Prism doesn't have to be perplexing

In this article Peter Chapman gives a brief overview of types of prism, how they are created in ophthalmic lenses, and solutions to overcome differential prism at the near vision point.

Basics of Prism

A prism is a solid, clear material bounded by clear, polished faces. They are usually triangular in shape with 3 faces, one being the base and two refracting faces. The angle between the two refracting faces is known as the apical angle (Fig.1).

Prisms fall into two main categories, refracting and ophthalmic. Refracting prisms are commonly used in optics for splitting beams of light. This may be used in inferometry or photometry. Spectroscopy uses prism to produce dispersion of light into its component colours.

Ophthalmic prisms are used for correction of binocular vision disorders, which are producing symptoms, usually decompensated heterophorias or heterotopias/strabismus. It is only ophthalmic prisms that will be considered in this article.

As light passes through a prism it is deviated away from the apex on both entrance and exit of the prism (Fig.2). This principle is different to that of a block with parallel sides, where the deviation is annulled by the two parallel surfaces. The amount the light is deviated is dependent on the apical angle of the prism and the angle of incidence and emergence.

Prisms can be classified into two groups, those with large apical angles and those with small apical angles. Ophthalmic prisms fall into the latter category where the apical angle is less than 10°.

Prisms are described by the unit prism dioptre. This relates
to the amount of deviation the prism creates (in cm) at a distance of one metre. Hence a prism of power $1^\Delta$ will create a displacement of 1 cm when light is projected onto a screen measured at 1 metre. A relationship between the power of a prism and deviation of a prism can be shown with the formula:

$$P^\Delta = 100 \tan d^\circ$$

Prisms are often assumed to have the light at a normal angle of incidence with the first refracting surface. This is widely acceptable as prisms are usually glazed with the front surface normal to the incident light. Therefore in images of ray tracing with ophthalmic lenses, the prism is often represented as a right-angled triangle.

Creating prism on a spectacle lens

Prism can be created on a spectacle lens by either decentration or by working prism on the lens.

Prism by decentration is created by the use of Prentice Law/Rule Fig.3. This states that there is a relationship between the magnitude of prism, the power of the lens, and how much the lens is decentred from the optical centre of the lens.

$$P^\Delta = cF$$

Where $P =$ Prism power in Dioptres
$C =$ Decentration in cm
$F =$ Lens power in Dioptres, D

If the lens is -6.00DS in power then the decentration needed would be:

$$P^\Delta = cF$$
$$3^\Delta = c \times 6$$
$$3/6 = c$$
$$c = 0.5cm$$
$$= 5 \text{ mm}$$

Following decentration of a spectacle lens it is always important to ensure that the new lens layout can be cut from the blank size given. Most common blank sizes range from 50–70mm. To ensure the lens can be cut, it is important to calculate the minimum uncut size. This is found by adding the effective diameter of the lens to be cut (the largest diameter) to double the decentration + 2mm for wastage during glazing. Therefore, assuming the geometric centre and optical centre of the lens coincide, the above lens of -6.00 DS is to be glazed to achieve $3^\Delta$ dioptres of prism into a frame with an effective diameter of 48mm then a blank size of 56mm would be needed. As this is not a standard blank size an uncut lens of 60mm would be required.

As described earlier, in some cases decentring a lens is not possible, as the blank size needed falls outside that can be ordered. Also, it is not possible to create prism by decentration when using an aspheric lens, as this alters the optics of the lens. In these cases worked prism is necessary. This uses the principle of prism being created by working the surface of a prism lens with the surface of the optical lens using special tools. This has the effect of making the edge thickness of the uncut lens different and therefore the effect of shifting the position of the optical centre.

