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Ophthalmic Lenses

SECOND EDITION

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2 Chapter

Ophthalmic Lens Material and Design

Ophthalmic lens materials refer to all materials used during manufacturing of lenses, i.e., all materials entered into the composition of the basic ophthalmic lens. The end result is the new lens material which has specific physical and other properties and specific lens geometry, 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
- Resin material

GLASS MATERIAL

The different raw materials are used in a given proportion and composition while manufacturing spectacle lenses so that it can be used to provide its final application, i.e. refracting the rays of light and thereby improving the eyesight. The lenses so made are in the form of semi-finished lens and 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 iron-free 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 by limestone and dolomite. These basic components are accompanied by numerous other ingredients such as rare earths.

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The role of different components is:

Oxides

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

1. *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, SiO_2, B_2O_3, P_2O_5.
2. *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, K_2O, Na_2O, 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.

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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.

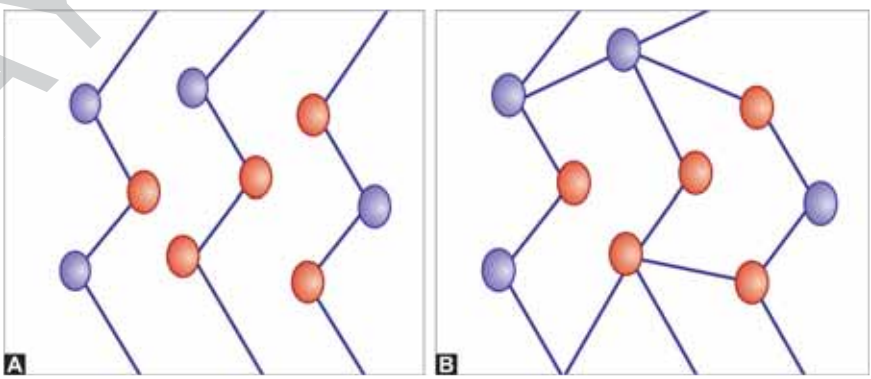
RESIN MATERIAL

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 cross-linked molecular structure, resembles a ladder with extra rungs. They do not melt or flow when heat is applied and makes the material less flexible. 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.



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

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

CR_{39}

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} 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/cm^3 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 CR_{39}. A high refractive index of 1.586 makes it comparatively thinner. Specific gravity of 1.20g/cm^3 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/cm^3 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

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

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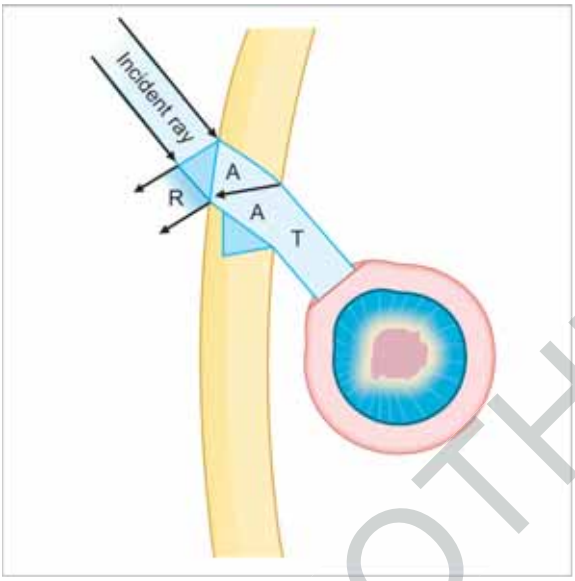

Fig. 2.2: Incident light on an ophthalmic lens

by the number 1, reflectance by R, absorption by A and transmittance by T, the intensity may be expressed as follows:

$$R + A + T = 1$$

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:

- Optical properties
- Mechanical properties
- Electrical properties
- Chemical properties
- 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

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it. Abbe number represents the relative degree of distortion generated while looking through off center 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 center 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:

$$\text{Reflectance} = 100\,(n - 1)^2 / (n + 1)^2\%$$

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

$$100\,(1.5 - 1)^2 / (1.5 + 1)^2$$

$$\text{Or, } 100\,(0.5)^2 / (2.5)^2$$

$$\text{Or, } 100 \times (0.5 / 2.5)^2$$

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%

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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)**.

