The Fitting of Spectacle Lenses

The fitting of single vision spectacle lenses is often taken to mean, simply, the accurate measurement of the distance between the centres of the subject's pupils. The advent of more technically sophisticated spectacle lenses, such as aspheric lenses for the normal power range, has emphasised the importance of the correct centration of spectacle lenses for the entire power range. In order for a lens to provide the off-axis performance which the designer intended, its optical axis should pass through the eye's centre of rotation. In the case of aspheric lenses, in addition to the centre of rotation condition, the optical axis should also pass through the pole of the aspherical surface so that the primary visual axis passes normally through the aspherical surface.

Whether this condition is achieved or not depends upon any prism which is incorporated in the lens. We will begin by considering lenses without prescribed prism.

Centration of lenses for distance vision

It is convenient to discuss the centration of spectacle lenses in the horizontal and vertical meridians separately. We will begin with the horizontal centration of spectacle lenses.

The points at which the optical centres are to be located in the absence of prescribed prism are known as the **centration points**. The distance between the right and left centration points is known as the **centration distance**. It will emerge from the following that it is actually the right and left **monocular** centration distances in which we are interested.

Consider the subject depicted in Figure 1 whose head is supposed to be held in the primary position with the eyes fixating a distant object. Careful inspection of the figure will confirm that the mid-point of the bridge of the spectacle frame is not exactly midway between the centres of the subject's pupil. In the Figure, M_L is somewhat greater than M_R. In practice, this situation occurs either because one eye is further from the centre of the bridge of the nose or, with a perfectly symmetrical face, because the nose is not symmetrical, pushing the centre of the bridge of the frame to one side. Common sense dictates that in reality it is likely to be a combination of these two factors, one of which, in theory, could cancel out the other!

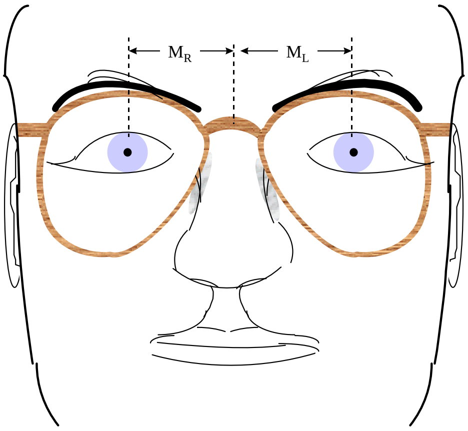


Figure 1. Monocular centration distance

The mid-point of the bridge of the frame need not coincide with the point midway between the pupil centres. The only reference point which is available to the technician who must mount the lenses is the mid-point of the bridge of the frame.

From a practical point of view, the technician who must mount the lenses into the frame could know nothing of any facial asymmetry which the subject might possess and must centre the lenses horizontally with respect to the centre of the bridge of the spectacle frame. It will be realised from the outset that it is not the horizontal interpupillary distance in which we are interested but rather the horizontal distances between the right and left centration points, measured from the centre of the bridge of the spectacle frame which the subject is actually to wear. When the eyes are directed towards a point on an object the image of that point will be produced on the fovea. The line joining the object point and the fovea is the eye's visual axis. It is assumed that the eye's entrance and exit pupils and the eye's centre of rotation lie on the

visual axis. If a spectacle lens is placed before the eye so that its optical axis coincides with the visual axis there will be no prismatic effect and the object will not be displaced.
Figure 2 depicts a plan view of the eyes which are directed towards an object lying at infinity. The visual axes are parallel and making use of the foregoing assumptions the distance between the eye's visual axes is the same as the distance between the eye's centres of rotation, the pupil centres and the centration points in the spectacle plane. In the horizontal meridian, in the absence of prescribed prism, the optical axes of the lenses should coincide with the visual axes. This will be achieved if the lenses are centred horizontally according to the monocular centration distances. Individual centration for the right and left eyes will ensure that the poles of the surfaces lie on the visual axes.