During manufacture of the uncut lens, the amount of prism worked on the original blank is checked by measuring the difference in edge thickness. On any prismatic lens there is a relationship between the thickness at the apex and the thickness at the base. This is shown below. During the construction of the blank, the difference in edge thicknesses will be calculated and controlled over a specified diameter. Two approximate formulas can be used to check this:

$$G = \frac{D \times P}{100(n-1) + \left(n_P^2\right)}$$

Or

$$G = \frac{D \times P}{100(n-1)}$$

Example: if $3^\Delta$ dioptries of prism needs to be created by a -1.00DS lens then the lens must be decentred by:

$$P^\Delta = cF$$
$$3^\Delta = c \times 1$$
$$3/1 = c$$
$$c = 3 \text{ cm}$$

So the lens must be decentred 3cm
The use of prisms

As stated earlier, prisms are used to overcome symptomatic binocular vision problems. The binocular vision system relies on the eyes pointing at the same fixation point. This uses the visual processing system to control the extraocular muscles to enable the eyes to rotate to achieve this. The eyes are controlled by six extraocular muscles. These move the eyes in specific directions, accounting for the six diagnostic positions of gaze during motility testing in Table 1.

Any weakness in the extraocular muscles can lead to asthenopic symptoms including headaches, eye strain and diplopia as the visual system fights to control a misalignment of eye positioning and tries to create binocular single vision.

Three common factors for asthenopia are:

1. A weakness in the vergence system
2. A problem with sensory fusion
3. An unusually large heterophoria.

Fusional reserves play an important role in determining the likelihood of asthenopia as this represents the amount of divergence and convergence which can be induced by prism before fusion is compromised and blurred or double vision occurs. Table 2 shows the normal fusional reserves.

<table>
<thead>
<tr>
<th>Direction of gaze</th>
<th>Right Yoke muscle</th>
<th>Left yoke muscle</th>
<th>Blur</th>
<th>Break</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>Lateral rectus</td>
<td>Medial rectus</td>
<td>9</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>Left</td>
<td>Medial rectus</td>
<td>Lateral rectus</td>
<td>-</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Up and right</td>
<td>Superior rectus</td>
<td>Inferior oblique</td>
<td>17</td>
<td>21</td>
<td>11</td>
</tr>
<tr>
<td>Up and left</td>
<td>Inferior oblique</td>
<td>Superior rectus</td>
<td>13</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>Down and right</td>
<td>Inferior rectus</td>
<td>Superior oblique</td>
<td>-</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Down and left</td>
<td>Superior oblique</td>
<td>Inferior rectus</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. The six diagnostic positions of gaze

Table 2. Normal fusional reserves (adapted from Pickwell’s Binocular Vision Abnormalities, Bruce JW Evans, 2007)

Ordering prism

When ordering prism, two different notations can be used. Firstly, and most commonly used in the UK, prism can be ordered by specifying the amount of prism required and the base direction. Alternatively, a 360 notation may be used, with the direction of the prism indicated by the position on a compass. 0 is always positioned right on the lens and 180 left, 90 superiorly and 270 inferiorly. The use of 360 notation Fig.4 is more commonly used for oblique and compounded prisms due to its abbreviated form.

Example:

\[ R \ -6.00DS \ \ \ \text{prism} \ \ 2^\circ \ \text{DN} \ \ 3^\circ \ \text{Out} \]
\[ L \ -4.50DS \ \ \ \text{prism} \ \ 2^\circ \ \text{UP} \ \ 3^\circ \ \text{Out} \]

Can also be written as:

\[ R \ -6.00DS \ \ \ \text{prism} \ \ 2^\circ \ \text{base} \ 270 \ \ 3^\circ \ \text{base} \ 180 \]
\[ L \ -4.50DS \ \ \ \text{prism} \ \ 2^\circ \ \text{base} \ 90 \ \ 3^\circ \ \text{base} \ 0 \]

Prism Thinning

This special use of prism is found on progressive lenses. When a progressive lens is designed with a front surface add, it is the difference in radius of curvature between the top
<table>
<thead>
<tr>
<th>Condition</th>
<th>Right eye</th>
<th>Left eye</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exophoria/tropia</td>
<td>Base in</td>
<td>Base in</td>
</tr>
<tr>
<td>Esophoria/tropia</td>
<td>Base out</td>
<td>Base out</td>
</tr>
<tr>
<td>R/L hyper</td>
<td>Base down</td>
<td>Base up</td>
</tr>
<tr>
<td>L/R hyper</td>
<td>Base up</td>
<td>Base down</td>
</tr>
</tbody>
</table>

Table 3. The base direction of prism needed to correct differing binocular vision anomalies

Anisometropia

Anisometropia is the name given to where a patient has different spectacle corrections in each eye. This may be physiological or following surgery, such as in the case of aphakia or following cataract surgery. It is usually classified when the difference is 0.75-1.00 D or greater in any meridian and usually becomes problematic at levels of 2.00 D or greater.

