal points and display similar optical properties. The eyes naturally converge when the wearers gaze is lowered for near vision. The power progression must be positioned in the lens in such a manner that it follows the eyes path of convergence downwards in the nasal direction. Both right and left lenses must offer approximately equal vertical prism on each side of the progression path. The retinal images formed in both eyes must be similar in all directions of gaze. For that purpose, the power and astigmatism encountered on corresponding points of right and left lenses must be approximately equal.



Fig. 11.25: Binocular vision with progressive lenses

In designing the following zones of the progressive addition lens, the lens designer works towards respecting these physiological functions:

Vertical Location of the Near Vision Area

Higher position of near vision area relieves strain to extra ocular muscles and eases binocular function with downward gaze. But a shorter progression usually results in rapidly varying peripheral aberrations. A good compromise consists in locating the usable near vision at a downward gaze position of about 25°.



Fig. 11.26: Progression of power in relation to head posture and downward eye movement

Power Progression Profile

A suitable power progression along the meridional line enables the wearer to explore the object field without tiresome vertical head movements. This is achieved by associating the shape of the power progression to the

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orientation of the vertical horopter linked to the natural tilting of reading material (Fig. 11.26).

Horizontal (lateral) Location of the Near Vision Area

Once the power profile has been defined, its lateral positioning on the lens must be adapted to the natural convergence of the eyes and the value of the addition. With the advanced presbyopia, the reading distance becomes closer, the meridional line, therefore, must be shifted nasally as the addition increases.

Besides, balancing of vertical prism between right and left lens is very important to respect retinal image fusion in binocular vision. This is achieved by an asymmetrical design of the progressive addition lens surface coupled with proper positioning of the meridional line. In the lens periphery, image quality constraints are less demanding, while the control of prismatic effects is of utmost importance for motion perception.

All of the above optical requirements are introduced in the Merit function and are then integrated into the lens design optimization software. The merit function evaluates the numerous points of the lens and also overall performance of the lens by the weighted sum of the found merit function values and then the lens design is optimized. Numerous lens prototypes of each design are then produced and tested through rigorous clinical trials. Comparative lens evaluations are made after in depth analysis and patients comments, leading to a final selection of the progressive addition lens design.

PRISM THINNING

The progressive addition lenses are designed by increasing the curvature of the progressive zone in the near vision area. As a result of this, the progressive addition lens is thinner at the bottom and thicker at the top. To



Fig. 11.27: Thinning prism

produce a thinner lens, the lens surfaces generally use an "equithin" technique which consists of incorporating a vertical prism in order to reduce the thickness and weight of the lens in the back surface specification of the lens. Since the same amount of vertical prism is incorporated into both right and left lenses, there is relatively no prismatic effect for the wearer. This prism is often referred to as Yoked prism, as no net binocular prismatic effect is produced.

So prism thinning is the process of grinding prism into a progressive lens blank to reduce the thickness difference between the upper and the lower edges. Prism thinning typically involves grinding base down prism into the progressive lens. In addition to balancing the thickness difference between the top and the bottom of the lens blank, prism thinning also reduces the centre thickness of the lens with plus and/or higher add powers. The overall reduction in thickness also makes the lens lighter in weight.

Prism thinning is accomplished during the generating process by literally tilting the front surface of the lens on the chuck of conventional generator, using a base up positioned prism ring. When the back surface is ground normally, the surfaced lens is left with a prismatic effect at the centre. Newer three axis generators produce this prismatic effect without the use of prism rings grinding the back curve with a tilt. The end result in either case is the reduction of unwanted thickness.



Fig. 11.28: Base down prism is ground into the lens blank using prism-ring (with its base positioned up) with conventional generators

The amount of prism thinning used is roughly equal to the 2/3rd of the addition power. This is often recommended when the power through the vertical meridian of the lens exceeds + 1.50 D or so. This formula does not consider factors like the fitting height and the distance power, but still produces satisfactory results in most cases. It is possible to prism thin the minus powered lenses as well. Depending upon the fitting height either base down or base up prism may be required to balance the thickness difference.

We can verify this prism onto the progressive addition lenses by placing the prism reference point of the lens in front of the centre of the lens of the focimeter. This is very important especially where only one lens is being replaced. If the previous lens had not been prism thinned and the new one was or vice-versa – an unwanted vertical prism imbalance will be induced. In summary prism thinning is a useful tool that improves both the finished cosmetics of many progressive addition lenses with little visual impact to the wearer.

LIMITATION OF CONVENTIONAL PROGRESSIVE ADDITION LENSES

With all the advancements from hard to soft design and from a required minimum fitting height of 26 mm to 14 mm, many eye care professionals assumed that progressive addition lenses had come relatively close to perfection. However, this is not true. There are still four basic limitations in conventional progressive addition lenses created by their inherent designing:



Fig. 11.29: Progressive addition lens magnifies the image in its various section

1. Differing Magnification throughout the Lens

The changing curves on the front lens surface and the change in power through out the channel and reading portion of the lens create varying magnification through out the lens. The magnification increases throughout the progressive zone. The result is that the vertical lines viewed through the progression zone exhibit skew distortion.



2. Restricted Visual Field

Progressive addition lens restricts our field of vision particularly for intermediate or near areas. The curves are always on the front side of the conventional progressive addition lenses which position the visual area of the lens at considerably away from the eye. The ultimate result is restriction of visual field.

3. Compromised Optics

Conventional progressive addition lenses are produced in varying base curves averaged for a wide range of prescription and a nearest suitable front base curve is used for a given prescription. Ideally the base curve selected should match the exact curves used on the backside. This is simply not possible in conventional progressive addition lenses. As a result acuity is compromised to some extent in all visual areas, depending on how close the front base curve is averaged for the patients prescription.

4. No Control over the Inset of the Near Portion

Some progressive addition lens designs do have an inset, which varies with addition and/or distance correction, but not yet with interpupillary distance.

5. Difficult to check with Focimeters

Progressive addition lenses are relatively difficult to check with the help of focimeter, specially if the original engravings including those indicating distance power circle and near power zone cannot be found.

REMARKING PROGRESSIVE ADDITION LENSES

Majority of the progressive addition lens manufacturers employ laser etched molds or fluorescent markings on the front lens surface to help dispenser

Fig. 11.31

identify the lens brands, lens style, addition power, distance power circle and near power circle and thereby enabling the dispenser to fit the lens into the frame properly. These micro engraving, if removed can be detected under a bright light a using a dark background.

Some manufacturers also make instruments with appropriate lighting background and magnifier to make viewing the markings easier.



Fig. 11.32: Essilor's PAL ID

The first step in identifying a progressive addition lens is to locate the hidden circle or manufacture's symbol located on the 0-180 degree line, 4mm below the fitting cross on both nasal and temporal sides of the lens. Below these two markings, we find the near addition power (sometimes abbreviated) on the temporal side and the symbol identifying the particular lens on the nasal side. Once the two hidden circles and the brands are

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identified, place the lens on the respective brand layout card with two circles of the lens coinciding with the two circles on the card. Now mark the other markings.

The following options may be followed:

The microengraving can be detected by reflecting light from the overhead lights off the lens surface.



Fig. 11.33: Stripped grid

Or, fogging the lens surface by breathing warm moist air onto the lens surface.

Or, position the light source behind the lens.

Or, hold the progressive addition lens 10-15 cm in front of the striped grid. Focus on the lens surface.

The marking will stand out against the background as shown in the Figure 11.34:



Fig. 11.34: Hidden circles relocated

GENERATING PROGRESSIVE POWER SURFACE

A progressive power lens surface is an aspheric surface of the nonrotationally symmetric type, generated by means of computer numerically controlled (CNC) machining of either the surface itself or the mould from which the surface may be cast or slumped. The actual geometry of a given progressive lens surface is always regarded as proprietary information of the lens manufacturers. However, some insight into how the design of a surface might proceed can be obtained by the following illustrations:

To understand the geometry of progressive addition lens surface, we need to consider the E-style bifocal with two different spherical surfaces placed together so that their poles share a common tangent at point D, as shown in Figure 11. 35, where two surfaces are continuous.

At all other points, there is a step between two surfaces, which increases with the increase in distance from the point D. To produce a truly invisible bifocal design, the two surfaces must be blended together such that the DP surface and NP surface are continuous at all point.

A progressive lens may be considered to have a spherical DP and NP surfaces connected by a surface that's tangential and sagittal radii of curvature decrease according to a specific power law between the distance and near zones of the lens. Theoretically, to make a surface with curvature that increases at the correct rate to satisfy the given power law, we need to combine small segments of spheres of ever decreasing radii, all-tangential to one another in a continuous curve. These sections will be continuous only along a single so called meridian or umbilical line and at all other points of the sections; the surface of the sections must be blended to form a smooth surface.



Spherical NP surface

Fig. 11.35: E-style bifocal made by placing together two spherical surfaces with a common tangent at D

The simplest concept of this can be explained with a section taken from an oblate ellipsoid, as shown in the Figure 11. 36, where the radii of curvature of the spherical surfaces which represent the distance and near portions are shown as r_D and r_N respectively. It can be seen that the solid ovoid, which is obtained by inserting the ellipsoidal section between the two hemispheres shown in the figure, will result in a surface which has no



Fig. 11.36: Concept of a progressive lens surface. A section of an oblate ellipsoid is inserted between two hemispheres of radius of curvature $r_{_D}$ for the distance portion and $r_{_N}$ for the near portion

discontinuities. Along the meridian line, DD^1 , a cross section through the surface would be circular and the radii of the circles in a plane parallel with either the distance or near portion circles do indeed decrease from r_D to r_N continuously.

