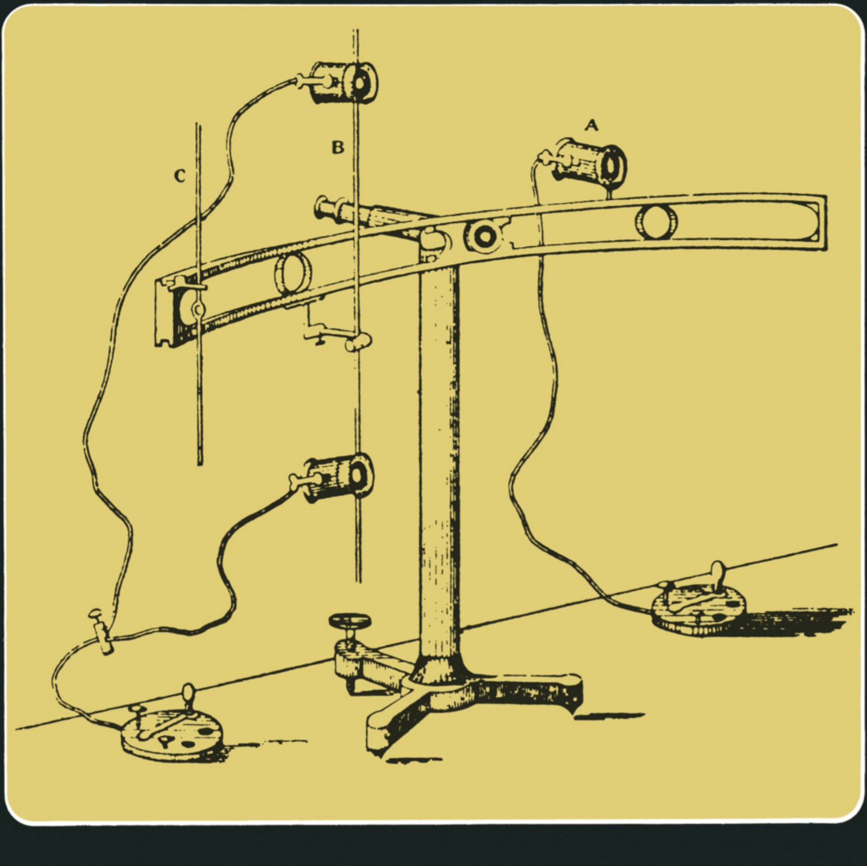
REVISION CLINICAL OPTICS

MONTAGUE RUBEN

E GEOFFREY WOODWARD



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Montague Ruben
and
E. Geoffrey Woodward

Drawings by
Terry Tarrant

M

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Preface

This text was first published almost twenty years ago by the Institute of Ophthalmology, London, for the use of postgraduate students taking the D.O. course. Prof. Montague Ruben selected and designed the drawings, which were drawn by Mr T. Tarrant.

A second edition some years later included a short text for each drawing, but it has long since been out of print.

The present text is designed as a revision text to supplement courses on ophthalmic optics and does not pretend to replace textbooks recommended by teachers. It may be of use to the student who is preparing for examinations in ophthalmology, optometry or orthoptics, and provides a quick method of revision; in particular it will enable the student to discover areas where further tutorials, or the reading of larger texts, are required. The new text has been co-authored by Dr Geoffrey Woodward, thus combining the attitudes of ophthalmologist and optometrist. The text has been enlarged and revised by including physiological optics and most instruments in current use.

London, 1982

M.R.
E.G.W.

Acknowledgements

We have been fortunate in obtaining once again the services of Mr Terry Tarrant who has done all the drawings.

The diagrams on pp. 149 to 151 were prepared with the help of Dr M. Guillon, PhD, FBOA.

The authors wish to thank the Institute of Ophthalmology for permission to use the original drawings of *Diagrammatic Outline of Clinical Optics*, by M. Ruben and T. Tarrant, second edition, 1966.

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SECTION I

Physiological Optics

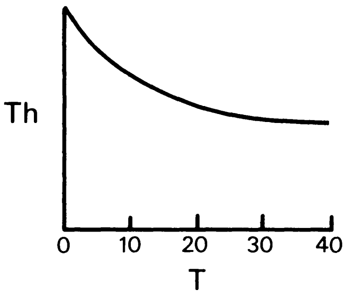
ABSOLUTE THRESHOLD

Definition

Smallest amount of light stimulus which will produce any sensation

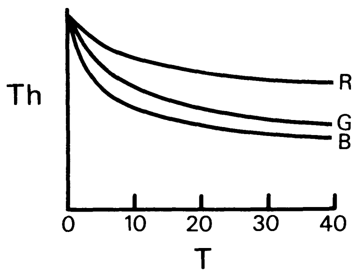
Factors which influence absolute threshold

1. State of dark adaptation of the retina. This shows that the maximal sensitivity is obtained after 30 minutes' dark adaptation.



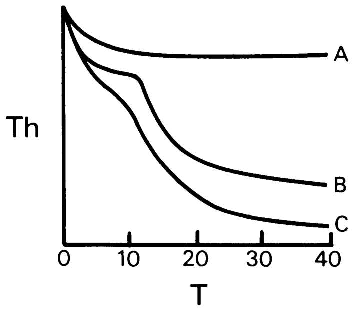
Th = Threshold (intensity of light)
T = Time (min)

2. Wavelength of light lowest with blues and greens. Using different colours the sensitivity is highest for the short wavelengths.



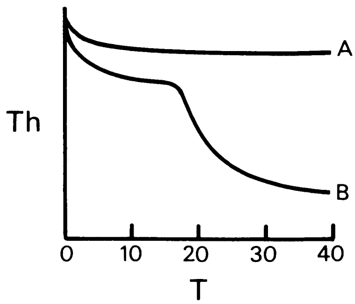
Th = Threshold (intensity of light)
T = Time (min)
R = Red light
G = Green light
B = Blue light

3. Position of retinal image. The parafoveal retinal zones have an increased sensitivity for low stimulus of illumination.



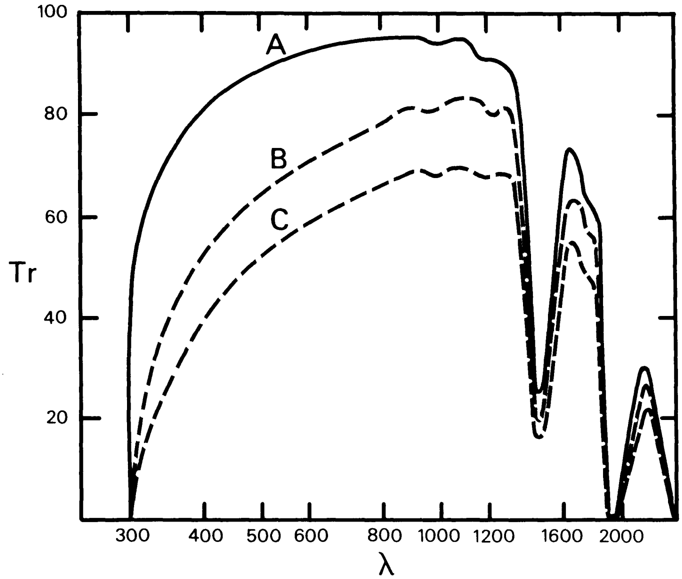
Th = Threshold (intensity of light)
T = Time (min)
A = Stimulus on fovea
B = Stimulus $2\frac{1}{2}^{o}$ off fovea
C = Stimulus 10^{o} off fovea

4. Size of retinal image. The area of retina stimulated is directly related to the threshold.



Th = Threshold (intensity of light)
T = Time (min)
A = Small stimulus subtending 2^{o}
B = Large stimulus subtending 10^{o}

TRANSMITTANCE OF CORNEA

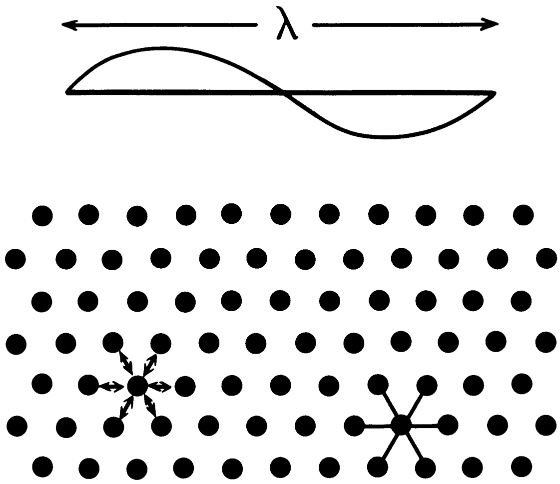


Tr = Percentage transmittance
λ = Wavelength of light
A = Total transmittance, age 4 years
B = Direct transmittance, age 4 years
C = Direct transmittance, age 53 years

The cornea transmits light of wavelengths between 300 and 3000 Å. Virtually all harmful ultra-violet light is filtered out by the cornea but infra red can penetrate in sufficient amounts to be harmful. Transmission decreases with age.