This is for two main reasons:

1. The retinal image sizes formed by the spectacle lenses on the retina become greatly different in size due to spectacle magnification, thus making it difficult for the visual cortex to fuse the retinal images. This is called aniseikonia.

2. When an image is viewed off axis through the spectacle lens and away from the optical centre, prism is induced by the spectacle lens. When the spectacle corrections are similar, the prism induced by each lens is similar in magnitude and opposing so has a neutral effect. When the powers of the lenses are different, as in the case of anisometropia, the amount of prism induced is different by both lenses and so there is a net introduction of prism. This unwanted prism has the potential to disrupt the binocular status of the visual system and is especially troublesome when vertical prism is induced.

Anisometropia can be considered as induced or adaptive. Induced anisometropia is used when a sudden change in prescription is created, which quite commonly may be following cataract surgery to one eye. Adaptive anisometropia is found where the prescription slowly changes over a period of time leading to anisometropia. Example of this may be the formation of nuclear sclerosis leading to a myopic shift.
Due to the nature of adaptive anisometropia occurring over a long period of time, patients in practice generally adapt better to this than induced anisometropia, with often 2-3DS of anisometropia being created before the patient becomes symptomatic. This is most likely due to a phenomenon called prism adaption, the response of the ocular motor system to the presence of differential prism. Some studies have found that patients with $5^\circ$ differential prism have no symptoms. Adaption to prism can be fairly rapid with studies showing that 1.5D of prism adaption can occur in 3 minutes. Prism adaption is most commonly found in the position of most binocular fusion, which is generally the patient’s habitual gaze for distance vision. However prism adaption does not necessarily happen with every anisometropic patient. Early studies by Ellerbrook and Fry found that out of 47 anisometric patients given spectacles both with and without correction for prism compensation, 29 patients felt more comfortable with the prism compensation in their spectacles. The same researchers conducted another study, which found 60% preferred prism compensated spectacles. However, prism adaption does not necessarily happen with every anisometric patient. The significance of this is that whilst some patients with anisometropia may be able to adapt to spectacles, it is important that the 60% of patients who are likely to struggle are identified so lenses with prism compensation can be considered.

One possible way for this to be done is to test for a vertical fixation disparity with near vision when it is absent for distance vision. Should this be present, a compensating prism can be used to see if this gives a positive increase in comfort. Likewise this can be done in cases of non-tolerance where compensating vertical prism is held in front of the bifocals or progressive lenses to see if an improvement of symptoms is found.

Similarly to adaptive anisometropia, significant anisometropia that has been present since childhood for example amblyopic anisometropia, (prevalent in approximately 5.6% of 16-19 year olds is often less bothersome to patients, as they have learnt to adapt over many years and these patients are often found to have an element of suppression that eliminate binocular fusion and their symptoms.

Near vision symptoms and anisometropia

As has been seen earlier, the horizontal fusional reserves of the eye are much larger than the vertical. This enables the binocular system to overcome induced prism in the horizontal meridian easier than in the vertical, and thereby patients are less symptomatic when looking horizontally off axis. Due to the limitation of the vertical fusional reserves, patients notice most symptoms associated with anisometropia.

When reading, a patient's eyes will look rotate so the viewing axis is passing around 10mm below the optical centre of the lens. For this reason, all bifocals are created with the segment drop 10mm below the geometric centre of the lens.

**Example:** The effect on inducing prism can be seen in the following example using Prentice's law:

\[
\begin{align*}
R & \quad P = 1 \times 8 \\
L & \quad P = 1 \times 4
\end{align*}
\]

It is presumed that the patient views 10mm from the optical centre of the lens to read.