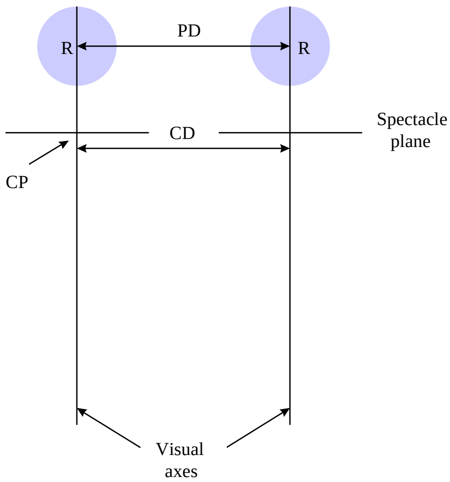


Figure 2. Inter-pupillary distance and centration distance

R = eyes's centres of rotation
CP = centration point
CD = centration distance

Spectacle lenses are mounted before the eyes in a plane which is approximately parallel to the plane joining the supra-orbital ridge to the chin (figure 3).

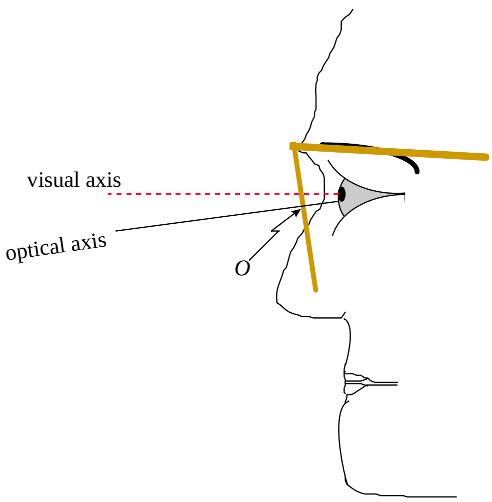


Figure 3. Vertical centration of spectacle lenses

O = optimum position for optical centre

This plane is usually inclined at an angle between 5° and 15° to the normal to the primary direction of the eye and the angle is referred to as the *pantoscopic angle*. If the line of the side of the spectacle frame is horizontal, as it often is, the pantoscopic angle is the same as the *angle of side*. In order for the optical performance of the lens to match that which the designer intended it is necessary for the optical axis of the lens to pass through the eye's centre of rotation. This can be achieved by lowering the optical centre of the lens to compensate for the tilted spectacle plane.

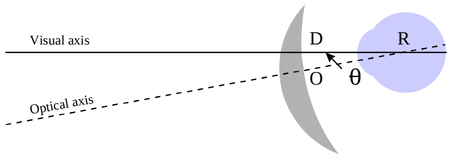


Figure 4. Vertical centration - the centre of rotation condition.

The amount by which the optical centre should be lowered, DO, can be deduced from Figure 4. If the pantoscopic angle is denoted by θ, and the distance from the back vertex of the lens to the eye's centre of rotation by ***s*** then the amount by which the optical centre should be lowered, *DO* can be seen to be

$$DO = s \tan\theta.$$

The accompanying table 1, gives values of *DO* for various values of pantoscopic tilt, θ, when s is assumed to be 27mm. The dispensing rule, that the optical centre should be lowered by 0.5mm for every 1° angle of pantoscopic angle has its origin here.

pantoscopic angle	lower optical centre
2.5°	1.2mm
5°	2.4mm
7.5°	3.6mm
10°	4.8mm
12.5°	6.0mm
15°	7.2mm

Table 1
Vertical centration of lenses and pantoscopic angle

It can be deduced from the table that, in general, the optical centre of a lens should not be placed directly in front of the centre of the eye's pupil, but on average some 4 to 5 mm below the pupil centre. Providing that the lens is of good optical form, the 10° performance of the lens is virtually the same as the performance at its optical centre and no deterioration in the performance of the lens should be anticipated from this procedure.

Centration of lenses for near vision

When recording the PD, or CD, for distance vision we measure the distance between the visual axes which are supposed to be parallel and directed to infinity and assumed to pass through the centres of the pupils. In near vision, however, the separation of the centres of the converging pupils are not required. Instead we are interested in the horizontal separation of the converging visual axes as they intersect the spectacle plane. This distance is known as the *near centration distance* (**NCD**) and is invariably less than the inter-pupillary distance in near vision owing to the forward position of the spectacle plane (figure 5).