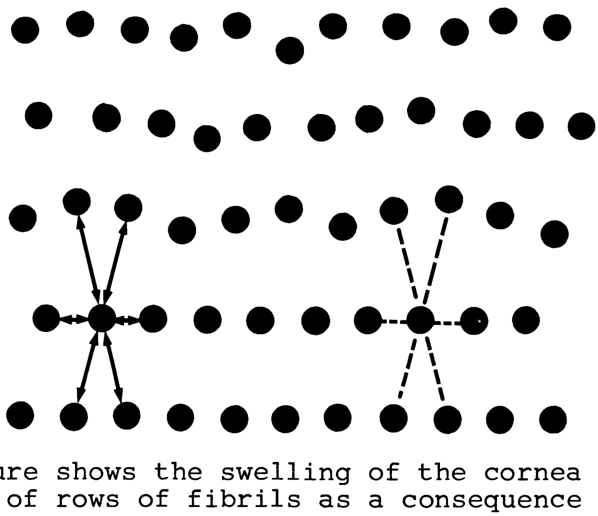
Spectacle lenses (especially of tinted materials) further decrease the amounts of long- and short-wavelength light entering the eye. Clear plastic, such as polymethyl methacrylate, does not absorb ultra-violet light. See also p.43 .

LATTICE THEORY



λ = Wavelength of light

Cross-sectional view of fibrils arranged in lattice. The size of wavelength is shown above for comparison Forces of repulsion and rigid links between fibrils are shown schematically.

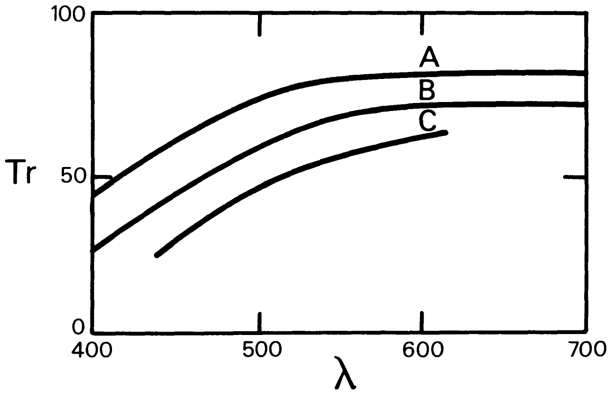


This figure shows the swelling of the cornea and the disorder of rows of fibrils as a consequence of the weakening of forces of alignment from neighbouring rows. (From Maurice, D., 'The Physics of Corneal

Transparency'. In Duke-Elder, S. (editor), Transparency of the Cornea, Oxford, England, Blackwell Scientific Publications, 1960.)

The corneal stroma is not optically homogeneous, the fibrils having a different refractive index to the ground substance. Nevertheless, the cornea has a high degree of transparency and it is suggested that this is due to the particularly regular arrangement of the fibrils. Scattered incident light is cancelled out by destructive interference leaving undiffracted rays unaffected. However, a slight degree of swelling causes a rapid loss of transparency owing to the loss of this interference phenomenon.

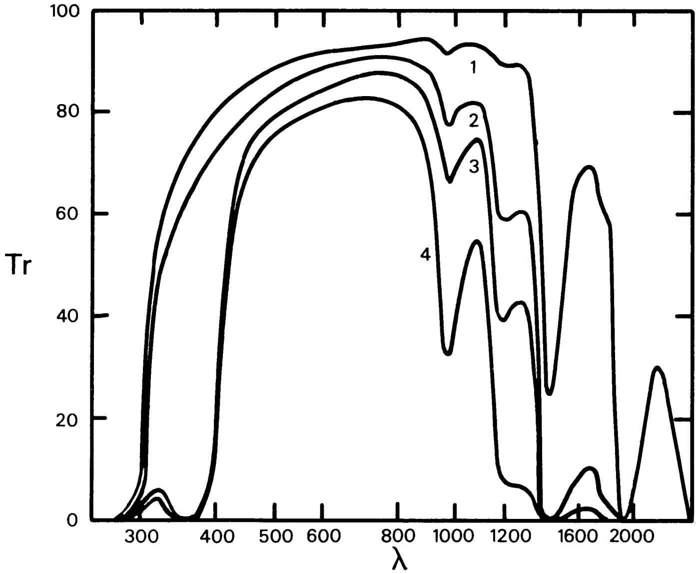
TRANSMITTANCE OF THE HUMAN LENS AT VARIOUS AGES



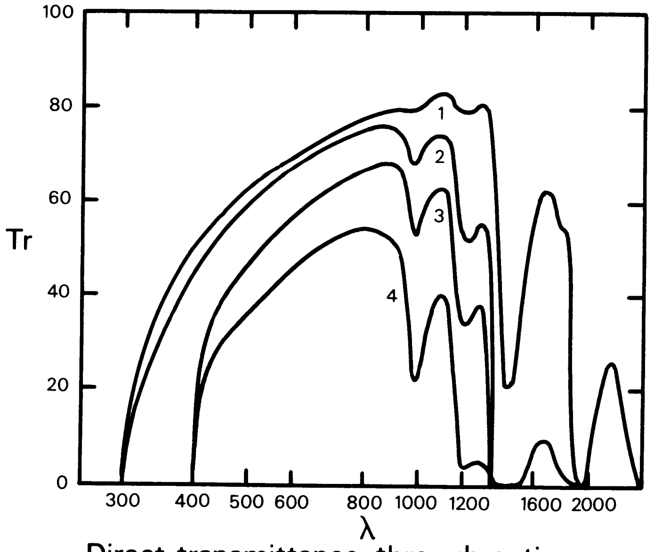
Tr = Percentage transmittance
λ = Wavelenth
A = At age 20 years
B = At age 45 years
C = At age 60 years
(after Said and Weale)

The transparency of the human lens decreases with age especially in the shorter wavelengths. Yellowing of the lens gradually occurs from puberty onwards.

TRANSMITTANCE OF OCULAR MEDIA



Total transmittance through entire eye

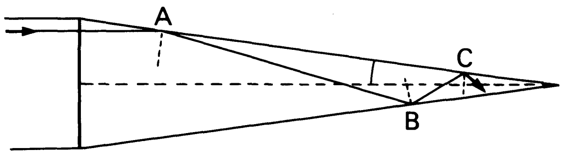


Direct transmittance through entire eye

Tr = Percentage transmittance
λ = Wavelength
1 = Aqueous
2 = Crystalline lens
3 = Vitreous
4 = Retina

The eye behaves approximately as if it were full of water. There is a heavy absorption band in the infra red and this causes heating of the ocular media in prolonged exposure (see p. 43). The aphakic eye is more efficient at seeing than the phakic eye in near-ultra-violet light.

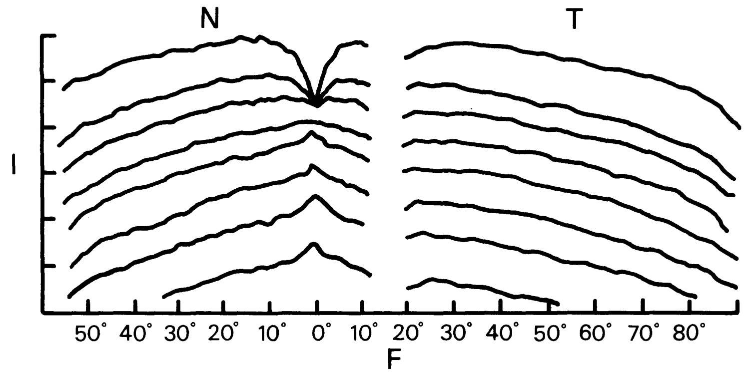
THE STILES-CRAWFORD EFFECT



Theory of Stiles-Crawford effect. Reflections and some absorptions at A, B and C

Under photopic conditions a x20 increase in pupil size only produces a x3 retinal response to light. Stiles and Crawford suggested that each cone is pigment sheathed and that oblique light is absorbed by pigment. The presence of pigment is unproven but it would appear that oblique rays are internally reflected (as shown in the diagram) and that some are absorbed (see p. 52, critical angle).

The magnitude of the directional effect varies with wavelength causing monochromatic light to change its subjective hue with varying angle of incidence; this is known as the Stiles-Crawford effect of the second kind.



I = Illumination
N = Nasal
T = Temporal
F = Fovea

The diagram shows the perception of the ten-minute test object at different levels of adaptation.

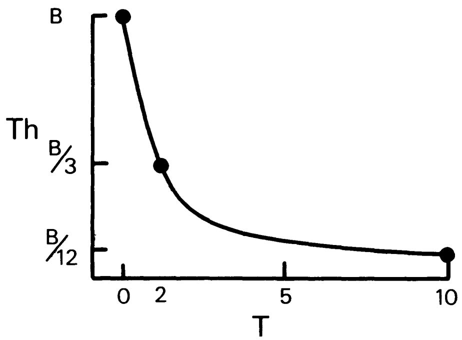
$$\text{Sensitivity or perception of light} = \frac{1}{\text{Threshold}}$$

This diagram illustrates that sensitivity of the foveal region is higher than the mid-peripheral retina at higher levels of illumination. At lower levels of illumination the most sensitive area is in the region of 25° from the visual axis.

Definition

The process whereby the visuum undergoes increased sensitivity to light when the brightness of the visual field drops.