Therefore, using Prentice's law \(P = CF\)

\[
\begin{align*}
R & \quad P = 1 \times 8 \\
L & \quad P = 1 \times 4
\end{align*}
\]

This leaves to a net differential of \(4^\circ\) base up in the R eye when reading, much more than the normal fusional reserves can overcome. Therefore, when dispensing patients with anisometropia, especially those with induced anisometropia, control of this differential prism must be considered.

Whilst asthenopic problems associated with anisometropia are most commonly found in presbyopic patients, they can also be found in non-presbyopes. However, due to prism adaption, the numbers of symptomatic patients are far less and are generally restricted to those patients who spend many hours performing critical tasks at near vision.

**Solutions to differential prism at the near vision point**

Common solutions to differential prism at the near vision point are:

- Two pairs of spectacles
- Uneven segment sizes
- Prism segment bifocals (solid visible)
- Slab-off bifocals and progressives
- Fresnel prism
- Franklin split bifocals
- Cemented bifocals
- Contact lenses

**Two pairs of spectacles**

This is optically the best solution and probably the easiest way to compensate for differential prism, but not necessarily the best solution for the patient due to a high inconvenience factor. With two pairs of spectacles, patients can compensate for off-axis viewing by altering their posture to view distance objects, reducing the induced prismatic effect. With near vision, the patients' eyes will still rotate from the geometric
centre of the lens, so this can be compensated for by glazing the lenses with the optical centres 10mm lower than usual. This ensures that when the eyes rotate downwards the viewing axis is now passing through the optical centre of the lens, thereby eliminating induced prism in accordance with prentices rule. It should be remembered that as the optical centres are lowered by 2mm, the pantoscopic tilt of the spectacle frame should be increased by 1°.

Uneven segment sizes
Creating compensating prism using different segment sizes usually involves using round segment bifocals as this enables a larger amount of prism to be created, generally with other segment shapes there is insufficient difference in the position of the optical centres at the near vision point to create prism. With round segment lenses the larger segment sizes have their optical centres lower than the smaller segment sizes, and therefore produce more base down prism. Therefore the larger segment size is positioned in front of the most plus or least negative powered lens. Common round segment sizes are 24mm, 25mm, 28mm, 30mm, 38mm, 40mm and 45mm.

To calculate the sized segments needed, the differential prism must firstly be calculated. As stated earlier, the patient is presumed to view an object 10mm away from the optical centre of the lens. The formula below is then used:

Example:

\[
\text{Difference in seg sizes} = \frac{20 \times \text{differential prism}}{\text{Add}}
\]

\[
\begin{align*}
\text{R + 7.00 DS add} & + 3.00 \\
\text{L + 4.50 DS add} & + 3.00
\end{align*}
\]

Differential prism using prentices Law is 2.5\(^{\Delta}\)

So using the above formula: \(20 \times 2.5 = 16\text{mm}\)

This indicates there must be a difference of 16mm between the segment sizes. The segment sizes of choice would be R24 and R40mm with the +7.50DS lens being the R40 segment.

Certain manufacturers produce large D segment bifocals, either 40 or 45mm in diameter, which have the optical centre of the segment at the top of the segment. This allows them to be combined with a D segment where the optical centre is 5mm below the segment top, allows a small amount of differential prism to be controlled (0.5\(^{\Delta}\) per dioptre of add).

Table 4 shows the differential prism created by different segment sizes 5 mm below the segment top with all values being Base Down prism.

Prism controlled segment bifocals
This is probably the most versatile prism controlled bifocal lens, allowing for different prism amounts for distance and near incorporated into one lens. As the prism can be different in every direction is beneficial for prescriptions where different magnitudes of prism are needed for distance and near as well as controlling differential prism.

This particular lens is only available in crown glass, the blank being 70 x 66mm with a segment size of 30mm. The lens is created by surfacing the segment independently of the main lens and a total of 6\(^{\Delta}\) of prism can be worked into the segment.

For correction of differential prism it is always best not to split prism and to incorporate the entire amount of prism into one lens, with this being the lens needing base UP prism to allow an easy transition from distance to the near segment.