The ability to cut surfaces of such a complex nature was made possible by the use of computer numerically controlled (CNC) grinding machines. The single point diamond tool cuts the surface under computer control, sweeping in an arc over the work piece with the program positioning the cutter in exactly the right place as the cutting tool traverses the work piece.

The work piece could be a glass blank or a glass mould from which plastic lenses might eventually be cast, or it could be a ceramic block upon which glass blanks or finished lens could be slumped with or without vacuum assistance.

The important stages in the production of progressive power surface are as under:

- 1. Surface designing and numeric description.
- 2. Generating the aspheric curve.
- 3. Grinding, smoothing and polishing
- 4. Inspection.

Surface designing and computation of the surface topography is translated into numeric data in the form of co-ordinates that can be fed directly into the CNC generators. As much as 50000 numeric data point may be required for an individual progressive power surface. The basic reference for the progressive power surface is usually taken to be the spherical surface of curvature required for DP curve. Then the spherical curve is subsequently made aspheric in accordance with the design philosophy for the lens. Before that the spherical convex surface must be smoothed and polished accurately so that its topography has precisely the known desired characteristics.

CNC diamond tool is used to create the aspheric surface as explained earlier. If the work piece is glass blank, it must be smoothed and polished, using floating pad system. It is essential to ensure that the pads do not remove any more glass material than intended; otherwise an accurate surface geometry will not be maintained.

Ceramic slumping moulds produced by CNC cutters can be used to produce progressive power surface. The glass blanks are placed on ceramic moulds as shown in the Figure 11. 37. The entire assembly is then heated to the high temperature at which the glass starts to flow.

The glass slumps and the geometry of the convex surface of the mould is transferred to convex surface of the blank. The entire process has to be done under highly sophisticated temperature control to ensure that the glass flows correctly. Slumping can be assisted by vacuum forming also, whereby the glass is heated to just beyond its softening point, whereupon, a vacuum is applied to the interface between the forming block and the concave surface of the blank – which pulls the surface into shape.

It is the dream of the lens designer to create a progressive addition lens with no areas of distortions at the either side of the lens, which unfortunately is just not possible. The distortion on the either side is the result of induced cylinder, which is due to the presence of unwanted surface astigmatism and is evident during the lateral gaze within the progressive zone. All that the designer can do is to reduce distortions to the minimum. Progressive designs vary from one to another only by how these "no go" areas of the lens are distributed across its surface.



The astigmatism across the pupil is inversely proportional to the length of the progression zone. The longer is the progression zone, the smaller is the surface astigmatism. In other words the rate of change in the surface astigmatism in the periphery depends upon the addition. Higher addition gives faster changes and hence peripheral astigmatism is more evident.

The reduction of peripheral distortion is also accomplished by using the conic sections of changing asphericity rather than spherical sections as power is increased in the vertical meridian. These varying sections reach a relatively uniform power at a given peripheral portion of the lenses so that prismatic and cylindrical effect at these edges are much the same through out the peripheral vertical range of the lens. To achieve this in the upper portion, the distance section is increased slightly in power towards the periphery by + 0.30 D. This type of design also reduces the "optically pure" zone for near in width by allowing the reduced remaining power variation to spread over more area. As the curves are aspherical, the near zone reveals a spherical area of only 12 mm wide. However, the power change is so gradual that a much wider defective zone of practically equivalent power exists, depending upon the power of addition.

EVOLUTION OF PROGRESSIVE ADDITION LENS

The first commercially successful progressive addition lens was introduced by Essel under the name of Varilux in 1959. The design consisted of large spherical distance and near zones, linked by a series of circles of ever decreasing radii between the distance vision sphere and the near vision sphere. More attention had been given to ensure larger distance and near zones than to the quality of peripheral vision on either side of the progressive corridor as shown in Figure 11. 38. Today such a design would be described as very hard design.

The second generation of progressive lenses, Varilux 2 was introduced in 1973. It too provided large distance, intermediate and near fields of vision, but still it was at the cost of quality vision in the lateral regions of the progressive zone. Conic sections of changing eccentricities from one section of the lens to another replaced the circular section employed in Varilux 1 design. The effect of this was the reduction of power in the periphery of the progressive zone. The new concept of "horizontal optical modulation" was introduced which took care of the extra-foveal vision also. Binocular vision was optimized as a result of an asymmetrical design. The overall design of the lens is represented by a succession of conic sections as shown in the Figure 11. 39.

During the next decade other manufacturer introduced progressive addition lens design focusing specific optical characteristics. Some emphasized on large distance and near vision zones, concentrating the

Progressive Addition Lenses



Fig. 11.38: First progressive addition lens



Fig. 11.39: The "Physiological" progressive addition lens

inevitable astigmatism in the lens periphery. American Optical Ultravue, Rodenstock Progressive R, Sola Graduate etc., were in this category. Other manufacturer took a different approach, reducing the amount of unwanted astigmatism in the periphery by spreading it more widely in the lens. Truvision Omni of American Optical became popular. Zeiss Gradal HS placed special emphasis on the concept of the lens asymmetry and comfortable binocular vision.

Soon multi-design concept was introduced in Varilux Infinity in 1988 - the third generation progressive. The multi-design used district designs to match the wearers changing needs with advancing presbyopia. Multidesign concept refers to the change of power progression profile with

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near addition, generally resulting in a larger progression length for a low addition and hence soft design. The corridor length becomes shorter and the design harder as the addition increases. The multi design concept is well illustrated with the change of power progression profile by addition in the Figure 11.40.

Essilor introduced the fourth generation of progressive lenses under the brand name of Varilux Comfort in 1993, which offered more natural vision than any previous progressive lens designs. The near vision area in this lens design is located high, so that the wearer can reach it easily and naturally when lowering their gaze. Fewer head and eye movement are required to explore the near and intermediate vision fields and hence the wearer enjoys more comfortable posture. These advantages were because of specific power profile in the progression zone adopted for Varilux Comfort. For example in case of + 2.00 D addition, 85% of the full addition is reached just 12 mm below the fitting cross compared to a minimum of 14mm or 15 mm for previous progressive designs. Due to the softness in the lens periphery, the wearer enjoys additional comfort in the peripheral and dynamic vision as the necessary horizontal head movement required to explore the full of the field was greatly reduced. The asymmetry design incorporated also offered balanced binocular vision, while at the same time integrating the multi design concept of previous progressive lens design. Several competitive designs from other manufacturer appeared during the decade.

In 2002, the fifth generation progressive design – "Varilux Panamic" was introduced. This new design was based on the success achieved by Varilux Comfort in providing a larger field of vision, which resulted from the softness and regularity of the lens periphery. The Varilux Comfort



Fig. 11.40: Multi-design progressive addition lens

design showed that the vision was a global process and the wearer would perceive their field as larger if they had the ability to see comfortably through the lens periphery. In the Varilux Panamic design, the balance between the control zone and the periphery was shifted towards the peripheral zone of the lens, so that peripheral effect were lens dramatic than the previous designs. This change also brought the advantages of reducing the swimming effects obtained by rotation of the head and eyes around the field and improving binocular fusion in the lens periphery. Clinical trials have found significant enlargement in the field of vision in all zones of the lens.

New generation designs from other manufacturers include the BBGR Evolis, the Nikon Presio W, the Pentex Super Atoric F, the Seiko P-ISY – the first of the new designs to have the progression on the concave surface, Hoya's Hoyalux D design, is double sided progressive.

The most recent development in the progressive addition lenses is the Varilux Ipseo from Essilor – the personalized progressive lens that takes into account the actual degree of head and eye movement which the wearer employs when viewing through the intermediate and near zones of the lens. Research has been shown that each individual has specific head and eye behavior, which can be measured and then the progressive surface is designed to incorporate the wearers behavior.

Over the last few years rapid strides have taken place in ophthalmic lens production technology. Through a combination of better software, faster computer processing and free form surfacing, it has become possible to modify some aspects a progressive design to take into account the individual characteristic of the frame in which the lenses are to be mounted.

CURRENT PROGRESSIVE LENS DESIGN DEVELOPMENT

With the changing scenario in the trend of spectacle dispensing, lot of new development have come in progressive addition lens designing, with special regard to the followings:

Shorter Corridor Progressive Lens



Fig. 11.41: A typical shorter corridor progressive

When the progressive lenses were, first introduced, the recommended minimum fitting height was 22 mm. That was fine when the eye sizes of the spectacle frames were large and had deep 'B' measurements. However, as the smaller and narrower frame shapes become popular, a need for progressive with shorter corridor was crucial to their continued success. Smaller frames proportions differ from large frames in that they have a higher horizontal to vertical ratio. In other words the lens has to be not only shorter vertically but also relatively wider. The second challenge is to provide distortion free distance vision in the lens periphery. Finally the shorter corridor lens must account for the fact that the wearer's head and eye movement are influenced by frame size. Wearer of small frames tend to move their head more and eyes less when transitioning from distance to near viewing than that of large frame wearers. When looking down a short corridor lens, the eyes simply run out of the lens, so the head has to move to maintain focus on the items of regard.