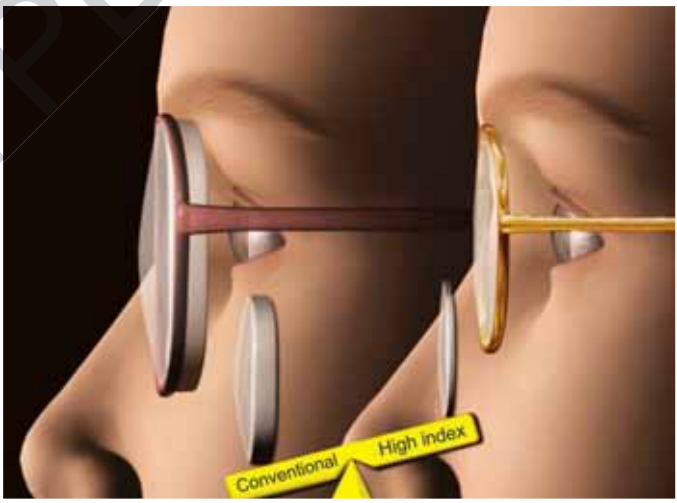

Fig. 2.3: Edge thickness reduces in high index concave lenses

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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 ... 587.6 nm (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.

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

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

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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.

Thermal Properties

Thermal properties are those properties of ophthalmic lens material which is related to its conductivity to heat. In other words, these are the properties

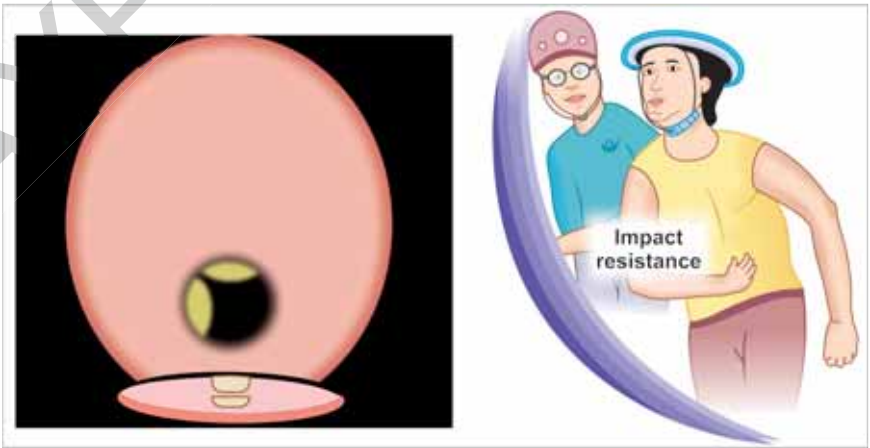

Fig. 2.4: Drop ball test for impact resistance

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which are exhibited by a material when the heat is passed through it. Linear expansion coefficient is one of the important thermal properties of ophthalmic lens material. A moderately low expansion coefficient means that lenses can undergo, without any great risk of damage, treatments such as tempering and vacuum depositing of tinted or anti-reflection coatings, all of which expose them to high temperature cycles. Likewise, moldings have to be capable of resisting machining operations where they are exposed to considerable increase in temperature followed by sudden cooling.

Chemical Properties

Chemical properties of ophthalmic lens material refer to those properties that can be observed when they are being exposed to various acidic agents, alkaline agents and other organic solvents. International standards also require testing to determine fire resistance of materials used to manufacture lenses.

Electrical Properties

Electrical properties characterize effects of electromagnetic waves and electricity on the materials. They are governed by complex laws of physics.

Optical lenses modify the direction of the propagation of light and the relative spectral energy distribution of ultra-violet, visible and infra-red. Therefore, the above properties are the essence of optical lens material and need to be controlled very strictly. Optical lenses must be free from internal defects and strain, with a high standard of homogeneity. They must be produced within tight limits with respect to each property.

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:

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

Where, Ns = refractive index of standard lens material.

Nr = refractive index of substituting lens material.

CVF in above example would be:

$$\text{CVF} = \frac{1.523 - 1}{1.70 - 1}$$

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$$= \frac{0.523}{0.700}$$

$$= 0.747 \text{ D}$$

$$= 0.75 \text{ D approx.}$$

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 x – 10.00 D, i.e., – 7.50 D. In other words the use of 1.70 index material would result in a lens that has a power of – 10.00 D, but in all other respect looks like a – 7.50 D lens made in crown glass.