Slab off bifocal/progressive lenses
Slab off lenses can be made in bifocal or progressive format, with the maximum amount of prism able to “slab off” being from 1 to 10\(^{\Delta}\). These lenses are particularly useful for induced anisometropia following cataract surgery, where the prescription has been suddenly altered, inducing anisometropia, which would normally restrict a patient form wearing bifocals or progressive lenses as they had pre-surgery.

The lenses are created by removing base up prism from the
upper half of one lens. Firstly a mask lens is prepared and bonded to the front surface of the lens with base up power. This combination lens is then surfaced to remove base up from the combination lens with the surfacing aligning with the segment top. Remaining mask lens is removed leaving base up prism in the reading portion only. A reverse slab off is available from Younger Optics where base down prism is created on the lens rather than removing base up prism. The lens needing to be “slabbed off” is the least plus or most negative lens; however this is reversed for a reverse slab off lens. Slab off lenses are easily identifiable by a faintly visible horizontal line across the lens at the level of the segment top. When using an executive style lens or large D segment, this line is virtually invisible due to the positioning being concealed by the segment top.

A slab off progressive lens is also available, but the dispenser has to decide where the prism starts. This decision is quite easy for a bifocal I sit would correspond to the segment top as this produces the least jump effect and gives the best cosmetic appearance. For a progressive it would be advisable to start the prism in the same position as a bifocal segment would be fitted.

Franklin Split Bifocals
The original bifocal lens designed by Benjamin Franklin in 1784, this lens is effectively 2 single vision lenses that are cut in half and then bonded together using an epoxy resin to take the appearance similar to an executive bifocal. These lenses are best glazed into full rim metal frames as the extra tension created by the metal frame stops the lens slipping. The benefits of this lens are that the top and bottom segments are completely independent, so as well as vertical differential prism being created by the addition prism to the near vision portion, horizontal prism can also be corrected. Franklin split bifocals are cosmetically unappealing and often heavy so generally not tolerated by the more discerning patient, however they are easy to dispense as fitted like a normal bifocal but the order specified as a Franklin split bifocal.

Cemented bifocals
This type of prism controlling bifocal uses Canada balsam to cement an independently surfaced addition with incorporated prism onto the back surface of a single vision lens. The cemented lenses are made out of glass and work best when the segment has base down prism as this creates less jump and better cosmesis as the thickness of the segment is at the base of the lens and better concealed by the rim and natural lens thickness. The prism segment is usually cemented onto the most positive or least negative of the lenses. Canada balsam is used as a bonding agent due to the refractive index being very similar to that of crown glass (n=1.55) so has little effect on the ray tracing of the lens, dries from a transparent yellow colour to a clear adhesive, whilst maintaining all of its optical properties.

Fresnel prism
Fresnel prisms are thin sheets made up of many small prismatic segments formed into a sheet of PVC around 1mm thick. One surface is perfectly smooth, that once wetted can be applied to the smooth surface of a spectacle lens and is held in place.

A Fresnel prism (Fig.4) is a cost effective way to see if prism would benefit a patient as one can be applied temporarily to a spectacle lens. However the long-term use of Fresnel prisms is not recommended as they reduce the visual acuity between 1-2 lines.

Contact lenses
Contact lenses eliminate the need for correction of differential prism as they move with the eye so no prismatic effect is induced. Their other benefit is the reducing in spectacle magnification and correction of aniseikonia, which is also associated with anisometropic prescriptions.

Contact lenses can be used on their own, but can also be used to correct distance vision and allow standard progressive lenses with little distance correction to be worn over the top. A novel use of prism thinning

Whilst prism thinning is designed to reduce lens weight, edge thickness and centre thickness, this manufacturing technique could possibly be used to correct asthenopic symptoms associated with differential prism at the near vision point, as described by Stephen Golding, a dispensing Optician at the Manchester Royal Eye Hospital, although has not been tried by the author.