To make the progressive addition lens work in small frames, many lens manufacturers came out with shorter corridor progressives. In 1999, American Optical introduced A.O. Compact – the first short corridor progressive lens. A.O. Compact has a 13 mm corridor that permits full reading function with a minimum fitting height of 17 mm. Soon other companies followed the suit and shorter corridor progressive becomes popular: Nikon Presio, Essilor Ellipse, Shamir Piccolo, Hoya Hoyalux Summit CD, Kodak Concise, Pentex Mini AF etc., became popular.

Internal Progressive

Internal progressive addition lens is a big step forward in overcoming many of the limitations of progressive lenses widely available today. Seiko is proud to have designed and patented the world's first internal progressive lenses. In an internal progressive lens, the curves producing changing power are positioned on the back surface of the lens, and front surface is spherical. The backside is a free form surface with progressive surface and cylinder surface on the back. Therefore, it is possible to have a spherical front curve. The design provides a field of vision that is 30% wider than a front side progressive lens. This is due to the fact that the progressive surface rests closer to the eyes. Besides Seiko, Rodenstock ILT is also being test marketed in the USA. The new internal design offers following additional advantages:

- 1. Expansion of the visual fields
- 2. Magnification differences between various areas of the lens are reduced.

Customized Progressives

Customized or personalized or individualized progressive surface design is the most unique and the latest development in the progressive addition lenses. The latest design from Essilor's Ipseo takes into account the actual degree of head and eye rotation that the wearer employs when viewing through the intermediate and near zones of the lens. Research has shown that each individual has specific head and eye movement behavior, which can be measured and the progressive surface can be designed to incorporate the wearer's behavior. This principle has been incorporated into the personalized progressive design from Essilor-the Varilux Ipseo.



Fig. 11.42: Vision print system

A new instrument the vision print system as shown in the Figure 11.42, has been developed to determine eye/head movement for a specific individual, the result of which can be incorporated into the progressive surface. The system consists of three lamps - the central lamp is viewed at 40 cms from the centre of the wearers forehead, with two separate lamps, 40 cms on either side of the central lamp. The wearer is directed to look at the lamp, which is illuminated and their head movement is recorded by an ultrasonic signal that is emitted by the system and reflected by a transponder attached to the special trial frame the wearer is wearing. As far as the wearer is concerned, the lamps are illuminated at random following a short 15 second cycle and it continuous over a 90 second cycle which enables the systems to calculate and display the eye/head movement ratio, along with a consistency factor referred to as the "Stability co-efficient" (ST). ST is used to adjust the rate of transition between the central and peripheral zones of the lens. Most people's eye/head ratio is relatively stable, having stability co-efficient below 0.15. ST value 0.00 shows the high stability of head and eyes movement. The indicator A in the instrument indicates head/ eye proportion, the number at B shows the head/eye movement ratio and the number at point C shows the stability co-efficient. The number 0.31 in the Figure reflects that the subject is performing 31% of the gaze movement with their head and 69% with their eyes. The ST of 0.07 indicates high stability of the head and eye movement behavior.



Fig. 11.43: The information displayed on the screen



Fig. 11.44: Studies show that the head-eye movement ratio directly influences the area of the lens that is used by the wearer

The eye mover uses more of the surface of the lens, so they need a larger acuity zone. For them the harder design as shown in the Figure 11. 45 can be more useful. On the other hand the "head-mover", having more dynamic vision, will be more influenced by the periphery of the lens as their head moves in their visual world and will be benefited from the peripheral "softness" as shown in the Figure 11. 45. Each Varilux Ipseo lens is designed



for the individual wearer, manufactured by free-form technology and to recognize its individual nature, micro-engraved with the wearers initials.

WHO IS SUITABLE FOR PROGRESSIVE ADDITION LENSES?

(Criteria for good candidate)

The introduction of numerous varieties of progressive lenses has made it suitable for almost every presbyopes, for every visual demand and for every wallets, Still proper selection of an ideal candidate is the first criteria for the successful dispensing of progressive addition lens. Before identifying a suitable candidate, the evaluation must be done on the following factors:

General Factors

Careful consideration is needed before advising progressive addition lenses for those with any history of difficulties in adapting to changes in lens power or frame styles. Persons having an interest in trying new things can be good candidates. People with small pupil are more suitable for progressive addition lenses as the effect of peripheral aberration is reduced. An unsatisfied patient with other designs of bifocals may found himself motivated to adjust with progressive lenses. The patient with narrow papillary distance and wider facial width may also be an unsatisfied user of progressive lenses.

Visual Needs

Information about the patients visual needs enables the practitioner to understand whether the progressive addition lenses will meet the patient expectations or not. Those who require a larger field of view can immediately be eliminated from the consideration. An avid user of computers will be benefited more by occupational lenses rather than a progressive addition lenses. The progressive addition lenses for him may be prescribed as a supplement for general use. Most commonly used near working distance also influence the selection criteria. A patient who invariably works at shorter and middle distance will be a happy user of progressive addition lenses, whereas a constant user of shorter reading, working distance will prefer to have bifocal lenses. Relative use for distance/ near visual zones also sometimes influences the criteria. Myopes who depend more on distance visual zone have always been more successful user of progressive lenses.

Refractive Status

Progressive addition lenses should be avoided for that refraction which may induce vertical prism between the eyes including different refraction between the eyes by more than 2.00 D in spherical power or more than 2.00D in effective cylinder power especially in the vertical meridian (horizontal axis).

IDEAL FRAME SELECTION FOR PROGRESSIVE ADDITION LENS

The ideal frame selection is an important criterion for the successful dispensing of progressive addition lenses. Many a times it has been seen that in spite of having perfect refraction and fitting, the patient is not the happy user of the progressive lenses and the reason established is not other than poor frame selection. The frame should be selected in such a manner so as to cover adequate facial width and also minimizes the vertex distance. Metal frames with adjustment nose pad are more suitable than plastic frames as the fitting height can be adjusted, if required, using the nose pads. While selecting the suitable frame for an individual who is opting for progressive addition lens, the following two factors must be taken into consideration -

Shape of the Frames

Square and panto shapes as shown in the Figure are the most suitable shapes for the progressive addition lenses. Steep rectangular shapes extending beyond the temporal bone of the face may not be suitable. Another important factor in frame selection is ensuring that the shape of the frame

Progressive Addition Lenses 1



Fig. 11.46: Ideal square shape of frame for progressive addition lens



Fig. 11.47: Ideal panto shape of frame for progressive addition lens



Fig. 11.48: Aviator shape cuts away the reading area in the nasal side

does not reduce the size of the reading area by being too "cut away" in the nasal area of the frame. For example, an aviator shape frame coupled with narrow pupillary distance may present such a difficulty.

Size/depth of the Frame

The frame must have sufficient depth to accommodate the entire zones of the progressive lens from the top of the distance power circle to the bottom of the near power circle within its aperture, i.e., the 'B' measurement should be adequate to include full distance and near optical zones. Another

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important factor, which is usually overlooked, is the 'A'-measurement of the frame, i.e., it must minimize the distance between the position of the fitting cross and the temporal end of the frame.





Once the lenses are properly marked and verified on the wearer's face, the layout card can be used to ensure the confirmation of above factors.

DISPENSING PROGRESSIVE ADDITION LENSES

Progressive lenses should be centered with respect to the eye so that the vision zone can be used ideally at all distance. The fitting of progressive lenses should be carried out with normal, relaxed head and body position and with the eyes looking horizontally straight ahead. The fitting can be done using manual measurement. But before that it is important that you fit the selected frame on the wearers face and then take the measurement. The following adjustment needs to be confirmed:

Frame Front Adjustment

Adjust the angle of the temples so that the frame sits squarely on the face.



Fig. 11.50: Front of the frame not in alignment

Pantoscopic Tilt

Adjust temples to achieve 8 to 12 degrees tilt, avoid contact with cheeks.



Fig. 11.51: 8 to 10 degree Pantoscopic tilt

Facial Wrap

Ensure that the front of the frame follows the line of the face but not excessively.



Fig. 11.52: Poor facial wrap



Temple Length

Adjust length of temple to minimize sliding.



Fig. 11.53: Needs to lengthen side bend

Vertex Distance

Minimize Vertex distance by adjusting nose pads but avoid contacting the eyelashes with the lens.

Once the above adjustment are done, take the following two measurement:

- 1. Monocular PD for distance
- 2. The fitting height

Monocular PD for Distance

The monocular PD is the distance from the centre of the nose bridge to the centre of the pupil, specified to the nearest 0.5mm. A number of devices can be used to measure monocular PD:

1. Pupillometer



Fig. 11.54: Measuring PD with Pupillometer
2. PD Ruler



Fig. 11.55: Measuring monocular PD with ruler

3. Marking directly on the lens insert



Fig. 11.56: Marking on the lens inserts

After determining the monocular PD, mark their location on the lens insert in the following ways:

- Place the frame symmetrically and level on the progressive addition lens layout card.
- At the determined PD, mark a vertical line on each lens insert.
- Place the frame back on the wearers face to check the accuracy of PD.