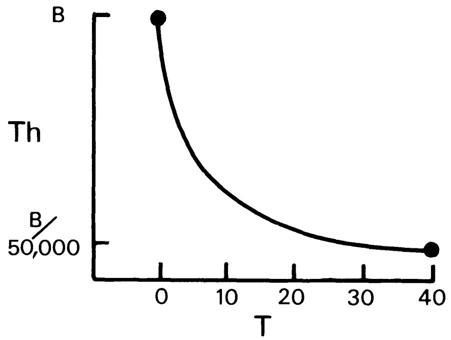
Cone (Foveal) Dark Adaptation



Th = Threshold
T = Time
B = Brightness

Adaptation is rapid, but small in extent.

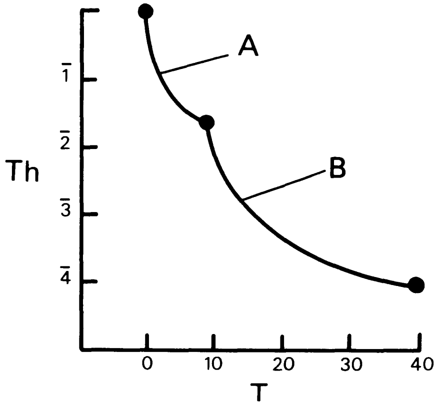
Rod (Peripheral) Dark Adaptation



Th = Threshold
T = Time in dark (min)

Adaptation is slower but great (relatively rapid in first 10 min).

Cone and Rod Combined to Produce a Typical Dark Adaptation Curve



Th = Log threshold
T = Time (min)
A = Mainly due to cones
B = Only due to rods

Factors Which Slow Adaptation

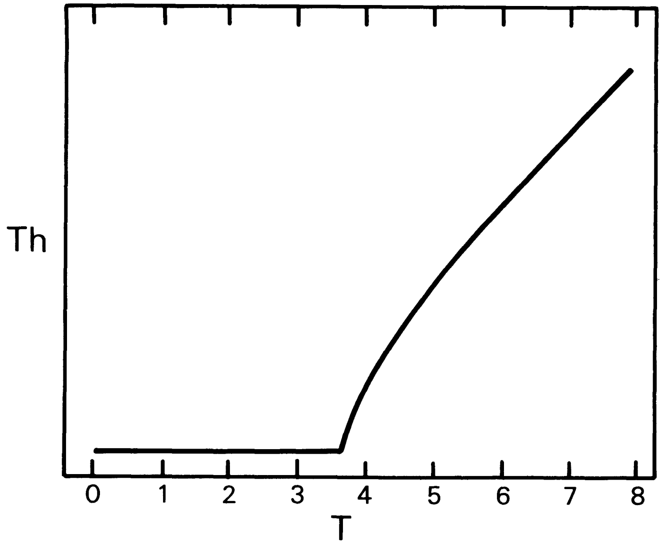
1. Age - decreases with increasing age.
2. Ocular pathology (e.g. Retinitis Pigmentosa).
3. Persistent brightness extremes.
4. Nutritional deficiencies (e.g. vitamin A).
5. Oxygen deficiency (e.g. at high altitudes).

Method of Measurement (Goldman Adaptometer)

The retina is bleached by exposure to bright light and the patient is then placed in a dark room and the threshold of light used as a stimulus.

The time required to adapt to the stimulus is measured.

RISE IN DARK ADAPTATION THRESHOLD IN VITAMIN A STARVATION

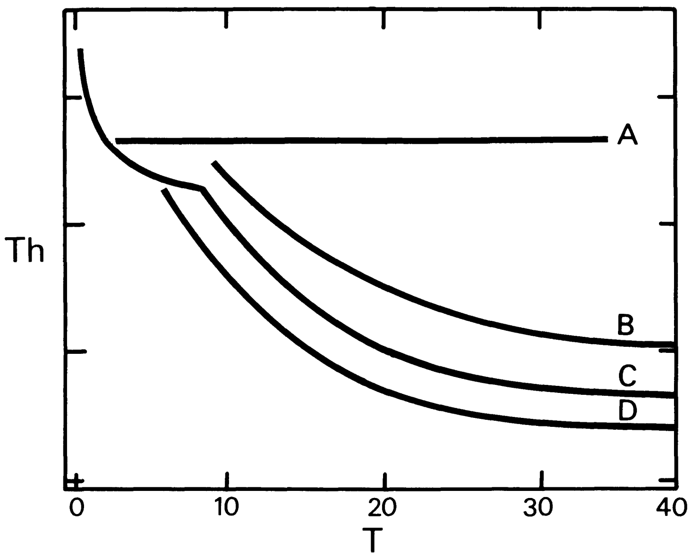


Th = Log threshold
T = Weeks on Vit-A-deficient diet

It has been demonstrated that failure of dark adaptation may be caused by a deficiency of vitamin A in the diet. Vitamin A is an integral part of the rhodopsin cycle and it is shown that decreasing dark adaptation is correlated with loss of rhodopsin.

The example shown is for vitamin-A-starved rats (from Dowling, Amer. J. Ophthal., 50,875, 1960.)

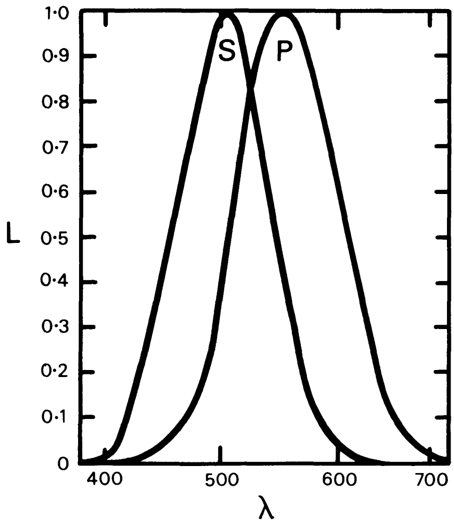
DARK ADAPTATION OF DIFFERENT PARTS OF THE RETINA



Th = Log threshold
T = Time in dark (min)
A = 2^{o} field of fovea
B = 2^{o} field at $2\frac{1}{2}^{o}$ from fovea
C = 2^{o} field at 5^{o} from fovea
D = 2^{o} field at 10^{o} from fovea

As can be seen from the above diagram, adaptation occurs at a different rate and for a different period of time in rods and cones. Hence one could expect different adaptation curves for different parts of the retina. As can be seen, there is no rod element in the adaptation in the foveal region.

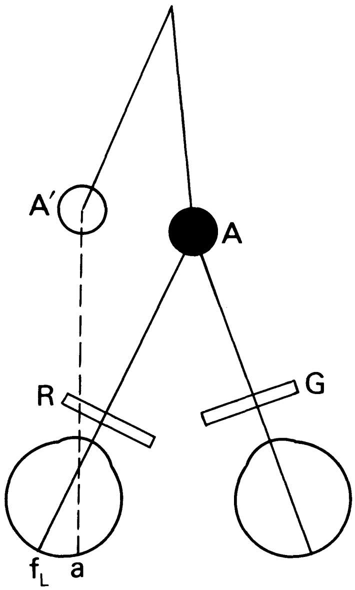
PURKINJE SHIFT



L = Luminosity
λ = Wavelength (μm)
P = Photopic
S = Scotopic

The peak sensitivity of the human eye varies in its wavelength according to the state of adaptation. Under photopic conditions the eye is most sensitive to wavelength 555 (yellow-green). Under scotopic conditions where colours cannot be discriminated the eye is most sensitive to wavelength 510 (blue-green) and red light produces little response.

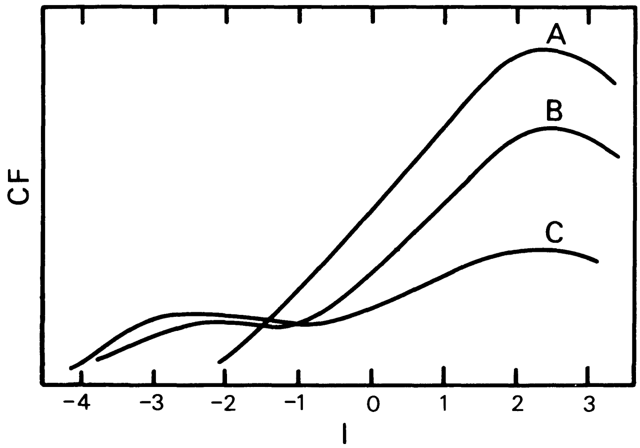
In twilight the shorter wavelengths appear to have more intense contrast due to adaptation to the scotopic state. Furthermore, the low myope (-0.50 to -1.0) may see clearer at distance in this state (see diagram on p. 107).



R = Red filter
G = Green filter

If a swinging pendulum with a luminous end is observed simultaneously through a green glass with one eye and a red glass with the other, it will appear to move in an elliptical path instead of a flat plane. The same effect may be produced by simply placing a neutral filter in front of the one eye to reduce the light entering it.

The explanation of this is the difference in reaction times of the two eyes in response to different colours or different luminances. Thus, when the bob is in position A the left eye is still seeing as if it were at A′, i.e. as if its image on the left retina were at a and not f_L. The disparate images are fused to a point outside the plane of the pendulum; on the return swing the reverse effect occurs, bringing the apparent position inside the plane of the pendulum.