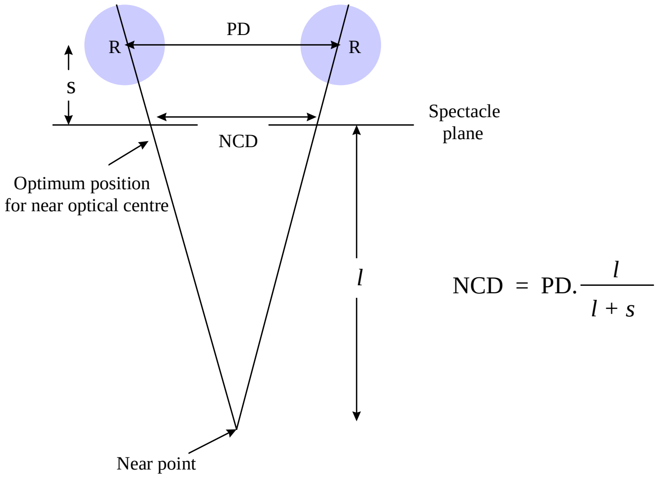


Figure 5.   Near centration distance

The PD for distance vision remains constant as the distance between the eyes's centres of rotation

If the monocular CD is taken to be the distance between the eye's centre of rotation and a line passing through the centre of the bridge of the frame, it can be seen in the figure that the NCD is a function of the monocular CD, the working distance *l* and the position of the spectacle plane in relation to the eye's centres of rotation, *s*.
By means of similar triangles it is easy to show that:

monocular NCD = monocular CD.*l/ (s+l)*

Using the value of 27mm for *s,* this expression reduces to the following forms for various working distances, *l*:

Working distance	**25cm**	**NCD = 0.903CD**
	33.3cm	**NCD = 0.925CD**
	35cm	**NCD = 0.928CD**
	40cm	**NCD = 0.937CD.**

The following table showing the monocular NCD for various monocular CDs has been obtained by means of these expressions.

CD	**NCD for near vision at**			
	25cm	**33.3cm**	**35cm**	**40cm**
37	33.5	34	34.5	34.5
36	32.5	33.5	33.5	33.5
35	31.5	32.5	32.5	33
34	30.5	31.5	31.5	32
33	30	30.5	30.5	31
32	29	29.5	29.5	30
31	28	28.5	29	29
30	27	28	28	28
29	26	27	27	27
28	25.5	26	26	26.5

Table 2 Relationship between monocular CD and NCD for various working distances (s = 27 mm)

It was pointed out above that when a spectacle lens is tilted about a horizontal axis in front of the eye, by the value of the pantoscopic angle, the optical centre of the lens needs to be decentered downwards, in order to compensate for the tilt, allowing the optical axis of the lens to pass through the eye’s centre of rotation. It goes without saying, that if we decentre a lens horizontally, for example, to ensure that there is no horizontal prismatic effect at the near centration points, then the lens should be tilted about a vertical axis to compensate for the decentration! Since the decentration is of the order of 2.5 mm for each lens, the dihedral angle of the lenses should be about 5° corresponding to a reverse bowing of the front of some 10°.
Such a drastic step is almost never taken in spectacle frame fitting, the front is more likely to be given a bow which corresponds with the curve of the face. If this is the case, then it has been suggested that the centration of the near vision lenses be made the same as that of the distance pair, ie, no horizontal decentration be given to compensate for the convergence of the visual axes. The purpose of this suggestion is, simply, to ensure that the optical axis of the lens passes through the eye’s centre of rotation and in the case of a monocular subject would prove to be a sensible alternative to providing a reverse bow to the front of the frame. However, bearing in mind that aspheric lenses are often dispensed to improve the mechanics of medium-to-high power prescriptions, centring near vision lenses of positive power for distance vision will give rise to base out prism for near. This may prove intolerable in cases of convergence insufficiency and the best expedient is to decentre the lenses inwards as normal, reserving the ability to apply a reverse bow to the front to fulfil the centre of rotation condition only if it appears that the subject would benefit from such a procedure to improve comfort in near vision.
In the case of minus lenses, no horizontal decentration for near results in a small amount of base in prism at the near visual points which is normally quite harmless.
Surprisingly, the requirements for the vertical centration of lenses in near vision is exactly the same as it is for distance vision. In near vision, the zone of the lens which is used for reading lies below the distance visual zone. The centre of the near visual zone, the near visual point (NVP) is normally taken to lie some 8 to 10 mm below the distance visual point and $2^{1}/_{2}$ mm inwards. It was pointed out that, for distance vision, the optical centre of a spectacle lens is lowered from the position directly in front of the pupil to satisfy the centre of rotation condition, by an amount which depends upon the pantoscopic angle of the lens.