Fig. 11.57: Marking vertical lines on the layout

Fitting Height

The fitting cross on progressive addition lens must coincide with the pupil centre of the wearers in their natural posture. The position of the pupil centre relative to the correctly adjusted frame is the fitting height, and is specified as the distance above the deepest point of the inner frame rim to the nearest 1mm. Occasionally some practitioners prefer to specify the fitting height as mm above datum, which is the line halfway between the uppermost and lowermost rims of the frame.

The following procedure is used to measure the fitting height:

- Place your self opposite and at the same height as the wearer.
- Ask the wearer to adopt a comfortable posture and look straight ahead.
- Ask the wearer to look at your LE.
- Hold a pen torch just below your LE.



Fig. 11.58: Fitting height measurement

- Close your RE to avoid parallax error.
- Observe the position of the light reflection in the wearers RE relative to the vertical PD line already marked on the lens.
- Place a small horizontal mark on the PD line corresponding to the pupil centre.



Fig. 11.59: Fitting height measurement (29 mm in this picture)

- Ask the wearer to look at your RE and complete the procedure for the other eye.
- Move the frame up and down slightly, let it settle, and report for both eyes.
- Confirm the final marked lens insert.

The ideal position of the fitting cross should be as shown in the Figure 11.60:



Fig. 11.60: Ideal position of the fitting cross

Safety Lenses

Studies show that there is unacceptably large number of eye injuries occurring in the world. The visual impairment as a result of an eye injury may vary from a slight reduction in visual acuity to the total blindness. In the past these eye injuries have been associated with industrial occupations only but now there are increasing number of eye injuries seen in sports, leisure activities and at home also. All such ocular hazards caused by eye injuries can be divided into two groups:

Mechanical, and

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Non-mechanical.

Mechanical injuries may arise from a variety of causes and their effects are generally divided into two main categories – contusion and perforation. Contusion injury may result from various causes including flying blunt objects, falling objects, explosions or compressed air accidents, fluids under pressure escaping from burst pipes and water jets from fire hoses. The effects of contusion on the various ocular structures are numerous. It may lead to black eye, sub conjunctival hemorrhage, corneal abrasion, blow out fracture, hyphaema, iridodialysis, cataract, choroidal ruptures, scleral ruptures, angle recession, retinal hemorrhage etc., perforating ocular injuries can be caused by foreign bodies.

Non-mechanical ocular injuries fall into four main categories – Chemical, thermal, electrical and radiation. Most chemicals harm the eyes by direct contact with the external ocular tissues. Concentrated Sulphuric acid from exploding car batteries, household bleaches, detergents, disinfectants and lime are examples of chemicals that can cause burns to the eyes. Thermal injuries can be caused by flames and contact burns. Hot bodies, fluids or gases are the usual sources. Burns usually involve the eyelids and not the globe, which is often protected by reflex blink. Electrical injuries are basically due to lighting and high tension electrical appliances. Injuries to eyebrows, eyelashes with superficial burns of lids which are usually associated with marked swelling and conjunctival chemosis are hazards caused by electrical

injuries. Radiation injuries involve damage to the eyes as a result of absorption of harmful radiation. UV radiation can affect both the skin and the eyes. Pingeculae, pterygium and band shaped keratopathies are thought to be caused partially by long term chronic exposure to UV radiation. Cataracts are also thought to be caused by absorption of UV radiation. Visible light may also cause damage by thermal photocoagulations. Retinal burns may occur when high intensities of light are focused on the retina. Infrared radiation, when absorbed, leads to thermal effect on the tissue.

These ocular hazards are associated not only with industrial occupations, but also with sports, leisure activities are on the increase. In USA, the greatest number of injuries results from base ball, ice hockey and racket sports. Racket sports are responsible for many ocular injuries, and this is not surprising, given the speed of the ball. A squash ball may reach speed of 224 km/hour, a tennis ball 192 km/hour and a shuttlecock 232 km/hour. There is also the risk of the player being hit by the opponent's racket. Many severe ocular injuries occur to children at play and in the home and at times such accidents become the major cause of blindness.

Many of such ocular hazards can be prevented by widespread use of eye protectors in the form of safety glasses. Tinted lenses protect the eyes from harmful radiations. It may also be necessary to protect the eyes against the other ocular hazards, arising from dust, flying particles, industrial environment, sports injuries etc. Legislation is now there to protect the eyes both in the work environment and in certain sports, such as squash and protection may need to be provided, whether the lenses include a refractive correction or not, in the form of safety glasses.

Safety glasses provide protection against impact, chemical or molten metal splashes, dust or radiations from welding arcs of lasers. It may take the form of spectacles, goggles, visors, face shields or hoods. Good safety glasses are made from polycarbonate and are shatter resistant. This does not mean they are unbreakable or that they will last for ever. Their purpose is to protect the wearer from injury from accidental projectiles and particles. As the lenses become exposed to more and more bits and pieces of materials over time, they will become pitted. The more pitted they become, the less clear the wearer will be able to see things. More importantly, after a while, the bombardment of particles will weaken the lens and they should be replaced. Most safety glasses also provide a high level of UV protection and therefore, can be used as sunglasses.

When you look for safety glasses, there are a number of things to be considered:

- Ensure that the safety eyewear meets the standards applicable for your region and also usage. In USA "ANSI Z 87" should be marked on the frame and the manufacturer's initials and any special lens attribute should be noted on the lens.
- Look for the safety glasses made with high quality, virgin resin polycarbonate material. Recycled resins are cheaper, but they are also burdened with a high degree of distortion and yellowing lenses are not as durable.
- Zero distortion lenses allow you to not only see more clearly through the safety glasses, but also allow you to wear them for longer periods of time without eyestrain or fatigue.
- If you wear the safety glasses over top of your prescription lenses or reading glasses, make sure that they are large enough to fit. Safety glasses with bifocal lenses are available, sometimes allowing you to take off your prescription glasses altogether.
- Fit is very important. There are a few aspects to this width of the frame, width of the nosepiece, length of the temples and angle of the temple with respect to the lenses.
- Fit ensures comfort, but additional features can enhance this. If the nosepiece is soft, rather than a molded in part of the lens, it will enhance comfort. If the glasses have soft pieces on the temple tips, they will be easier on your ears. If the temple frame is thinner and more flexible, that also adds to comfort. Lastly, if the glasses are lighter in weight, that will help ensure a comfortable wear.
- Replacement lenses, if they are available, can help reduce ongoing costs. However, for most styles of safety glasses, the most expensive component is the lens, so don't expect to be paying a lot less for just the lens.
- Degree of protection is more important than just the safety rating. So the glasses can have the added features of side shields, wrap-around lenses and brow guards.
- Lastly make sure the lens tint is applicable for your specific application.

LENS MATERIALS

The lenses for safety eyewear may be made of:

- Glasses
- Plastics
- Wire gauze.

Glasses

Glasses may be:

- 1. Laminated glasses
- 2. Heat toughened glasses
- 3. Chemically toughened glasses
- 4. Special heat toughened safety glasses.

Laminated Glasses

Laminated glass lenses are made by the adhesion of two layers of crown glasses to an inner layer of plastic material. These lenses are not very strong, but are able to withstand significantly more impact than a standard glass lens. When broken, however, they tend to remain intact as the particles generally adhered to the centre plastic layer.



Fig. 12.1: Broken laminated glass



surfaces of a laminated glass

Heat toughened Glasses

Heat toughened glass lenses are usually made from spectacle crown glass. The toughening process begins when the edged lens is placed in a furnace and heated to 637°C for 50-300 seconds. The time spent in the oven depends on the weight, size and average thickness of the lens. After heating, the lens is withdrawn and cooled rapidly, usually by a jet of cold air. The sudden cooling creates a state of compression at the lens surface and a state of



Fig. 12.3: Toughened lenses are impact resistance lenses. Normal glass lenses are processed to rearrange their molecular structure to withstand higher impact



Fig. 12.4: Birefringence pattern of heat toughened glasses

tension in the lens mass. This produces a compression tension coat, often referred to as the compression envelop. This improves the impact resistance. After the lenses have been manufactured, they are fitted into the frame or housing.

Advantages

- 1. Heat toughening is comparatively quick and cheap process.
- 2. It does not need skilled labour.
- 3. The equipment needed is inexpensive and requires little bench space.

Disadvantages

- 1. Heat toughened lens will always be thicker than an untoughened lens of equivalent power.
- Prescription lenses over + 5.00 D are not ideal for toughening, as the bulk of glasses require prolonged heating which can cause warping, degrading the optical qualities. Lenses over – 5.00 D have poor impact resistance due to the relatively thin centre substance.
- 3. Impact resistance is markedly reduced by scratches and other surface abrasions. Hence, they should be periodically inspected and replaced when distinct scratches are present.
- 4. The heat toughening process has an adverse effect on the photo chromatic lenses. The lens does not lighten to its original transmission.

Chemically Toughened Glasses

In this process the lenses are first preheated and then lowered into a potassium nitrate solution at 470°C for 16 hours. The compression coat is produced by exchanging the larger potassium ions present in the solution for the smaller sodium ions present in the glass. As this treatment occurs on the surface of the glass only, it produces a very thin but very tough compression coat. For photo chromatic lens toughening, the solution normally used is 40% potassium nitrate and 60% sodium nitrate at a reduced temperature of 400°C. This process does not generally affect the photo chromatic action of the lenses.