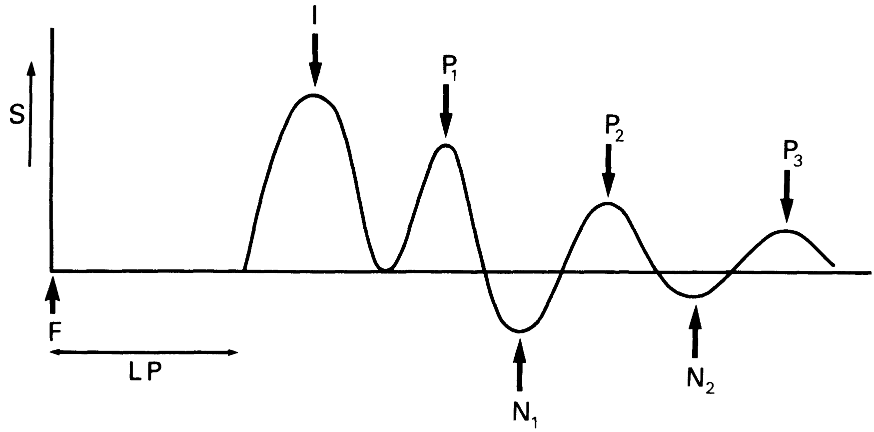
CF = Critical frequency (cycles/s)
I = Retinal illumination ($\log^{-1}$ photons)
A = At fovea
B = 5^{o} from fovea
C = 15^{o} from fovea

When intermittent light stimuli are presented to the eye at an increasing frequency there comes a point where the flicker sensation disappears to become one of continuous stimulation. This is known as the *critical frequency of flicker* (e.g. cinema photography).

As can be seen from the diagram, it varies with illumination and retinal position.

At lower levels of illumination the peripheral retina has a higher critical frequency; at higher levels the foveal area has a higher critical frequency. However, the critical frequency increases in all parts of the retina with increasing illumination.

Defects in the peripheral retina, either of the rods or sensory nervous system, can be analysed and assessed by the use of critical frequency of flicker measurements.

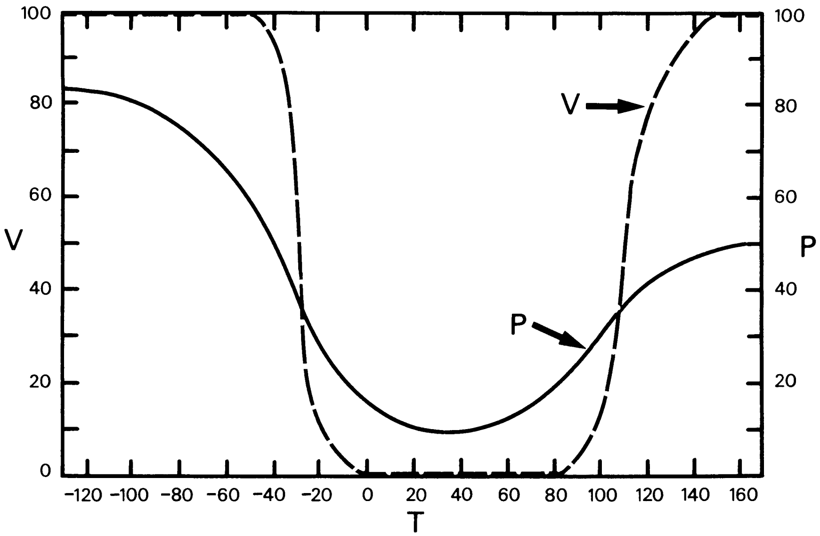


S = Sensation
F = Flash
LP = Latent period
I = Primary image
P_1 = First positive after image
P_2 = Second positive after image
P_3 = Third positive after image
N_1 = First negative after image
N_2 = Second negative after image

If the eye is exposed to a brief flash of light the subjective sensations last for much longer than the stimulus and are described as 'a succession of after-images'. Positive after-images indicate sensations of brightness, and negative ones darkness.

If the stimulus is coloured, e.g. red, the first positive after-image will be of the same hue; however, the secondary positive after-image will be the complementary colour. The second positive after-image is also known as the *Purkinje after-image* or *Bidwell's ghost*.

In orthoptic practice the after-image projection is studied to evaluate retinal correspondence.



V = Visual response (%)
P = Pupil response (%)
T = Time of flash (ms)

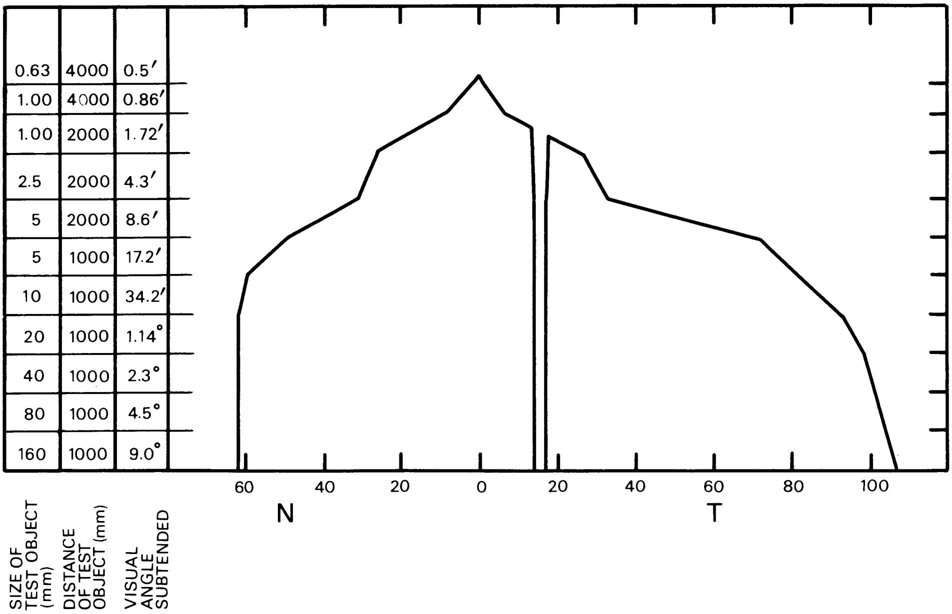
Flash presented before 8^{o} saccadic eye movement starting at time 0

The eye does not move in a smooth continuous manner when changing its function, but more in a series of small movements. For example, when reading a printed page, rapid excursions lasting about 0.1 s are followed by pauses during which the reader assimilates the usual impressions. These movements are called *saccadic*.

During a saccade there is a supression of target information. As can be seen from the diagram, visual response falls before a saccade and is essentially zero during the saccade. The latency of the pupil delays its response until after the saccadic movement has been completed. Flashes which observers fail to report may thus give rise to pupillary responses.

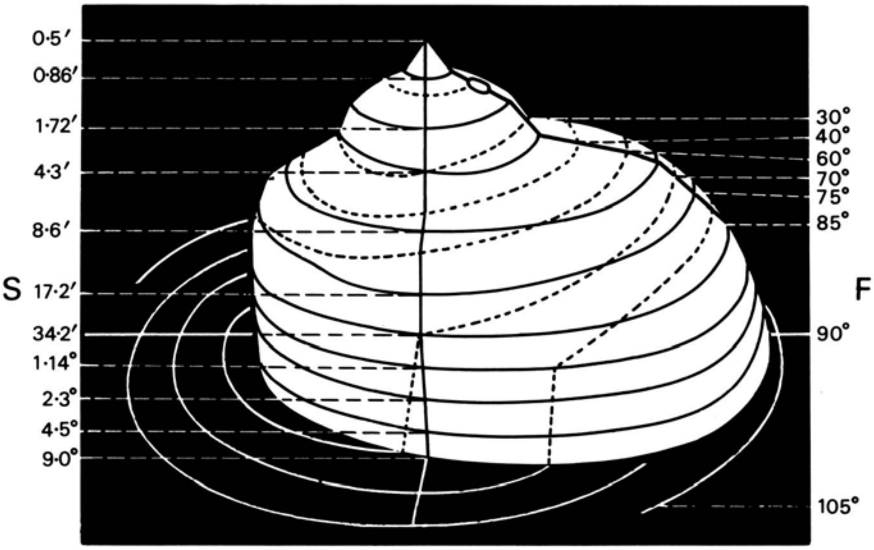
Using photographic recording methods these responses can be used to measure defects in part of the nervous system concerned with the sensory-motor pupil reaction pathways.

FIELD OF VISION — ISOPTERS



N = Nasal field
T = Temporal field

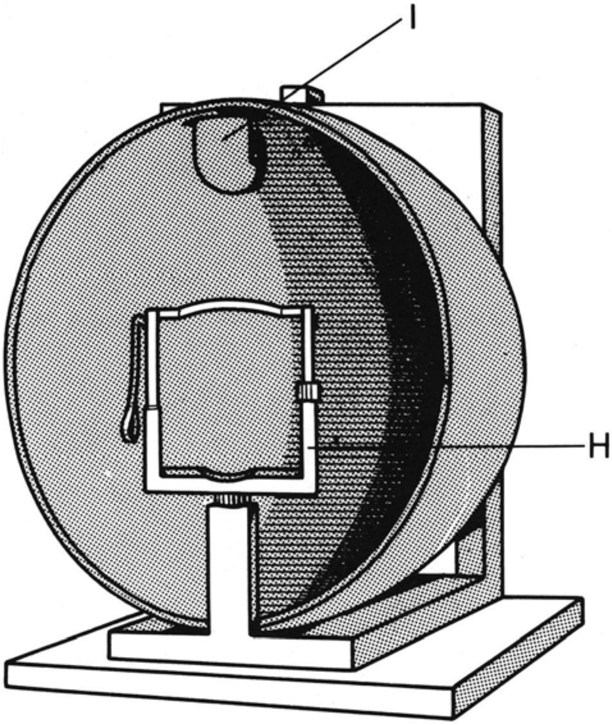
Isopters are lines which join points at which test objects subtending the same visual angle are recognised. The vertical lines show the diameter of the test object in millimetres, the distance of the object from the eye in millimetres and the visual angle subtended. In the horizontal meridian 0 represents the visual axis.