OPHTHALMIC LENS DESIGN

Lens Designing is the process of defining the lens forms. Lens form represents the shapes of two surfaces of a lens. The shapes of the two surfaces are given by their curves. The curves so designed may be either one single curve across the entire lens surface or multiple curves on one surface and the forms may be:

- Bi-convex
- Bi-concave
- Meniscus
- Plano-convex
- Plano-concave
- Aspheric
- Atoric
- Lenticular

Or, any other form of lens that improves its optical performance by minimizing the effect of lens aberrations. A complicated lens form may not be so specifically defined. It may be defined by mathematical equation.

There are two different approaches as shown in **Flowchart 2.1**, that can be adopted to design ophthalmic lenses:

Mathematical Process

This lens designing process for a lens involves calculation of off-axis errors in terms of sagittal and tangential errors from the lens for each principal meridian using computer software. A desired goal is set to achieve the optimum lens

Flowchart 2.1: Ophthalmic lens design approaches



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design. Calculation of the sagittal and tangential errors of each principal meridian for different sets of front and back lens curves are mathematically analyzed as the surface curves are altered. Best combination is determined that provides the best off-axis optical quality.

Laboratory Simulation

Various combinations of lens forms are tried in front of simulated far point sphere of human eye. This far point sphere is the optical conjugate of the retina of the unaccommodated eye in rotation. The image of an object point formed on this sphere is usually a blurred spot instead of a sharp point due to aberrations of the lens. In order to measure the quality of the image of any object point, the lens designer sends a set of selected light rays that enter the simulated eye after refraction through the lens. The image quality is determined by the shape and size of the blur spot formed on this sphere. The lens designers strive to improve the quality of image by working upon the shape and size of image. To achieve the desired goal they manipulate the effect of various lens' optical aberrations in the best possible way. Best design is achieved when near perfect image quality is determined. Finally, an optimal choice is made to balance between optics and cosmesis.

The goal of ophthalmic lens design is to give the patient clear vision at all distances through any portion of the lens. 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 lens designer has a very limited degree of freedom. Practical condition specifies lens materials, safety consideration fix 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 truth is that the central portion of the lens provides near perfect vision and is termed as 'On-Axis performance' of the lens. But the wearer has to look away from the optical center of the lens which results in wearer's line of sight makes an angle to the optical axis of the lens. It is only the peripheral or mid-peripheral portion of the lens that degrades and deforms the image quality and is termed as 'Off-Axis performance' of the lens. During off-axis viewing, the line of sight makes an angle to the optical axis up to 30 degree as the wearer observes the object in his visual field. All efforts of lens designing are directed towards improving the off-axis performance of the lenses.

The basic lens design is determined by the "base curve selection". The base curve of the lens is the curve 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 also the cosmetic look of the lens. However, the concept of

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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 manufacturer designed curve on the 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 **(Fig. 2.5)**.

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 'V' bevel back and forth to achieve a good fit. The introduction of more automated system of 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 **(Fig. 2.6)**.