Advantages

- 1. Although, chemically toughened lenses are thinner than heat toughened lenses, they have been shown to possess a greater impact resistance.
- 2. The toughening process takes the same time for all types of lenses.
- 3. The temperature required for chemical toughening is lower than that used for the heat treatment of lenses; therefore, warping is not a problem.

Disadvantages

1. Chemical toughening is an expensive process, as it requires equipments that must withstand the chemicals and the temperatures involved.

- 2. It is difficult to determine whether the lens has been toughened, as there is neither a stress pattern nor a conventional method that will provide this information.
- 3. It is not exactly suited for crown glasses. A special type of glass is needed for the best results which are more expensive.

When chemically or heat toughened glass lenses fracture, they usually show a radial fracture pattern, although concentric cracks can also occur. Therefore, only a few splinters of glass are produced and the fragments tend to stay in the spectacle frame.

Special Heat Toughened Safety Lenses

Special heat toughened lenses became widely available around 1970. The technology involved was developed by Chance Pilkington and is currently the property of Norville Optical Co. The lenses are heated in the same way as air-quenched lenses, but then cooled by immersion in oil. These lenses are somewhat thinner than the usual heat-toughened variety, and can be identified with a polarizing strain viewer. The strain pattern is obviously very different to that found in the conventional heat-toughened lens.

Plastics

There are different materials available in plastic material family:

CR₃₉

 CR_{39} was introduced by the Columbia Chemical Division of the Pittsburg Plate Glass Company in 1941 and first became available as a spectacle lens material in 1950s. The word "CR" stands for Columbia Resin and it was the 39th batch or formula made by the laboratory. It is a thermosetting material and offers greater impact resistance. However, when the lens breaks, it produces sharper fragments. The scratches on the lens surface do not obviously affect the impact resistance.

Polycarbonate

Polycarbonate material was first produced in the late 1950, since then there has been a steady increase in its quality and use. Initially, the ophthalmic use of this material was restricted to industrial safety lenses as it was quite grey in appearance. But now polycarbonate lenses are readily available, not only as safety lenses, but also as high quality spectacle lenses for dress wear. Polycarbonate lenses are thermoplastic polymer that melts at a fairly low temperature and can be molded and remolded easily by a process of heating and cooling. When the strength of polycarbonate is compared to that of metals, the mechanical strength is fairly low, but it is very light and



Fig. 12.5: Polycarbonate lenses

as a spectacle lens material they are very strong. Lenses can be produced by both molding and surfacing techniques with good quality impact resistant lenses. When hit polycarbonate crazes and the crazed areas that surrounds the point of impact can be seen easily by the way in which light is scattered through the lens. The amount of crazing produced is dependent on the time period of the load and the temperature of the material. When the temperature is low, the material crazes more readily and fractures by small high velocity particles occur at a low velocity.

The surface of polycarbonate is fairly soft and scratches very easily. To overcome this problem the usual practice is to hard coat the lens to protect its surface. Polycarbonate lenses are more difficult to glaze than CR₃₉ lenses. Machines dedicated to this material are fitted with special edging wheels, as it is very difficult to cut using standard diamond-edging wheels.

Cellulose Acetate

This material has not been used to manufacture ophthalmic lenses as it is too soft to hold its shape accurately. However, it is used to make both frames and side-shields and to make covers to protect the surface of lenses.



Fig. 12.6: Eye protectors and face shields

Wire Gauze

Goggles made from wire gauze have a very good impact resistance, but are generally not accepted because they degrade the visual function and give no protection against splashes of molten metal, etc.

TESTING PROCEDURE FOR SAFETY LENSES

The lenses used as safety eyewear must be tested to establish whether they are suitable for the specific hazard for which they were designed. The following factors may be assessed:

Impact Resistance

The impact resistance of all types of lenses may be influenced when the surface has been abraded. The size and the speed of the missile or particle also influence the impact resistance of the lens. Larger particles hitting a lens cause it to bend, and so the fracture is initiated on the back surface. Smaller particles on the other hand do not cause the lens to bend upon impact, so the fracture is generally initiated on the front surface. The impact resistance also increases as the lens thickness increases. Increase in base curvature also increases the strength of the lens in both heat toughened and CR_{39} lenses.

The type of material used for safety eyewear gives an indication of the mean fracture velocity that can be tolerated. Fig. 12.7 shows the fracture velocity for some of the materials available. The samples were all of the same thickness and were struck by a 6.5 mm steel ball. Polycarbonate offers the greatest fracture resistance of all the lens material.



Fig. 12.7: Fracture velocity of a 3 mm thick sample of different lens materials when struck by a 6.5 mm diameter steel ball

Surface Hardness

There have been many efforts to study the problems associated with surface abrasion. However, there are distinct advantages in coating plastic lenses, particularly polycarbonate, which is soft thermoplastic. A thinly coated polycarbonate lens is superior to an uncoated CR₃₉ lenses.

Chemical Resistance

Glasses are more resistant to most chemicals. Plastics, however, may show crazing and surface clouding with some strong chemical solutions. CR₃₉ has good chemical resistance, and is frequently used for chemical visors and box goggle windows.

Thermostability

Polycarbonate and PMMA are prone to distortion more readily than glasses.

Flammability

All the plastic materials are flammable. However, as their ignition temperatures are high, they are considered safe for use.

Resistance to Hot Particles

Eye protectors must be able to withstand hot particles impinging upon them, as can occur in such processes as grinding or welding. A glass surface is very easily pitted by these particles, as they fuse with the surface. Whereas, plastics do not pit easily. This could be due to the elasticity of the surface when heated by the particle.



Fig. 12.8: Resistance to hot particles by a glass lens (left) and a $CR_{_{39}}$ (right) lens. After equal exposure to spatter from an arc welder the glass lens is considerably more pitted than the $CR_{_{39}}$ lenses

Table 12.1: A Comparison of the major properties of glazing materials for eye – protectors								
Material	Impact Resistance		Hardness	Chemical Resistance	Thermost- ability	Fracture Pattern Particles	Resista -nce to Hot	Weight
	Large Missile	Small Missile						
Glass								
Heat toughened	Good	Good	Good	Very Good	Very Good	Fair	Poor	Heaviest
Chemically toughened	Good	Poor	Good	Very Good	Very Good	Fair	Poor	Heavy
Laminated Plastics	Fair	Fair	Good	Good	Fair	Poor	Poor	Heavy
PMMA	Fair	Fair	Poor	Good	Fair	Good	Very Good	Light
CR ₃₉	Good	Good	Fair	Good	Good	Fair	Good	Light
Polycarbo- nate (coated)	Very Good	Very Good	Poor	Fair	Good	Very Good	Good	Light

TYPES OF LENS HOUSING

The lens housing may be made of metal or plastics. Nickel alloy is usually used to make metal housing and polycarbonate, polyamide, cellulose acetate, etc can be used for plastic lens housing. These materials may be used to manufacture:

- 1. Spectacle frames
- 2. Goggles
- 3. Face shields
- 4. Helmets

Spectacle Frames

Cellulose acetate, polyamide, polycarbonate and many other kinds of plastics can be used to make plastic spectacle frames. They can also be made from metal wire also, but these frames have been shown to cause more damage upon impact than a plastic frame. Side shield spectacle frames are very good as eye-protectors. But these side shields must not restrict the wearers field of vision and hence they should be made of transparent material that does not discolour with age. Injection molded side shields with polycarbonate materials are best, as their shape does not alter.

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Fig. 12.9: Side shield spectacle frame

Goggles

The goggles can be made either cup type or box type for eye protection purpose. The cup type may be used to provide protection against molten metal, flying particles, dust etc. Box type goggles give a good fit around the brows and cheeks. They can also be worn over prescription spectacles.

Face Shields

Face shields are usually head band supported visors that cover the face and neck. They are used to provide protection from flying particles, molten metal and chemical splashes and can easily be worn over prescription spectacles, if required. They provide excellent field of view. Face shields are usually made either from polycarbonate or cellulose acetate.



Fig. 12.10: Face shields

Helmets

Helmets are commonly worn during welding. They provide protection of the face and neck from intense radiation and spatter. The filters can also be attached which can also be so designed that it can be flipped up to expose.

REGULATIONS AND STANDARDS RELATING TO EYE PROTECTION

The British and European Standards for eye protectors BS EN 166:2000 Personal Eye Protection Specification is at the heart of the strategy for eye protectors, but other standards like USA ANSI Z 87.1, Canada CSA Z 94 etc are also linked to it.

BS EN 165 – specifies personal eye protection vocabulary.

BS EN 166 - personal eye protection - specification.

BS EN 167 –specifies optical test methods.

BS EN 168 – specifies non optical test methods.

BS EN 169 - specifies tints for welding protection and similar operation.

BS EN 170 – specifies for UV filters.

BS EN 171 - specifies for IR filters.

BS EN 172 – specifies for sun glare filters.

BS EN 175 - specifies for ski-goggles.

BS EN 207 - specifies for filters and eye protectors against laser radiation.

BS EN 208 – Laser adjustment eye protectors.

BS 7930 – 1:1998 – Eye protectors for racket sports. Part 1 Squash.

BS 4110 – Eye visors for vehicle users.