S = Size (angle subtended) of test object
F = Angular field from visual axis

In the fourth century B.C. Euclid described the field of vision as an island in a sea of blindness. Traquair used the concept to produce a model from isopters described previously. The height of the model corresponds to the size of the test object perceived; note the steep nasal side and the more sloping temporal periphery. This corresponds to the field for an average individual of about 60° upwards, 60° nasally, 75° downwards and at least 100° temporally.

FIELD ANALYSER (GOLDMAN TYPE)

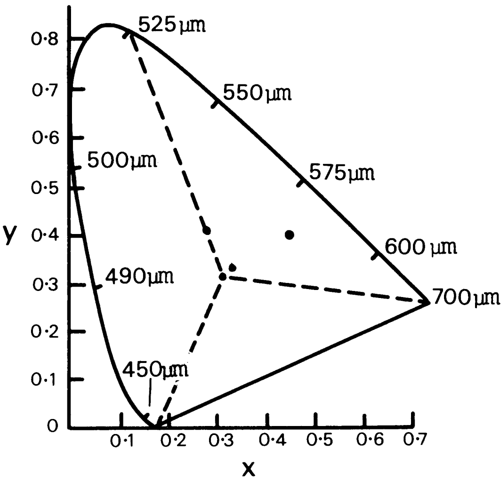


I = Illuminating system
H = Head rest

The light projected into the half sphere is controlled in relation to intensity, period of time, repetitive stimulation and colour. Both central and peripheral fields can be analysed and recorded. Automatic recording instruments are now available.

COLOUR VISION

The CIE Chromaticity Diagram

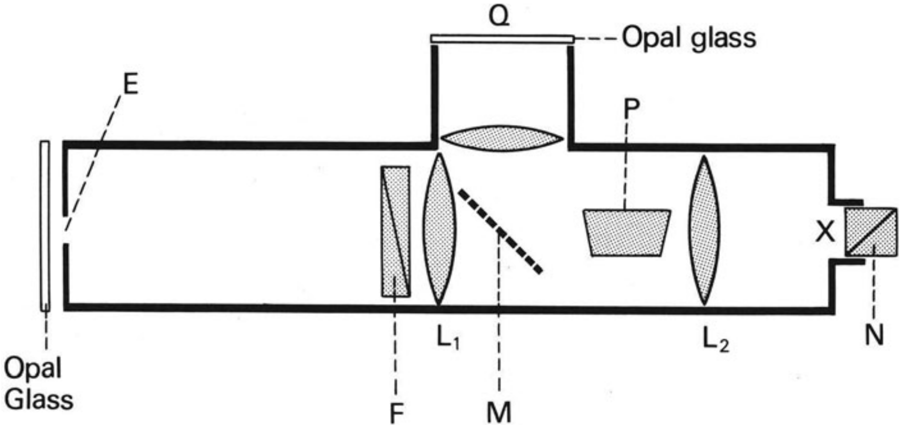


450 µm — blue
525 µm — green
700 µm — red

In this diagram any colour can be defined in terms of its *x* and *y* co-ordinates thus giving a simple and precise specification of the colour of a luminous source.

For example	red	700 µm	$x = 0.73467$	$y = 0.26533$
	green	546.1 µm	$x = 0.27376$	$y = 0.71741$
	blue	435.8 µm	$x = 0.16658$	$y = 0.00886$

The Anomaloscope (Nagel)



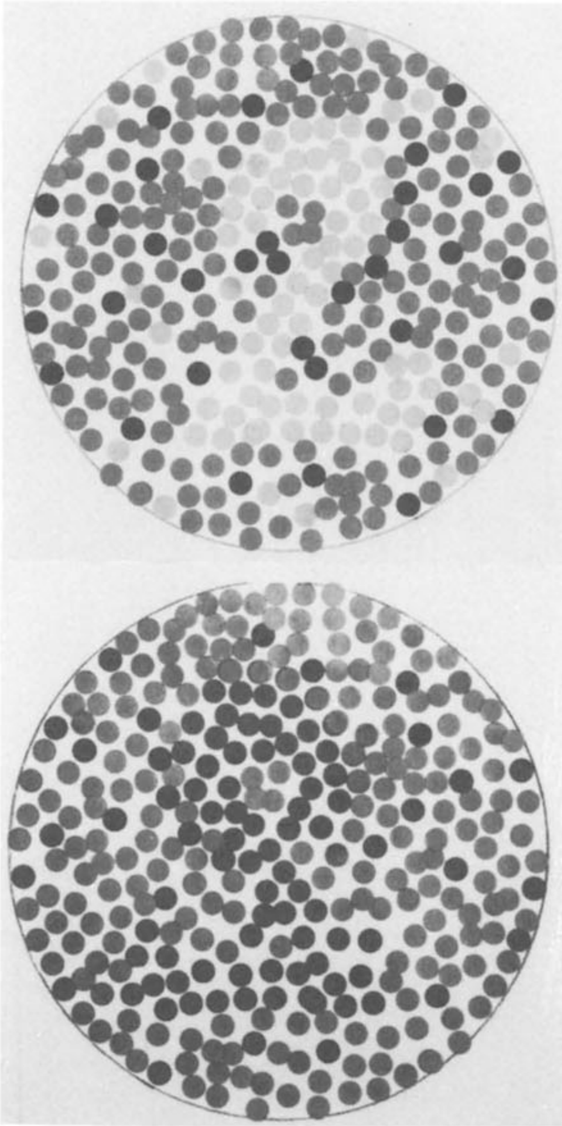
E = Entrance slit
F = Double refraction prisms
P = Direct vision prism
X = Exit slit
N = Nicol prism
Q = Light source
M = Mirror

The anomaloscope is used for the detection and diagnosis of defective colour vision and is especially useful for the anomalous trichromat who often cannot be detected and classified by the simpler tests such as confusion charts, wool tests and lantern tests. It is designed to determine the red-green ratio of the Rayleigh equation.

The light from the entrance slit E is split into beams polarised at right angles and slightly inclined to each other by double refracting prisms F (see p. 134); the beams are collimated by lens L_1, dispersed by the direct vision prism P and the two slightly displaced spectra are focussed at the exit slit X by a lens (L_2). The exit slit selects the red and green bands from the two beams and the relative intensities are varied by the rotation of a Nicol prism (N). The other half of the field is derived from a mirror (M) reflecting light from another source at Q, the mirror being adjusted so that the yellow part of the spectrum leaves the exit slit X.

The patient varies the proportion of red and green light until it matches the yellow in hue and luminosity. If more red is needed than usual the patient is protanomalous; if more green he is deuteranomalous.

Colour-Vision Tests



Pseudo-isochromatic charts

Confusion chart tests consist of a series of plates on each of which there is a background of irregularly spaced coloured spots of various sizes; amongst these are figures or letters also made up of coloured spots.

The spots which make up these figures or letters are printed in colours which the colour defectives habitually confuse. Care is taken that they are printed to be of low saturation and so that brightness discrimination cannot be used by the patient.

(a) shows a figure '2' easily distinguishable by a patient with normal colour discrimination. However, in the case of a patient with defective colour vision the figure may not be easily distinguishable as in (b).

Although these charts are quick and easy to use, they can only be regarded as a rather crude screening procedure for colour deficiencies. Care must be taken that they are viewed at the correct distance and in the recommended illumination. Refractive errors, if present, should be corrected before testing.

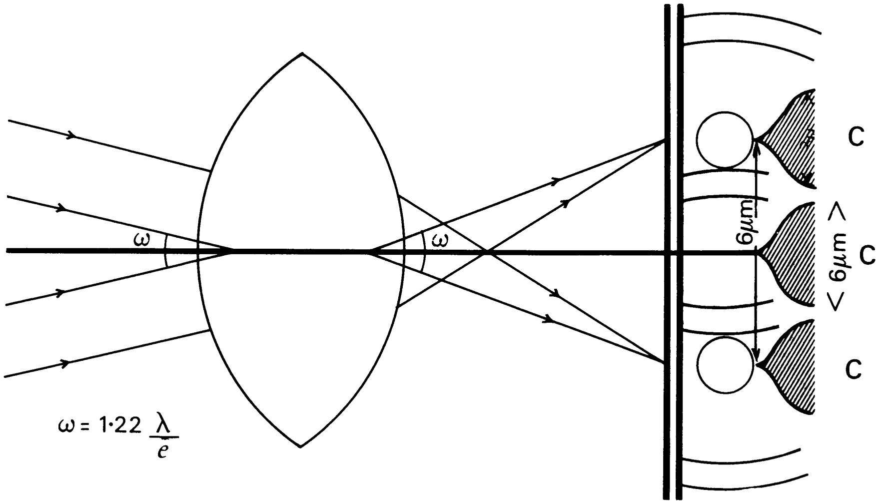
Charts in regular use tend to fade and should be replaced at regular intervals.