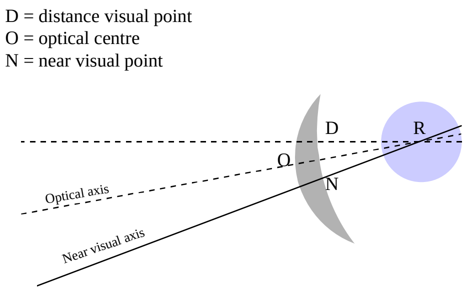


Figure 6.
Vertical centration - the centre of rotation condition for near vision.

When the spectacle lens has been correctly centred for distance vision by lowering the optical centre to compensate for the pantoscopic angle, no further vertical decentration of the optical centre is necessary for near vision. This should be obvious from Figure 6 where it will be seen that lowering the optical centre of the lens results in the centre of the distance visual zone lying as far above the optical centre as the centre of the near visual zone lies below the optical centre. In other words, centring the lenses correctly in the vertical meridian for distance vision, centres them correctly for near vision at the same time!

Prismatic lenses

When an aspheric lens incorporates a prescribed prismatic effect, the optical axis no longer passes through the pole of the aspherical surface since, to view a distant object, the eye will rotate towards the prism apex. It has been suggested that an improvement in the optical performance of prismatic aspheric lenses will be obtained if the lens is decentred in the direction of the prism apex, ie, in the opposite direction to the prism base, the amount of decentration depending upon the prism power and the centre of rotation distance.

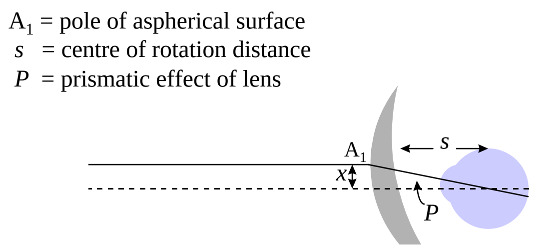


Figure 7.
Decentration of a prismatic lens to ensure that the pole of the aspherical surface coincides with the visual axis.

The principle is shown in Figure 7 where it can be seen that the amount of decentration, ***x***, is given by ***s.P / 100*** , where ***s*** is the distance from the lens to the eye's centre of rotation and ***P*** is the prism power.
For an average centre of rotation distance, the value of ***x*** is about 0.25 to 0.3 mm per prism dioptre and real benefit from this rule is seen only to be obtained for lenses which incorporate high prism powers.

Fitting Bifocal lenses

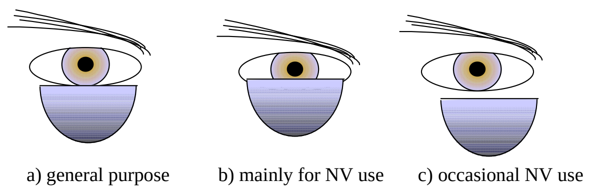


Figure 8. Bifocal segment positioning

Bifocal segments must be positioned so that the distance and near portions of the lens provide adequate fields of view for distance and near vision. It is convenient to consider the positioning of the segment in the vertical and horizontal meridians separately. In the vertical meridian, bifocal lenses which are prescribed for general purpose use are usually mounted before the eyes so that the segment top is tangential with the lower edge of the iris (Figure 8a). 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 position is the norm for the great majority of bifocal wearers and certainly the safest position for the segment top in the case of first-time wearers. If any doubt exists in the fitter's mind as to the best segment height to provide, the lenses may be dispensed in a frame which permits easy vertical adjustment of the height if the wearer finds that the normal position is unsuitable.