Table 12.2: 1 BS EN 166 Code numbers for filters				
Filter Code No.	Filter Property			
No code no.	Welding filters.			
2.	UV filter where colour recognition may be affected.			
3.	UV filter with good colour recognition.			
4.	IR filter.			
5.	Sun glare filter without IR specification.			
6.	Sun glare filter with IR specification			

Table 12.3: BS EN 166 – Optical Class – Tolerances				
Number	Sph & Cyl	Horizontal Prism	Vertical Prism	
1.	+, - 0.06D	0.75 deg out 0.25 deg in	0.25 deg up & down	
2.	+, - 0.12D	1.0 deg out 0.25 deg in	0.25 deg up & down	
3.	+ 0.12D-0.25D	1.00 deg out 0.25 deg in	0.25 deg up & down	

	Table 12 4: Grades of I	mpact registance	RS EN 166				
	Table 12.4: Grades of Impact resistance DS EN 100						
Symbol	Level of Impact resistance	Test Ball Speed	Best material can achieve				
F	Low energy	45 m/s	All types				
В	Medium energy	120 m/s	Goggles & Face shields.				
А	High energy	190 m/s	Face shields				
S	Increased robustness		Toughened glass				

Most BS EN standards use the specifications in BS EN 166. The old BS standards tend to use different specifications. BS EN 166 was first issued in 1994 and superseded BS 2092. It is now more than 10years old and was last amended in 2002. The standards there in are the most important to an optometrist.

A typical safety spectacle has the following lens markings:

5-3.1 "AOS" 1 F

The first digit, i.e., 5 is the code number. This specifies the wavelength of the radiation that the filter offers protection against (see table 12.1).

The second 3.1 is the shade number. The shade number signifies the tint density. The shade number ranges from 1.1 to 4.1. Welding filters are often specified with shade number only. 1.1 corresponds to the light transmission factor of 80% which is maximum permissible tint for night driving. 3 correspond to an light transmission factor of 17.8 to 8.5% - the maximum permissible tint for driving in day light.

The optical class is signified by the number 1 (see table 12.2). The optical class indicates the measure of optical tolerance to which the lenses have been manufactured. Prescription safety eyewear needs to be checked to the same standards as normal spectacles and can be marked only 1 or 2. Class 3 is only to be used in eye protectors that are not to be used for long use.

F on the oculars signifies the impact resistance (see table 12.3). There are two tests for increased robustness:

- 1. The oculars have to withstand the impact of a 22 mm diameter steel ball weighing 43 gm traveling at 5.1 m/s.
- 2. The eye protectors must withstand the impact of a 6 mm diameter steel ball weighing 0.86 g traveling at 12 m/s.

The letter 'T', for example, FT after impact resistance shows that the eye protectors will be effective at higher temperature also.

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Surface Treatments

There are various kinds of surface treatments that are applied on either side of the spectacle lenses. In addition to anti-reflection coating which has already been discussed separately, many other types of surface treatments are done to enhance optical and / or physical properties of the lens. Optical properties can be enhanced by tinting, UV coating and mirror coating and the physical enhancements can be achieved by hard coating, hydrophobic coating, anti mist coating, anti fog coating and toughening.

HARD COATING

Resin lenses are basically from two families of plastics—thermosetting materials and thermoplastic materials. A thermosetting material is created in a mould by chemical reaction, the cross linking of molecules is very strong to form a rigid structure, and if they are subsequently heated will not soften. CR₃₉ and most other high index resin lenses used for spectacle



Fig. 13.1: Different layers of coating on a lens

lenses are thermosetting materials. Higher index materials are usually softer and must be hard coated. Thermoplastic materials can be reheated and reformed. They consist of long chains of molecules that do not cross link with each other. Most common thermoplastic material is polycarbonate. All known thermoplastic materials are very soft and they must be hard coated.

Hard coating is a procedure by which a thin layer of material usually 0.5 micron to 10 micron thick is applied to the lens surface. The most common material used is lacquer which is applied either by dipping or by spinning procedure. Vacuum deposited hard coats are less common. It may be tintable or non tintable. Non-tintable hard coating offers more scratch resistance than the tintable.

It is not possible to see the layer of hard coating except of the edges of bifocal segments and there is no optical effect of hard coating if the refractive index of the lacquer used is same as that of the base lens material. If the refractive index differs, there is a change in surface reflection.

HYDROPHOBIC COATING

Anti-reflection coating needs to be kept clean. The reason is that a very small amount of oil or grease on top of coating can destroy its effect. The result is loss of the purpose for which anti reflection is being applied. Since the effect of this does not occur evenly across the lens surface , this could be very annoying to the patient. In fact, they are not so dirtier, the wearer is just more aware of it. This problem can be eased if a hydrophobic coating is applied to the lens surface. The basic principle is to create a high surface wetting angle, which allows the water or oil to run off rather



Fig. 13.2: Top layer coating is hydrophobic coating



Fig. 13.3: High surface wetting angle



Fig. 13.4: Water droplets on a hydrophobic coating

than wetting and then drying on the surface. It can be applied simply by dipping process. Baking after dipping enhances the life. It can also be applied in the vacuum chamber as the final stage of the multi-layer anti-reflection coating process.

ANTI-FOG COATING

The potential for eye injuries in sports and battlefield has increased over the years. Fogging of spectacle lenses can occur from a combination of body heat and environmental factors which can result in blur vision from sweat beads streaming down the lenses. A film of anti-fog coating can be applied on the back surface of the lens which is compatible with hard coating to protect the lens from being fogged. A good anti-fogging treatment has not only initial anti-fogging properties but also good anti-fogging retainability. At times anti-fogging lens cleaning solutions have been used in the form of sprays, the effect of the same has yet to be studied.

ANTI-MIST COATING

The same reason can be attributed to anti-mist coating on the lens surface. The property to prevent the formation of mist behind the lens is an important feature.

TOUGHENING GLASS LENSES

Spectacle glass lenses can be strengthened by toughening process. The finished lens is heated to its softening point and is followed by rapid cooling, either by a stream of cold compressed air directed at the surfaces or by submerging the lens in oil. This results in greater compressive strength in the glass since outer region of the lens material cools more rapidly than the interior, which remains hotter and more fluid for some time. When the interior finally cools, it contracts and exerts tension on the rigid outer surface to produce an envelop that encloses the interior under great tensile stress. Toughened glasses are far more durable and more resistant to scratches because of increased surface hardness. When they break, they shatter into relatively harmless cubes of glasses.



Fig. 13.5: Birefringence pattern of thermally toughened lens

Glasses can also be toughened by a chemical process, in which a compressive envelop, is produced by ion exchange as a result of hot dip of the finished lens into a salt bath. Chemically toughened lenses are stronger than air- quenched toughened lenses.

SURFACE TINTING OF LENSES

Tints are simply the methods of absorbing lights so that transmission is reduced. If all wavelengths of light are equally absorbed, then a neutral



Fig. 13.6: Varieties of tinted lenses

grey is produced. If the absorption is different for different wavelengths, then the tint has a particular colour. Tinting resin lenses are relatively simple procedure. The lenses are placed in a suitable bath of hot colour dye for an appropriate length of time. Excess darkness can be reduced and light colour can be made darker. Full colour and graduated colours are all possible.



Fig. 13.7: Mirror coating

Glasses can also be coated by vacuum process which has a unique advantage of uniform tint throughout the lens surface which is otherwise not possible in glass lenses. 14

Sports Lenses

The world in which we live has become more diverse and varied than it was before. Increasing complexities and ever increasing demands have changed lots of old philosophies. Today the concept of "one size for all" philosophy has no more importance. Both in the workplace and at leisure, things have changed. With so much of changes clear, comfortable and good vision in variety of situations also necessitate the need for specialized products and services for specialized occupation. The increasing competition in all spheres has further added to the fact that one can not take the chance any more. One mistake means the entire career is over.

Sports, today is one of the largest industries where more than 50% population of the world is engaged professionally or otherwise. Eyesight is extremely important in sports, especially when it comes to skiing and ice hockey. In dazzling light of the high mountains, where the sun's rays are multiplied by reflections and fresh snow, in thick snowdrifts and incident fog, visual perception is seriously limited. The complex movements are continuously coordinated, controlled and corrected by means of visual inspection.

Compared to the rest of the body, the high energy consumption of the eye frequently results in faster fatigue. Moreover, the eye has to adapt not only to the very strong light of the wave spectrum visible to human eyes, but also needs to be protected for longer use. At high altitudes, filter function is reduced. Protection is also diminished since ozone layer is thinner as you go higher. Ultraviolet light has very high damaging effect on our eyes. The omnipresent Infrared rays above 800 nm carry thermal effect on the eyes. In the enclosed spaces light intensity is less than the open spaces. There may be possibility that regular glasses may not give the adequate vision that a player is needed. At times he may be tired of not being able to accurately read the green and sink that putt. The glare coming off the water surface on sunny days while fishing or boating creates visual noise and wind making their eyes dry when they really get moving on the new mountain bike. Wind, flying dirt and debris can cause itchy and irritated

eyes. So protection is an important factor while dispensing lenses to the player. Each sport requires some sort of protection from high speed projectiles to play safely and comfortably. Besides protection, enhancing vision for superior performance is also very critical in sports.

The big advantage of an optical appliance is that they allow the eyes to be protected. A well designed sports specific frame is usually wrapping around the face following the facial anatomy, protecting against light, particles and insects from the sides and above and also shielding the eyes from pollen and wind, in contrast to everyday frame which are fairly flat across the front.