Most colour-vision tests do not attempt to give a quantitative result. They may be classified as follows.

1. Sorting tests, e.g. beads, cards, wool, matched in pairs by daylight.
2. Matching tests, e.g. colorimeters and anomaloscopes.
3. Lantern tests, where it is essential that the colour is identified by name — used by railways, merchant navy, armed services, etc.
4. Pseudo-isochromatic tests. Consist of patterns of dots, varying in size, saturation and hue. They are also called *confusion* tests as anomalous trichromats and dichromats confuse various dots thus reading a different number to the normal trichromats. For example, the deuteranomalous will confuse red with orange, fawn with green and purple with green.

VISUAL ACUITY

Resolution



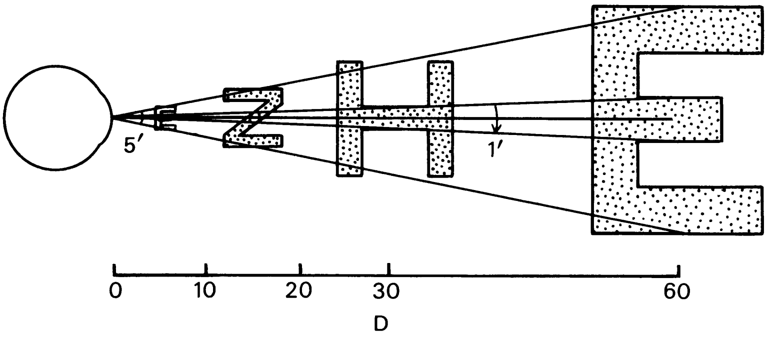
C = Cone and aperture of lens system
ω = Resolution angle
μ = Wavelength of light

Given a point source of light at infinity and parallel rays from this source incident to a positive-power lens system (of the eye), the rays will form a focus. The focus of a point source will not be a point image but a circular patch of light, with light and dark rings (Airy's circles). The size of the light and dark rings will determine the resolution of the optical system. The resolution ω is expressed as $\omega = \frac{K\lambda}{e}$ where K = 1.22, λ = wavelength of light and e = aperture of lens system. For a high-powered multi-lens system, such as the eye, the pupil aperture is small so as to avoid optical aberrations. A high degree of resolution in the human eye is therefore limited by the aperture. Furthermore, the human eye uses white light in the photopic state and the formula for resolution would be best with the shorter wavelengths of light (towards the green).

The optical resolution of the human eye needs only to be as good as the integration of the neurological retinal receptors with the cortex and the psychological interpretation of vision.

There are individual variations in the angle of resolution of the human eye, but it is assumed that a mean value is 1' of arc corresponding to $\frac{6}{6}$ acuity.

The Snellen System of Recording Visual Acuity



D = Distance (m)

Snellen in 1862 proposed using certain letters of the alphabet as fixation targets. The letters were designed so that at a specified distance the whole letter subtended 5' of arc and each 'limb' of the letter 1' of arc.

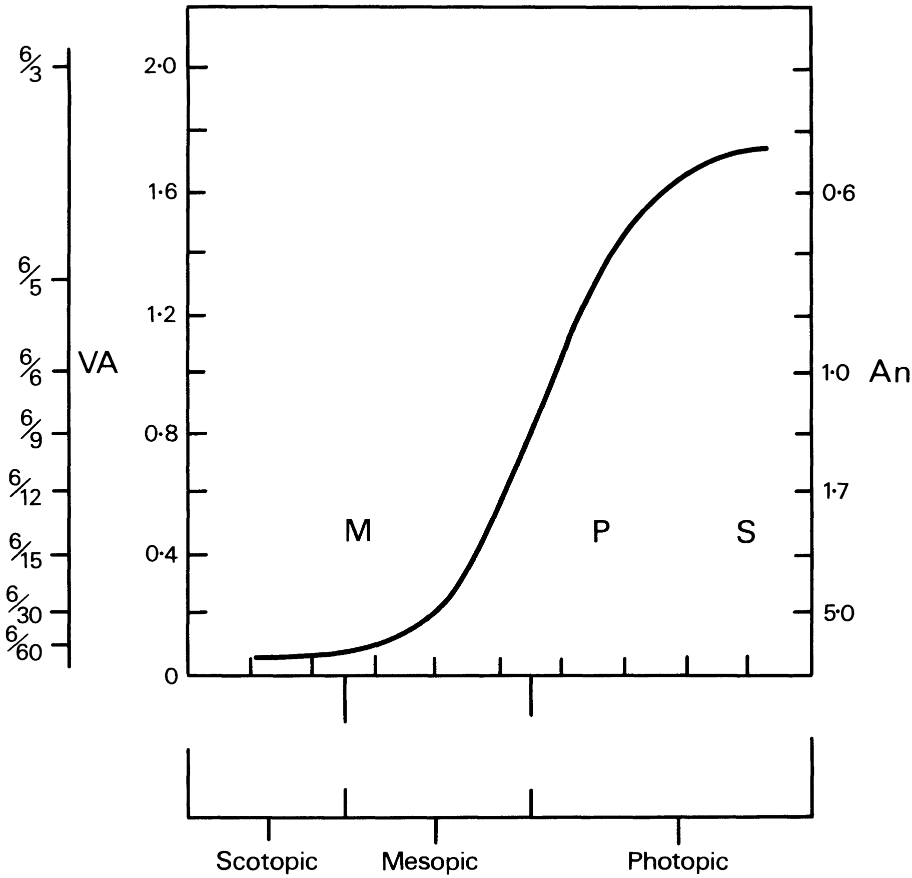
From the ancient astronomical literature he took the 'normal' resolving power of the eye to be 1'. Thus the size α of a letter to be read at a distance d is given by

$\alpha = d \tan 5' = d \times 0.00146$ (α and d being the same units)

Standards for recording acuity:

1. Standard illumination.
2. Literate or illiterate (C or E) response.
3. Line letters or single letters (macular versus paramacular fixation).
4. Recording as a fraction — $\frac{6}{6}$,etc... $\frac{6}{60}$.
   Recording as a decimal — 1, 0.9 ... 0.1.
   Recording as a percentage — 100% ... 10%.

Visual Acuity and Level of Illumination



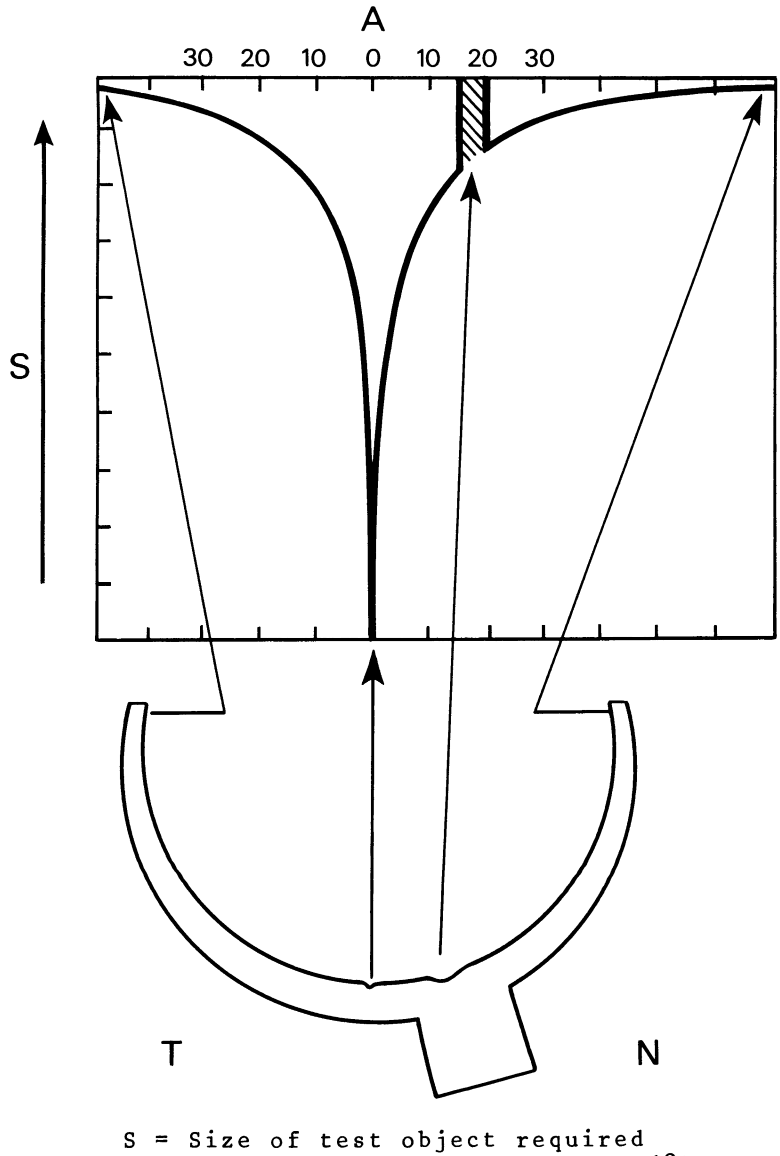
VA = Visual acuity
An = Visual angle (minutes of arc)
M = Luminance of sky at full moon
P = Standard Goldmann perimeter illumination
S = Luminance of snow in full sun

As would be expected from earlier diagrams, visual acuity falls under mesopic and scotopic light conditions.