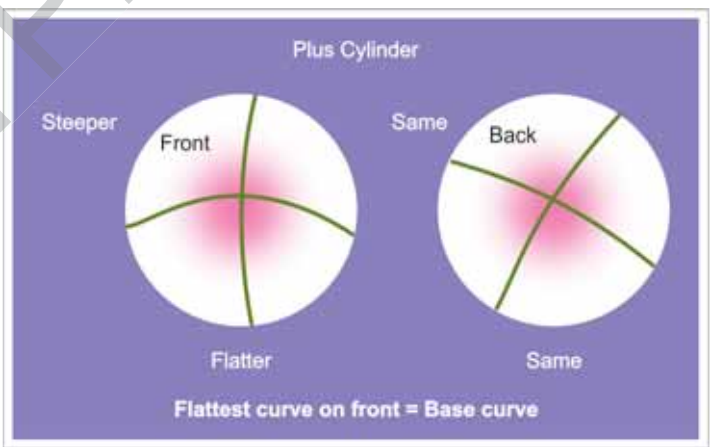

Fig. 2.5: Plus cylinder

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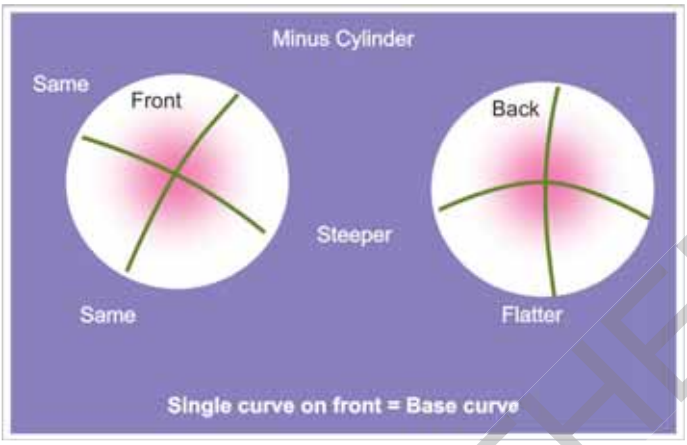

Fig. 2.6: Minus cylinder

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. However, patient 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. Also, 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.

Base curve is the starting point from where the remaining curves will be calculated. It serves as the basis to designate the lens form and it varies:

- For different ranges of power
- Also for the same range of power among different lens manufacturers.

Base curve of an ophthalmic lens can be altered to result in the best optics and cosmetic characteristics across the entire surface of the lens. Thus it is a basic design phenomenon for a spherical lens design. 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 two factors as shown in **Flowchart 2.2**.

Mechanical Factors

The maximum thickness of a lens, for a given prescription, also varies with the form of a lens in addition to lens material. Flatter lens forms are slightly

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Flowchart 2.2: Factors affecting selection of base curve

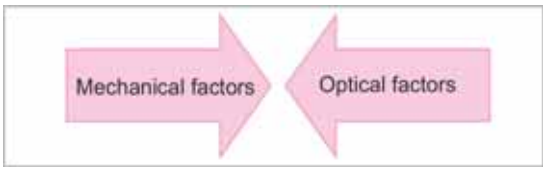



Fig. 2.7: Lens curvature

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. 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 **(Fig. 2.7)**.

Optical Factors

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 center 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 patient's 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)**.

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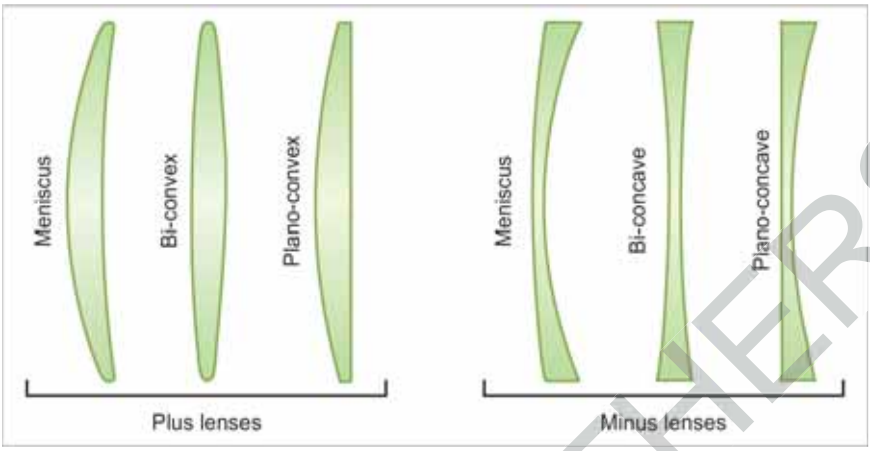

Fig. 2.8: Categories of lens form

The first step while selecting the correct base curve is to check the base curve of the existing glasses before manufacturing a new lens, 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 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