Fig. 14.1: Everyday frame



Fig. 14.2: Sports frame

With the right choice of lens, complete UV protection can be given and by removing blue and UV light, contrast enhancement can be achieved which is directly related to increased sporting performance. However, use of wrap around frames for prescription means that standard calculations are no longer valid because of the way in which the frames wraps around the eyes and cause:

- 1. Change in dioptric power
- 2. Unwanted prismatic effects
- 3. Oblique astigmatism.

The lens tilt also leads to induced decent ration. In addition, the high base curve lens leads to impaired optical properties in the periphery and one of the essentials of a sports spectacle is to enhance peripheral vision.

The solution to this is especially designed spectacle lenses which are individually manufactured to meet most prescription needs in terms of the following with the aim of fitting the lenses directly into the frames:

- 1. The base curve
- 2. The dioptric power
- 3. The cent ration.

So, while dispensing sports lenses following specifications must be considered:

- 1. Prescription (Spherical, Cylindrical, Axis, Prism)
- 2. Monocular P.D and fitting height.
- 3. Lens data:
 - a. Refractive index of the lens
 - b. Base curve of demo lens.
 - c. Diameter of the blank.
- 4. Frame data:
 - a. Eye shape
 - b. Bridge size
 - c. Horizontal inclination of the frame or dihedral angle.

From this information, sports software calculates an aberrationally corrected dioptre effect and optimizes the centering data to provide wider peripheral field of view and clear vision throughout the lens size.

HORIZONTAL INCLINATION

Horizontal inclination is measured by drawing a tangent to the optical centre of the lens and noting the angle it makes with the front plane of the frame. As it is clear from Figure 14.3 that the visual axis of a sports frame does not correspond to the optical axis of the lens and this is really the reason why we need to make compensations for sports lens dispensing. There will be some adjustments in the dioptric power and/or cylinder with



Fig. 14.3: Horizontal inclination



Horizontal inclination, frame not in wear 29°



Horizontal inclination, with a small head, frame in wear 26°



Horizontal inclination, with a large head, frame in wear 19°

Fig. 14.4

		Sph.	Cyl.	Α.	Pr.
Prescription		+ 3.25	+ 0.75	155	
Horizontal inclination, frame not in wear 29°	\bigcirc	+ 2.50	+ 1.25	168°	1.21
Horizontal inclination, with a small head, frame in wear 29°		+ 2.75	+ 1.00	166°	1.04
Horizontal inclination, with a large head, frame in wear 19°		+ 3.00	+ 1.00	161°	

Fig. 14.5: Change of dioptric power in ratio changing horizontal inclination

some deviation in axis and unwanted prismatic effect. There will always be some decent ration required as seen in the Figure 14.5.

Measuring Horizontal Inclination

While measuring the horizontal inclination, the frame must be on the head of the athlete because the spreading of the sides as the frame passes over the temples tends to decrease the horizontal inclination and the measurements must be made in this situation. It is not sufficient to take these measurements on the frame on its own. The following step has to be followed to take the measurement of horizontal inclination:

1. Determine the Geometric centre: Mark the geometric centre on the demo lens with vertical line using boxed lens system. The boxing system is based upon the idea of drawing an imaginary box around a lens shape with the box's sides tangent to the outer most edges of the shape. The system uses the sides of the boxes as reference points for the standard system of measurements (Fig. 14.6).

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Fig. 14.6: Step no 1

2. *Prepare the measuring aid* : The easier way to take the measurement is to prepare the measuring aid as shown in the Figure 14.7, setting knob (1) back, measuring arms (2) and (3) closed.



Fig. 14.7: Step no 2

3. Place the measurement aid on the frame: Now place the measuring aid onto the frame. When you place the aid, the measuring arms open. Make sure that the guide bar (4) is apposed to the upper edge of the frame and the mid marking of the guide bar accords with the frame mid point (Fig. 14.8).



Fig. 14.8: Step no 3

4. *Adjust horizontal inclination:* Adjust the measuring arms (2) and (3) by moving the setting knob forward. When the measuring arms rest on the lens vertical marking they are at the correct angle (Fig. 14.9).



Fig. 14.9: Step no 4

5. *Read the horizontal inclination:* Read the angle at the point where the measuring arm accords with the scale (Fig. 14.10).



Fig. 14.10: Step no 5

FEATURES OF SPORT LENSES

In sports vision is maximized by the correct use of lenses and trauma is avoided by the correct use of lens material. Everything that is being to protect and enhance vision has a bearing on safety. This sums up the following features of a good sports lens:

1. Impact Resistant Material

Sport is the commonest cause of severe eye injuries in the world today. People who get eye injuries in sports were not wearing eye protection. Over the last 10 years, the popularity of sports has increased enormously. There are a few standards enforced by the state. The purpose of standards is to make sure that the practitioners know what is available to ensure required protection in each sport. Unless the standards are available, advice and knowledge will inevitably vary from one practitioner to another. In such cases some athletes may get wrong advice. The need for protection of eyes in sports is evident and the ruling bodies will have to work upon this. However, currently all the sports lenses are made of polycarbonate or trivex material. It is difficult to justify anything less. Due to cost factor some may use CR₃₉ lenses also.

2. Ultraviolet Protection

The pathogenesis of ocular disease due to UV is well understood. Sports lenses reduce the amount of shorter wavelength non-ionizing radiations reaching the retina and also useful to provide protection to the ocular adnexa.

3. Anti-reflection Coating

In terms of light transmission, anti- reflection coatings are applied on both the surface of the lens. These coatings increase light transmission from 92% to up to 99%. The increase in visual information must improve contrast sensitivity and will particularly important in poor light.

4. Water Repellent

Anti- reflection coating can be made water repellent. This is very important as visual demands in sports can not be compromised.

5. Anti-mist Coating

The same reason can be attributed to anti mist coating on the lens surface. The property to prevent the formation of mist behind the lens is an important feature.

6. Scratch Resistant Hard Coating

Loss of vision due to scratches can not be accepted in sports lenses. They must be treated with hard scratch resistant coating which is not compromising as far as light transmission is concerned.

7. Aspheric

Any lens which enhances peripheral awareness or reduces lens weight is an advantage in sports. Weight contributes to instability of the frame and this has a profound effect on monocular and binocular vision, especially in vigorous and fast moving sports.

TINTS AND COLOURS IN SPORTS LENSES

When things go wrong with the visual system, it may have a profound effect on the everything we do. For some people changing the colour of their world may produce interesting and surprising results. The usefulness of colour and tints has already been seen in hospital eye screening as clinically significant in cases like albinism, aniridia, ARMD, cataracts and aphakia. Light sensitive people have been using dark tints comfortably to protect their eyes from intense light. Given the potential of tints to relieve symptoms and prevent diseases, it has been found necessary to have a standard method to test the colour preference in general practice. Research in the field of sportvision has already established the merits of Eyebright Test. The tint that is being preferred in the aforesaid test is the summation of psychological as well as its physical properties. It may not be duplicated in the spectacle, but is the guide to the practitioner to decide final prescription on clinical judgments based on their optical principle and degree of light sensitivity. Commonly LT 80% is the first choice for indoors and LT 20% for sun. The important thing is that tints are not occupation specific, they are person specific. Hence, the results of the Eyebright test are very important. However, considering the environmental conditions needed for different sports a general guideline can be worked upon what tints have been seen to be most effective in different sports:

Orange: In normal use, orange is the essence of brown, so a tint diagnosis of orange would translate to brown tint. Using clinical judgments, this would be given indoors or outdoors at appropriate transmission level. Orange is the most commonly used tint for clay shooting. They are good to enhance visual performance and comfort, shooting sports require lenses that increase visibility of targets, dampen backgrounds, ease eyestrain and fatigue, and provide protection from harmful sunlight. Hunters and other target shooters also benefit from orange tint.

Green: The diagnostic green is not usually prescribed unless for a specific purpose. It makes a very good sunglass tint, because of its contrast enhancing properties and good UV absorption. Green is also good IR absorber. Golfers rely heavily on green filter to distinguish the ball from green.

Blue: In particularly light sensitive subjects, the light scattering effect of blue is outweighed by the relief they get from the elimination of peak sensitivity wavelengths of yellow and orange. However, blue is absolutely contraindicated for outdoor use because of the danger of high energy blue light intensified by the brilliance of sun.

Yellow: A yellow filter increases the contrast between that colour and surrounding colours, and concentrates light in the area of the spectrum to which the eye is most sensitive. If an individual is already light sensitive then the experience is heightened looking through a yellow or orange filter. Contrast is also enhanced by its absorption of blue and UV, which makes it effective for night driving against oncoming headlights and in fog. In fading light , sports players may appreciate the effect on contrast. It is not suitable as a sun spectacle because of glare and toxic effect of light at peak spectral sensitivity. Hunters, pilots, shooters and tennis players find them helpful for this purpose.

Pink: Pink is the colour second least chosen but is an indication of low light sensitivity. Migraine sufferors favour this colour for indoor. For outdoor sun protection, second choice would be brown and green. It helps block blue light thereby improving contrast and offers high contrast and are very soothing to the eyes. It also improves road visibility. Many people feel that pink lenses are more comfortable for long periods of time than other lenses. They are great for computer users to reduce eyestrain and glare.