Boosting illumination will raise visual acuity above 'normal', but when illumination is so high that the pupil is smaller than 2.4mm, visual acuity will drop again.

In practice no optical device to correct vision is of value without the required light stimulus. In patients with macular and retinal disease supernormal light stimulus is often necessary.

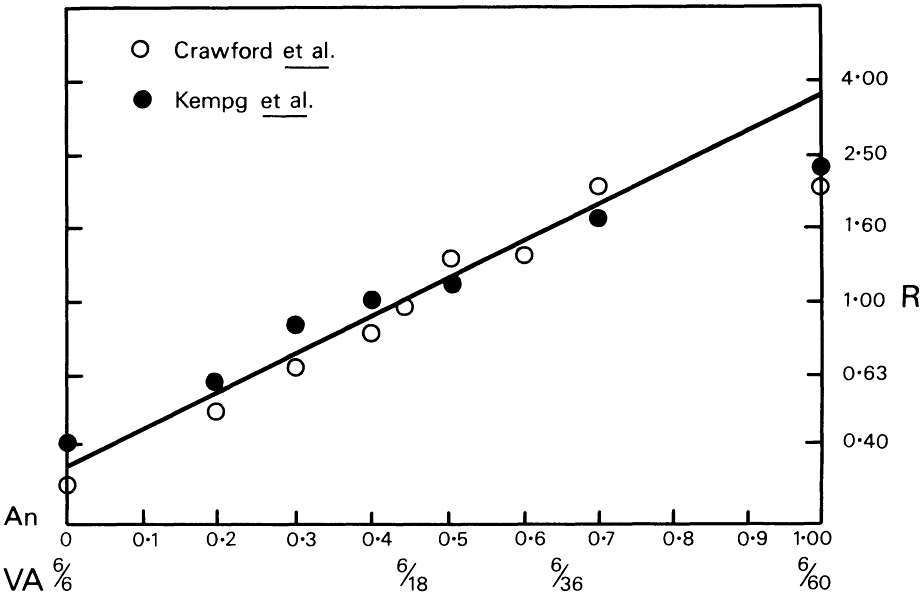
Variation of Visual Acuity across the Retina



S = Size of test object required
A = Angular subtense from fovea (^{o})
T = Temporal
N = Nasal

As seen earlier from graphs of variation of the visual threshold, visual acuity falls rapidly away from the visual axis.

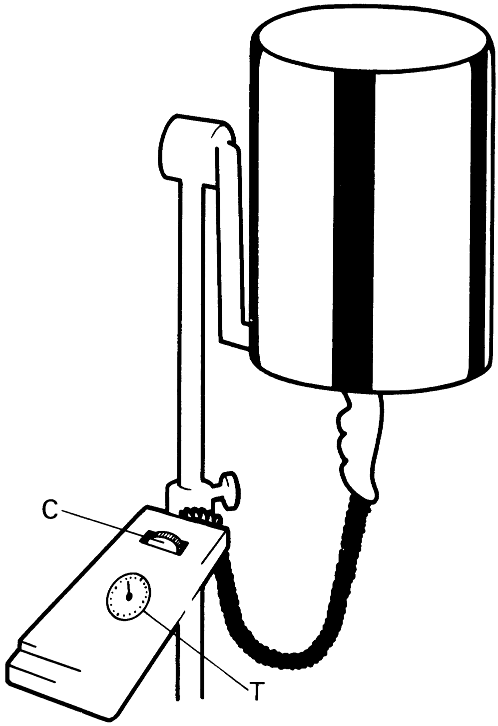
Relationship Between Threshold Visual Angle and Dioptres of Spherical Error of Refraction



An = Log visual angle
VA = Visual acuity
R = Spherical refractive error (D)

There is a linear relationship between threshold visual angle and spherical errors of refraction. If this linear relationship is not found in subjective refraction it is indicative of uncorrected regular or irregular astigmatism. A +1.00 dioptre lens should blur a patient back to between $\frac{6}{12}$ and $\frac{6}{18}$.
Compensating factors are physiological nystagmus, resolution, depth of focus (p. 126) and perception at binocular image fusion level (p.181 and 184). They all tend to affect this theoretical level of acuity.

Optokinetic Drum



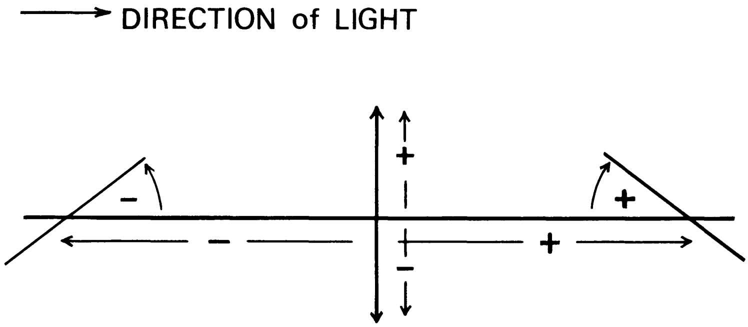
C = Speed control
T = Tachometer

The objective measurement of visual acuity may be carried out by eliciting optokinetic nystagmus when the patient is presented with a grating pattern on the surface of a rotating drum. Optokinetic nystagmus is elicited when the detail of the grating subtends a certain minimum angle size. The variables are (1) the dimensions of the grating,
(2) the speed of rotation of the drum and
(3) the distance of the subject from the grating.

SECTION II

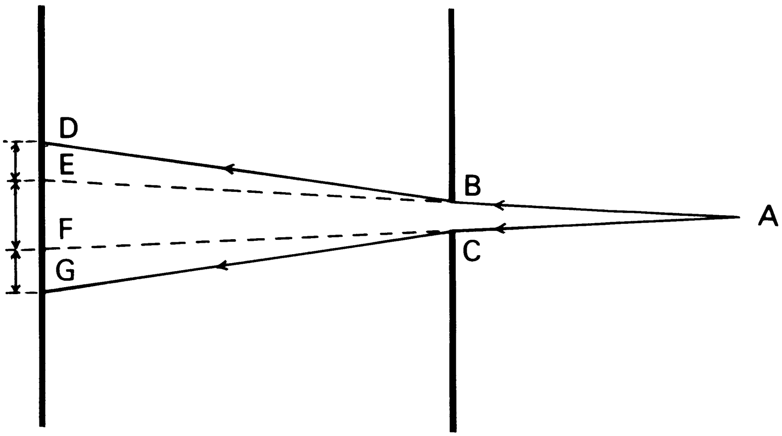
Basic Optics

SIGN CONVENTION



The use of formulae in geometric optics is only possible if the negative and positive signs are correctly observed and the units are of the same order. The sign convention must be rigidly adhered to when formulae are used.

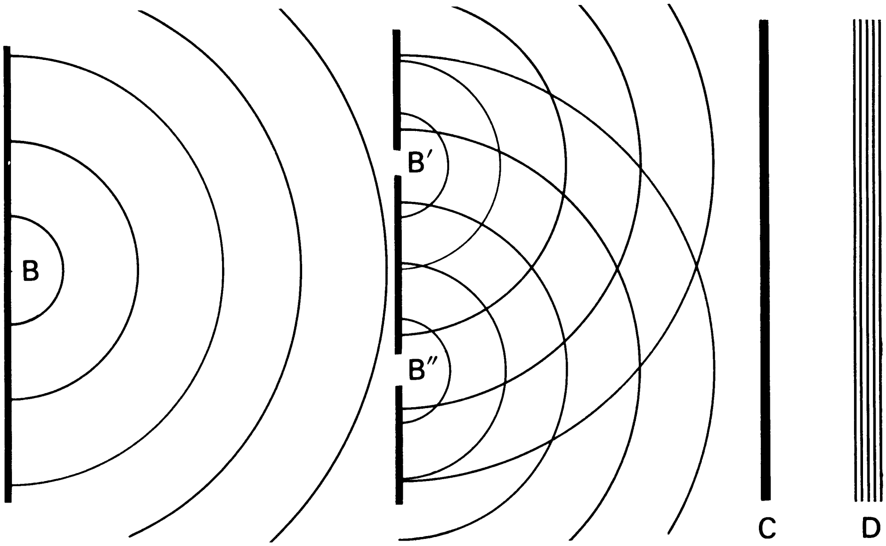
Distances are measured from the lens and, as indicated in the diagram, are positive if in the direction of the light. Measurements above the axis are positive, and below negative.



A	=	Light source
BC	=	Slit aperture
EF	=	Projected slit geometric area
DG	=	Actual projected area
DE and GF	=	Diffraction area

Light passing through a limiting aperture will 'bend' at the edges of the aperture. Thus the size of the projected aperture on a screen is not geometrically related to the size of the aperture. This is a phenomenon of interference which is further explained in the next illustration. Note that the pupil of the eye does not have a sharp edge but a cuff of pigment. The pupil is the limiting aperture as far as the eye is concerned. (See also Resolution on p. 28.)