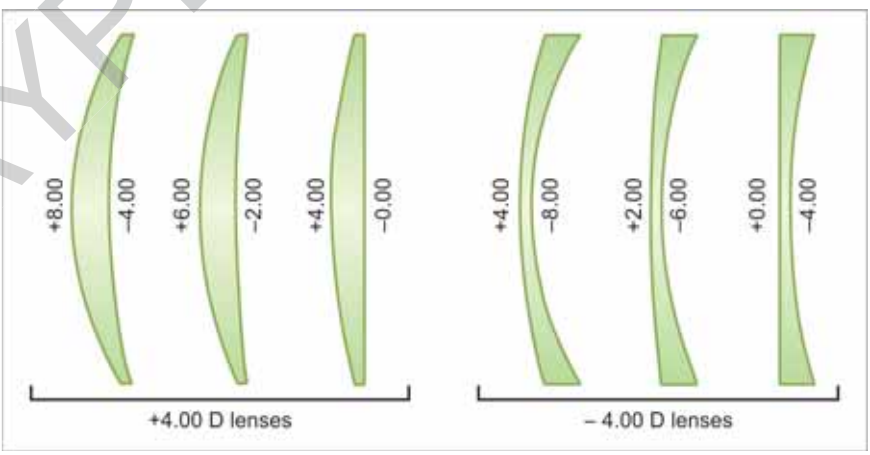

Fig.2.9: Lens form comparisons

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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. Oblique astigmatism
5. Curvature of field
6. Distortion

Chromatic aberration is caused because lens refracts the various wavelengths of light at different angles. Shorter wavelengths are refracted to a greater degree than longer wavelengths. The lens designer deals with this kind of aberration by selecting a lens material with low dispersive value. The small aperture of the pupil is effective in limiting the aberrant effect of comatic aberration and spherical aberration. Consequently, the lens designer pays little attention to these two types of aberrations. The effect of distortion does not alter the position of image, but merely affect its shape, to which brain adapts remarkably. The designers are left with oblique astigmatism and curvature of field. Oblique 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 oblique astigmatism. When a narrow beam of light rays strikes 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 oblique 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. In designing lens, the problem of oblique astigmatism and curvature of field are often closely related. However, field curvature is seldom totally eliminated.

The lens which is centered perfectly and also fits closer to the eyes and is able to keep the patient's 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 they intend 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".

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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 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 center, 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 the effect of oblique astigmatism **(Fig. 2.10).** It says that there is a range of power from about -23.00 D to about +7.00 D 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 – 5.00 D lens requires a back surface power in the region of -9.50 D in Ostwalt form, whereas the Wollaston form needs a back surface power in the region of -22.00 D, made with a lens of 1.523 refractive index.

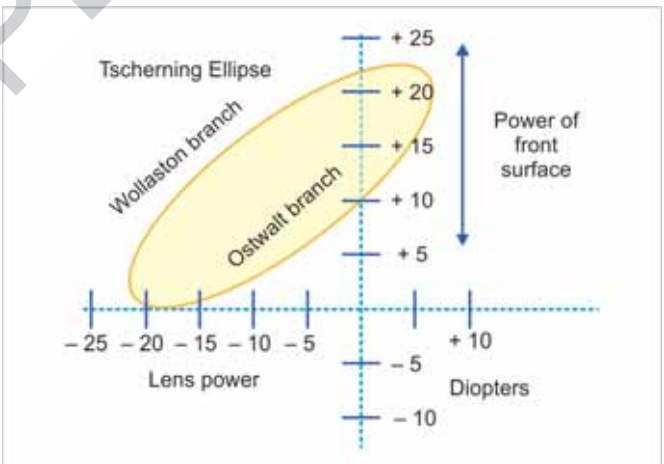

Fig. 2.10: Corrected curve theory

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Table 2.1: Vogel's formula

Power	Base Curve
10.00 8.00	10
6.00 4.00	8
2.00 Plano -2.00	6
-4.00 -6.00	4
-8.00	2
-10.00	Plano

Another method for matching the best curve for a given lens comes in the form of Vogel's Formula as given in **Table 2.1**.

When selecting the proper base curve for a given prescription it is important to follow some rules. Keep basic prescriptions (+2.00D to -2.00D) on 6.00 dioptre base curve and adjust 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 minus, add + 8.00 to that power to get a good approximate base curve.

Example

Given prescription + 4.00 Dsph + 1.00 Dcyl × 90
Spherical equivalent + 4.50 D
Base curve + 4.50 + (4.00) = + 8.50 D

Given prescription – 4.00 Dsph – 1.00 Dcyl × 90
Spherical equivalent – 4.50D
Base curve (– 4.50 D) + 8.00 = + 3.50 D.