If the bifocals are prescribed mainly for near vision, then the segment top might be fitted a little higher, say, midway between the lower edge of the pupil and the lower edge of the iris (Figure 8b). If the lenses have been prescribed for some vocational purpose and are to be designed for only occasional near vision use, then the segment tops might be fitted three to five millimetres lower than the norm (Figure 8c).

All these positions of the segment top assume that the head is held in the subject's primary position with the eyes viewing a distant object. Several dispensing aids have been proposed from time to time to assist in the fitting of bifocal lenses, *e.g.*, *segment height determinators,* and other forms of bifocal fitting instruments, but most practitioners obtain excellent and consistent results by simply measuring the segment height with a millimetre ruler. A typical routine for taking the measurement is described below.

1. Choose final frame and adjust to fit the subject correctly.
2. If the frame is empty attach vertical strips of transparent adhesive tape to each eye of the frame to enable reference points to be marked.
3. Replace frame on the subject's face and direct them to look straight into your eyes. If necessary, adjust height of stool so that your eyes are on exactly the same level as those of the subject.
4. Direct the subject to look straight into your open left eye and using a fine-tip marking pen and, preferably a light coloured ink, place a mark 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.
5. Direct the subject, without moving the head, to look straight into your right eye and place a second mark in front of the subject's left lower iris margin.
6. Remove and replace the frame on the subject and repeat the procedure, this time without making any marks to ensure that the marks do lie directly in front of the lower edges of the irides.
7. Record the segment heights or top positions with respect to the HCL and use a blank sizing chart to ensure that the lenses can be obtained from the blank diameters which are available for the design in question. Whenever bifocal lenses are ordered, it is preferable for the prescription laboratory to be given the segment top position (the height of the segment top above or below the horizontal centre), rather than, simply, the segment height, since there is then no doubt as to whether the measurement has been properly specified from the lower horizontal tangent to the lens periphery.

With experience, the transparent tape may be dispensed with and the segment top position recorded simply with the ruler.

Bifocal segment insetting

The purpose of insetting bifocal segments is to bring the near fields of view into coincidence. Contrary to popular belief, this is not achieved simply by insetting the segment by half the difference between the CD and the NCD. The fact that so many bifocal wearers do not have problems with insetting which is deduced from the above rule is explained quite simply by the fact that current bifocal segments are relatively large. Large diameter segments enable the individual monocular fields of view to overlap sufficiently to provide a large binocular field. If we were to attempt to dispense segments of only 10mm diameter, many more grief cases would arise from incorrect insetting!

The effect which insetting tries to achieve may be explained as follows. Imagine first that the segment is no more than a small aperture in an occluder placed close to the eye. The field of view through the aperture of course depends only on the size and shape of this aperture. If a subject wearing a pair of D-shaped apertures (like most modern bifocal segments) which had not been centred correctly on the converging visual axes, viewed a sheet of paper, the fields of view projected onto the paper would appear as shown in Figure 9. The situation illustrated in the figure assumes that the apertures have not been sufficiently inset. The shaded area represents the binocular field whereas the areas which remain unshaded either side of the binocular field are seen in monocular vision. The areas seen only by the right and left eye are marked R and L respectively. Ideally of course, the areas should overlap exactly to provide a single D-shaped field.