Example: consider the prescription:

\[
\begin{align*}
R & +1.50 \text{ DS add } +3.00 \\
L & +4.00 \text{ DS add } +3.00
\end{align*}
\]
The differential prism created at the near vision point would be 2.5Δ base up L eye. If prism thinning was applied to a conventional progressive lens, then the prism thinning applied would be approximately 2Δ base down to both lenses, which would not normally cause a problem to the patient due to the yoked effect of the prism.

It therefore has been suggested that by ordering the right lens without prism thinning, 2Δ of base down prism thinning would be worked to the left eye, which in turn would cancel out some of the base up prism induced by the anisometropia. This would leave a differential prism of around 0.5Δ base up in the left eye, which should be much more tolerable by the patient as equates to a 0.50DS difference in prescription, which is often very common.

One potential problem with this solution concerns the fact that prism thinning is worked over most of the spectacle lens and so would be applied to the distance portion of the lens. By this happening, would this not induce diplopia or asthenopia for distance? Well, it is reported that this does not happen. The theory as to why this is the case relates back to prism adaption earlier in the article, whereby it was discussed that research has shown that most people can adapt to 1.5Δ of differential prism in 3 minutes with some people being able to adapt to amounts as great as 5Δ.

**Conclusion**

Whilst prism can often seem to be perplexing to practitioners, a simple understanding of the basic principles will often help resolve areas of confusion. Whilst it is often

### References


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**About the author**

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Peter Chapman is an optometrist in private practice in Dorset and Somerset. Peter started his career in optics by training as a Dispensing Optician, and then completed a degree in Optometry. He now has his own practice in Somerset and also works part time for another independent practice. Peter has a special interest in dispensing and small business management along with shared community eyecare schemes.

Peter has written and developed CET and visual recognition quizzes for CLEARVIEW Training as well as presenting and supervising on a number of pre-registration training courses. He is also an experienced facilitator and a key driver in the company’s Peer Review programs.
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1. As light passes through the prism, the rays are
   A. totally internally reflected
   B. Deviated away from the apex
   C. Deviated towards the apex
   D. Passes through in a straight line

2. Which of the following statements is correct?
   A. P x F = C
   B. P x c = F
   C. P = c / F
   D. P = c x F

3. A patient has a prescription of R +6.00DS L +6.00DS, and the distance PD is 33 mm R&L. With what centration would the lenses be glazed at to include prism 1.5^\Delta BO each eye into the prescription?
   A. 27 mm R&L
   B. 30.5 mm R&L
   C. 35.5 mm R&L
   D. 39 mm R&L

4. When an right eye gazes infero-temporally, the activated muscles is:
   A. Inferior rectus
   B. Superior rectus
   C. Inferior Oblique
   D. Superior oblique

5. Which of the following options is incorrect?
   The amount of prism thinning applied to a lens is dependant on:
   A. The frame style
   B. The add power
   C. The lens refractive index
   D. The position of the fitting cross

6. An example of adaptive anisometropia is:
   A. Anisometropia following cataract surgery
   B. Anisometropia due to aphakia
   C. Anisometropia due to progressive nuclear sclerosis
   D. Anisometropia due to refractive surgery

7. Which one of the following is not a symptom caused by anisometropia?
   A. Headache
   B. Diplopia
   C. Difficulty focussing
   D. Drowsiness

8. If the optical centres of a near vision pair of spectacles are dropped by 10mm to account for differential prism, the pantoscopic tilt must be altered by:
   A. 2.5 degrees
   B. 5 degrees
   C. 7.5 degrees
   D. 10 degrees

9. Which of the following combinations could be used to control 2^\Delta of differential prism when the reading add is +2.50 R&L.
   A. R 24 & R38
   B. R24 & R40
   C. R22 & R45
   D. R25 & R38

10. A prism controlled segment bifocal is available in which segment size?
    A. R24
    B. D28
    C. R30
    D. R38

11. The most amount of differential prism can be controlled using which of the following?
    A. Prism controlled segment bifocals
    B. Uneven segment sizes
    C. Prism thinning
    D. Slab off bifocal

12. Canada balsam is used as a cementing agent due to its ideal refractive index of?
    A. 1.49
    B. 1.523
    C. 1.55
    D. 1.59