Fuchsia: This is often confused with pink but is actually from the shorter wavelength end of the spectrum and is the part of the family of violet and purple and is least chosen colour. Like blue it is favoured by light sensitive because of its tendency to absorb all the higher wavelengths, but is too dark even for the most light sensitive patients. Its contrast enhancing properties are likely to be poor.

Grey: Grey is a neutral density filter which does not distort colour. Gray is the general purpose tint because it tames bright sunlight. It is likely to be favoured by the light sensitive and those who can not tolerate colour distortion or whose job requires accurate colour discrimination as it absorbs equally over the whole spectrum. It is not the contrast enhancer and is the natural alternative to green in photo chromatic lenses. It is cosmetically good for indoor use to reduce glare from fluorescent lamps, VDU and television screen.

Polaroid lens: Polaroid lenses work similar to a Venetian blind by only letting in light at certain angles. Without the sun's glare, objects become more distinct and are seen in their true colors. Reduced glare off water, roads, and other objects make the polarized lens a favorite for water sports, fishing, cycling and driving. The additional density of silver mirror front complimented by back anti- reflection coating can be a great for sunny day fishing. Polarized lenses may be appropriate for the recreational skier, but as polarized lenses eliminate almost all reflected glare, they might pose a hazard for the professional or more accomplished participant. These athletes must be able to spot and respond quickly to ice and water patches. These would be all but invisible with polarized lenses. A more effective choice would be a mirror coating. Mirrors limit glare without eliminating it, offering the contrasts needed. Mirrors also add to the overall absorption of the lens. The denser the mirror coat, the more the absorption.

Photochromatic lenses: In changeable weather conditions or in sport where you are moving from areas of bright light to shade (for example golf and cycling) photochromic lenses are useful. These lenses darken in bright light and become paler in less intense light conditions.

Mirror Coating in Sports Lens

Mirror coatings on the lens not only look good but also provide a variety of visual benefits. Mirror lenses have changed considerably in recent years as technology has made it possible to create nearly limitless mirror colors and densities. Today's mirrors offer a broad range of possibilities and improved optical performance for both prescription and non-prescription wearers. Sure, colored mirror coatings are prevalent on sports lenses, and flash coatings have found a fashion home on Rx. lenses, but there are also some medical conditions that benefit from mirror coatings. The flash mirror coating creates a dynamic effect because the lenses appear to change color depending on how the light hits them. The latest trend in mirror coated lenses is the lightly visible "clear" mirror. Mirror coatings have become hugely popular on sports performance sun wear. Their colour and density are matched with the base lens colours tint to enhance the wearers visual comfort and performance. You'll find mirror tints specifically designed for water sports, land sports, snow sports, general sports, and bright sun. Light transmission in a mirrorcoated lens is reduced because of the high percentage of light being reflected. Mirrors reflect more infrared and ultraviolet than they do visible light, which will benefit patients bothered by glare or affected by dry eye.

The simple rule to select the suitable colour is by developing contrast absorptions which is possible by determining the colour of the object being focused on and matching the colour of the lens to the object. The colour of that item will become more vivid. The other option is to use a lens colour that matches the background. That colour will be enhanced, so the object being located will be more apparent in its difference In short we can analyse the application of tints in various sports as under:

Golf	:	Green tint
Tennis	:	Yellow tint
Clay pigeon	:	Orange tint
Target shooting	:	Yellow tint
Fishing, Sailing	:	Polaroid lens.
Skiing	:	Polaroid lens, orange or yellow tint.
Scuba diving	:	Blue, or bluey grey tint
Table tennis	:	Yellow tint
Cricket	:	Photochromatic or orange, red tint.
Driving	:	Polaroid lens, or brown tint
Cycling, skating	:	Brown tint
Swimming	:	Blue, or bluey grey tint

PRESBYOPIA AND SPORTS LENS

Presbyopia does not stop people playing sports. The important fact is that presbyopia has an ongoing effect on your eyes, so your corrective lens prescription may need to be changed over time, as a result. So sports progressives are very important.

With most sports activities, distance vision is the primary need- for presbyopes too. Visual needs with sports progressives are different from those of general wear. The lenses are larger and the peripheral lens area is used more often and more intensively. The whole lens surface of sports progressives is individually calculated, taking into account all data on the wearer and sports frame. The progressive is optimized point to point right out to the very edge of the lens, ensuring best acuity at all ranges. Tailor made progressive designs which takes into account the following factors are key to success in sports progressives:

- 1. Subjects posture
- 2. Frame position
- 3. Amount of head tilt used for near vision
- 4. Area of the lens used frequently.

Designing Prescription in Sports Progressive Lens

In designing the near addition for the high base curve sports sunglasses, the choice of addition is done on how the spectacle will be worn. If the spectacle will be worn for everyday use select the same add value and if the spectacle will be worn for sports, with occasional use at near, reduce the general wear add by 0.50 D. Reducing the add gives greater comfort in wear by reducing peripheral distortion and improved field of vision. The 0.50 D addition reduction represents the normally used sports near vision.

A general guideline for selecting the near add as under:

Sports spectacle tennis	2.00 D	if general wear addition is	2.50 D
Sports Spectacle golf	0.75 D	if general wear addition is	2.50 D

SUMMARY

Sports lenses dispensing is a specialized part of ophthalmic optics. It is established that vision is critical to sporting performance. The art of dispensing is to maximize the visual information. While the eye care profession has traditionally been considered satisfying, secure and relatively paid, these advantages over recent years have not been encashed. The role of eye care practitioners is changing and as one door closes another opens. The market for sports lenses is expanding, lucrative and is now available.

New Development in Spectacle Lenses

ANTI-FATIGUE LENS

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Increased computer time, electronic games and other work and leisure modes have created for ergonomic products to reduce the various kinds of eye strain. Essilor's new anti-fatigue lens is the first single vision lens designed to reduce the eyestrain for the population of 20 to 45 years of age and has produced excellent results. Studies have shown that this age group has been identified as suffering extensively from visual fatigue. The lens is designed to relieve the symptoms of visual fatigue as headache, itchy eyes, reddening and blurred vision.

The lenses support the wearers accommodation efforts with an additional plus power at the bottom of the lens (+ 0.60 D). This provides a greater level of comfort for the wearer as the natural accommodation pattern is retained. At the same time Essilor's anti–fatigue lenses are not progressive lenses and hence have none of the limitations inherent in the design of progressive lenses. The lens design allows clear far vision and at the same



Fig. 15.1: Essilor's anti-fatigue lens

time comfortable close and middle distance vision. They can be coated with anti-reflection coating also. The right and left lenses are symmetrical and the pupil centre has to be at the lens centre.

ENHANCED NEAR VISION LENS

In an age powered by microchips and computers, time spent working on computers is rapidly growing. Now, presbyopes who spend time on computers to communicate with the world and to carry out their occupational needs can turn to new type of lens in the form of enhanced near vision lens for the most efficient solution to their visual demands for near vision as well as intermediate vision. Designed for near and intermediate vision, this lens offers maximum comfort and wider field of vision at near and intermediate both. These lenses have become superior alternative to the near vision lenses and are very good for specific visual needs. These lenses are suitable for first time presbyopes, single vision users looking for enhanced near vision and also bifocal users who wants an additional pair for near vision work.



Fig. 15.2: Enhanced near vision lens

Dispensing criteria

Enhanced near vision lenses are fitted to the near vision prescription by taking near vision monocular pupillary distance and height. It is usually 3 to 5 mm below the pupil centre. In most cases this corresponds to frame datum line as shown in the Figure 15.3.


Fig. 15.3: Enhanced near vision lens fitted to near PD on Datum line

ATORIC LENSES

The rotationally symmetric aspheric lens provides excellent imaging properties for any lens prescription if it is in spherical. But in case of astigmatism prescription the two principal meridians requires two different eccentricity. For example, in case the lens prescription is $+4.00/+2.00 \times$ 90, the two principal meridians has +4.00 D and +6.00 D, which may need two different aspheric curves for the respective meridians. Such a surface is employed for the Zeiss Hypal series of lenses when dispensed for astigmatic prescription.

Advances in lens design have provided the lens designers with the ability to produce surfaces that are even more complex than aspheric. Just as aspheric denotes a surface that departs from being completely spherical,



Fig. 15.4: Optical performance comparisons between the three lens designs for plus and minus astigmatic lenses manufactured in a polycarbonate material of refractive index 1.586. The white area in the frame represents the field of clear vision while the shaded area represents regions of reduced vision

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atoric denotes a surface that departs from being an exact circular toric. In fact atoricity is an extension of aspheric lens design, allowing the lens designers to optimize both stigmatic and astigmatic lens. They provide a wider field of clear vision than the conventional best form lenses, especially for higher cylinder powers.

SUMMARY

The optical industry has certainly seen an avalanche of new developments in the ophthalmic lenses during last 10 years. The improvements have ranged from lens designs to lens coatings. The lens designers have really taken the challenge and looking ahead for newer lens materials with innovative properties so that one day they can fulfill their dream of making a lens which has:

- High refractive index
- Low dispersion
- Unbreakable and unscratchable
- Low density
- Aspheric in design
- Available in all multifocal forms
- Easy to tint and ARC
- Economical from the patients point of view
- More profitable from our point of view.

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