This is the basis of spherical lens design. A lens so designed will yield good balance between vision and cosmetic look. However, the sagittal height of the lens will be more that will lead to more bulge and thicker appearance of the lens. Besides, off-axis performance will be significantly poor which will reduce field of clear vision through the lens. The designer got the solution in the form of aspheric lens design. Aspheric surfaces vary gradually in surface power from the center towards the edge, in a radial fashion. It means the asphericity is the same in every meridian of the lens. A spherical surface has the same curvature in any direction across the entire surface, whereas

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Fig. 2.11: Digital lens surfacing

aspheric surface becomes progressively flatter or, steeper away from the center of the lens, i.e., the tangential meridian of the lens. Aspheric surface changes very little around the circumference of the lens, which is the sagittal plane of the lens perpendicular to the tangential plane. The difference in surface curvature produces surface astigmatism which neutralizes the oblique astigmatism produced by looking through the off- axis portion of the lens. Before the appropriate aspheric design is determined, the lens designer must first decide upon the base curve for the lens. Aspheric lenses generally use flatter front curves and then determine the asphericity required for the particular choice bending to eliminate oblique astigmatism. The lenses so made do not provide better vision than the best form lenses but they do provide equivalent vision. Nevertheless, asphericity gives lens designers the freedom to optimize just about any base curve for the chosen focal power or range of powers.

With the new Free-Form Lens Designing process in place the lens manufacturer uses digital technology to produce lenses **(Fig. 2.11)**. The process of lens surfacing starts using block of lens material. The block is cut using a single point cutter that removes material from the spinning blank to create a desired surface. The cutter is precisely controlled by motors which follows a path contained in the form of a digital file. The resulted finished surface can be virtually any shape or curve with the potential for great precision. The process enables lenses to be produced to 0.01 D power accuracy and can reduce lens aberrations and yield less peripheral distortion and peripheral blur.

No lens is perfect. A well design lens is the most perfect in that they achieve a best form that minimizes the effect of most lens aberrations. In this way it can be said that lens designing is the process in which an optimal choice is made from available options to provide the best possible form of lens.

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Multiple Choice Questions (MCQs)

1. **What is being mixed in the glass lens material to give rise to tints?**
   a. Oxides
   b. Sulphur
   c. Potasium
   d. None

2. **A lens made of glass material has an index of 1.70 without an anti-reflective coating. If the lens is clear, what is the percentage of light transmission entering the patient's eyes if 100 percent of light is incident at the front lens surface?**
   a. 84 percent
   b. 87 percent
   c. 90 percent
   d. 93 percent

3. **What does the Abbe Number of an ophthalmic lens material denotes?**
   a. Represents the relative degree of distortions generated while looking through the off-center areas of lens
   b. Represents the physical properties of the lens material to show the degree of hardness
   c. Represents the light transmissibility factor through the lens material
   d. Represents the weight of the lens material

4. **Which of the following properties denotes that the lens material is relatively heavier?**
   a. Refractive index
   b. Specific gravity
   c. Abbe number
   d. None of the above

5. **Which of the following is true about CVF?**
   a. CVF shows the variation in surface power when the lens material is other than standard crown glass
   b. CVF shows the variations in focal power of lens when the lens material is other than standard crown glass
   c. CVF shows the variations in vergence power of lens when the lens material is other than standard crown glass
   d. None of the above

6. **Abbe number of 60 is considered to have the least.....**
   a. Spherical aberration
   b. Coma
   c. Chromatic aberration
   d. Oblique astigmatism

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7. **The lens form or lens profile of a spherical lens is predominantly determined by:**
   a. Base curve selection
   b. Ocular curve selection
   c. Refractive index selection
   d. All of the above

8. **What happens when the lens designer deviates from the rule of "best form lens" and produces flatter lens which provides thinner look?**
   a. They induce unwanted aberration
   b. Blurred vision in the periphery
   c. Restricted field of clear vision
   d. All of the above

9. **Why is the concept of "best form lens" so important?**
   a. To provide clear vision from the center of the lens.
   b. To provide clear vision from the periphery of the lens
   c. To provide a wider field of clear vision
   d. All of the above

10. **Which of the following is true about polycarbonate lens material?**
    a. It is linear thermoplastic polymer with an amorphous structure
    b. It is more impact resistant and lighter than CR_{39}
    c. The material is very soft in nature and hence prone to scratches
    d. All of the above

Answers

1. a	2. b	3. a	4. b	5. a	6. c	7. a	8. d	9. c	10. d

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