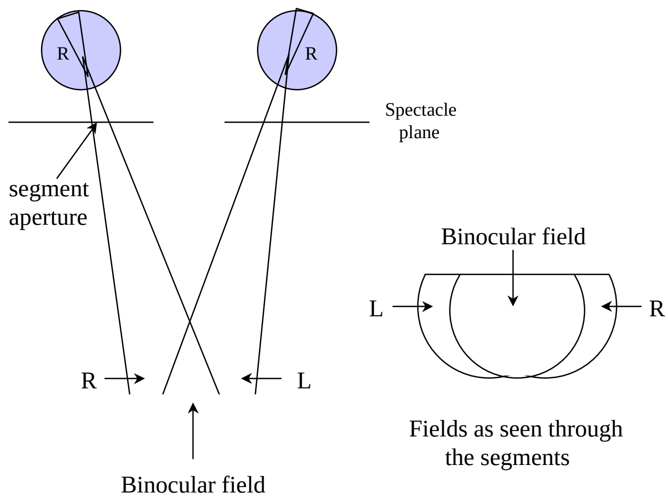
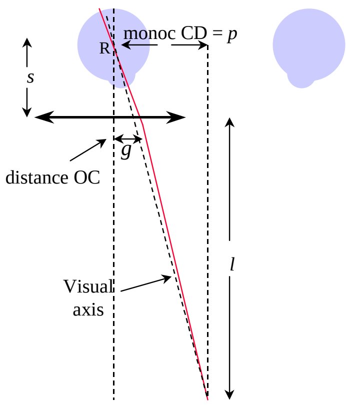


Figure 9
Non-coincident fields of view with D-shaped segments which have not been inset to bring the near fields into coincidence.

It is an easy matter to bring the near fields depicted in Figure 9 into coincidence. The amount of inset necessary to do so is exactly the same as that given in Table 2 above, which table also gives the geometrical insetting required when the distance portion of a bifocal lens has no power. Usually, however, the distance portion is not afocal and the main lens exerts horizontal prismatic effect at the near visual point. The influence which this has upon the geometrical inset can be deduced from Figure 10 which illustrates plan view of a plus lens, centred for distance vision, in front of the right eye.



$$g = p.L / (L + F - S)$$

$$= 3.p / (40 - F)$$

Figure 10
Geometrical insetting to bring the near fields into coincidence

If the lens had no power, the visual axis would lie in the direction shown by the dashed line. Since the distance portion of the lens is positive and exerts base out prismatic effect in the region of the near visual point, the direction which the visual axis must take up to view the near point B is indicated in the diagram by the direction RG. Clearly, the centre of the aperture that governs the near visual field, which is the bifocal segment itself, must be positioned at G, the distance OG being the geometrical inset.

It can be shown that the inset, g, which is required to bring the near fields into coincidence is given by the relationship:

$$g = pL / (L + F - S)$$

where p is the monocular centration distance, L the working distance in dioptres, F the power of the spectacle lens in the horizontal meridian and S the dioptral distance from the eye's centre of rotation to the spectacle plane.

If the spectacle plane is assumed to lie 27mm in front of the eye's centre of rotation, and the working distance is taken to be 33.3cm, this expression reduces to:

$$g = 3p / (40 - F)$$

Table 3 has been compiled from this relationship for various lens powers and a working distance of 33.3cm. Since the geometrical inset is a function of the monocular centration distance it cannot properly be expressed in terms of the binocular CD and is listed in the table for various monocular centration distances which cover the same range of values as those considered in Table 1.

	Geometrical inset in mm for working distance of 33.3cm.									
Lens Power	**monocular centration distances**									
	28	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**
+12.00	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.8	3.9	4.0
+10.00	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7
+8.00	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5
+6.00	2.5	2.6	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.3
+4.00	2.3	2.4	2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.1
+2.00	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.8	2.9
0.00	2.1	2.2	2.3	2.3	2.4	2.5	2.6	2.6	2.7	2.8
-2.00	2.0	2.1	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.6
-4.00	1.9	2.0	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.5
-6.00	1.8	1.9	2.0	2.0	2.1	2.2	2.2	2.3	2.3	2.4
-8.00	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.3	2.3
-10.00	1.7	1.7	1.8	1. 9	1.9	2.0	2.0	2.1	2.2	2.2
-12.00	1.6	1.7	1.7	1.8	1.8	1.9	2.0	2.0	2.1	2.1

Table 3 Geometrical insetting

It was customary for the prescription house to advise opticians that they need not state an inset on their bifocal orders unless an unusual specification was required. Otherwise, the insetting suggested in the table (Table 3) would be provided automatically.