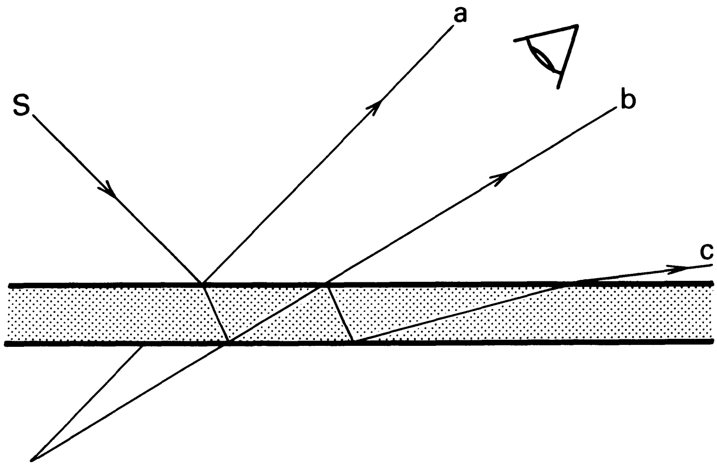
INTERFERENCE AND WAVE MOTION



B = Monochromatic light source
B' and B" = Stenopaeic apertures
C = Screen
D = Interferometry pattern on screen

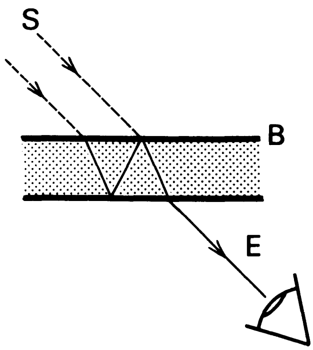
If two sources of light B' and B" are very close together so that the wave fronts intersect, there will be periods where the height and trough of a wave produces no light and periods of maximum brightness. This effect of interference can be seen as lines with monochromatic light, and as colours of the spectrum with white light. This method has been used to measure the size of molecules by using diffraction gratings (parallel lines cut on glass or metal). It is interesting to apply this knowledge to the structure of the cornea, which is not a homogeneous medium and yet shows physiologically no interference phenomena. Therefore the cornea does not form interference patterns providing the collagen bundles remain closely together. However, when separated by water of lower refractive index, coloured bands result which are seen as haloes. (See Lattice Theory, p. 6.)

DIFFRACTION FROM A THIN FILM



S = White light source
a—b—c = Spectral colours

Light rays incident to a film of optical medium placed in a rarer medium will be reflected and transmitted, and some rays internally reflected and then transmitted. This introduces a time factor and, if the incident light is white, the emerging rays will be in their separate wavelengths. This diffraction effect is seen in thin films of soap solution (bubbles). The pre-corneal tear film when viewed with a slit beam can sometimes show a diffraction effect.



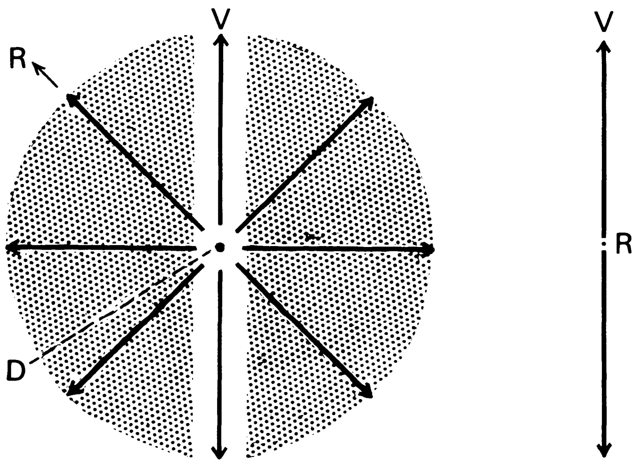
S = White light source
B = Bloomed or tinted front surface
E = Emerging rays

Special lenses are often bloomed with metallic dust on either the front or the back surfaces (preferably the front) to reduce light transmission. If the thickness of film is equal to half the wavelength of light in the middle region of the spectrum, light transmission is increased as reflection from the surfaces is decreased.

Surface coating is now replacing solid tints in most spectacle lenses, as the density of the tint is not affected by the prescription of the lens (i.e. the thickness). Tinted lenses are available with transmission factors of between 15 and 85% in most colours.

In clinical practice, for high transmission light-blue tints are suggested, for low transmission the green-brown end of the range is suggested. For industrial use Chance solid tints are advised. See also pages 7 and 9.

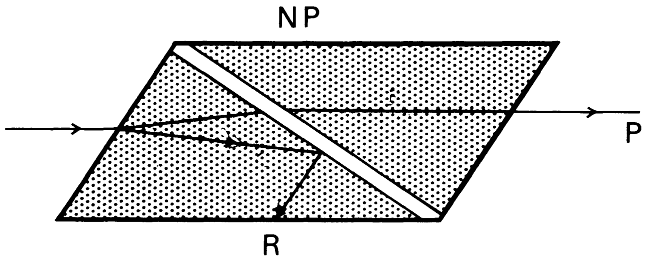
POLARISATION



V = meridian of vibrations at 90° to ray pathway
D = Internal reflection or occlusion of all rays (R) except V

Electromagnetic light rays when passing through an optical medium will form wave radiations at right angles to the direction of the ray path. The vibrations occur in all planes, and if only allowed to vibrate in one plane the light is said to be *polarised*.

POLARISER PRISM

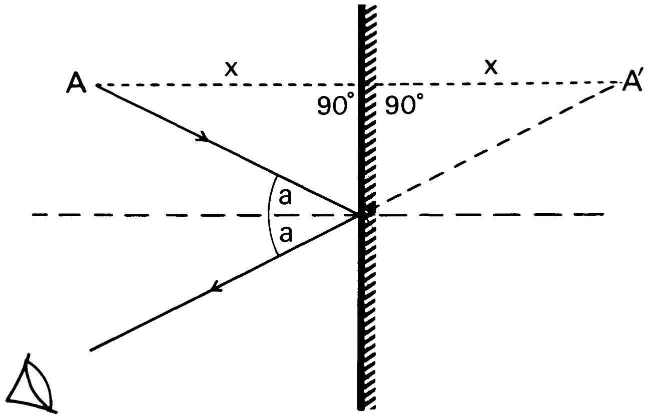


NP = Nicol prism
P = Transmitted polarised light
R = Reflected light

A polarising material can act as a polariser and as an analyser. The rotation of the analyser until no light is transmitted determines the plane of vibration.

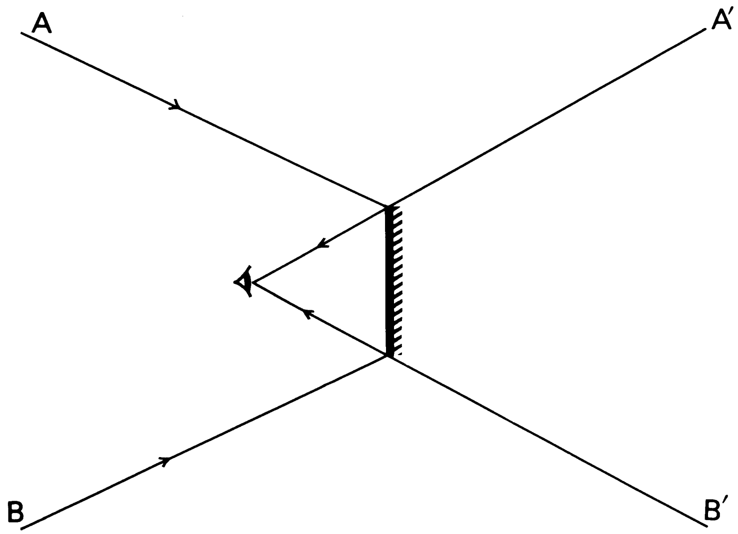
Polaroid material contains fine crystals which polarise light. A polariser will, if placed before the eye, reduce the amount of light incident to the eye. Polaroid material is used for sun-glasses; in pleoptics, for production of Haidinger brushes; to test for strains and flaws in lenses; in ophthalmoscopes and slit-lamps to reduce light scatter; to dissociate the two eyes in binocular function tests and in cameras.

The diagram shows how a beam of light is internally reflected in all planes except one, in which it passes through to emerge as polarised light.



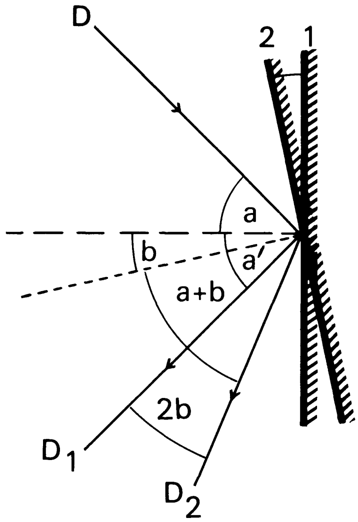
A = Object
aa = Angle of reflection
A' = Image (virtual)
x = Distance of object and image from plane of mirror

The *Law of Reflection*: light incident to a plane reflecting surface is reflected at an equal angle to the normal as an incident ray. The image of the emerging ray appears at an equal distance (measured perpendicularly) behind the mirror as the object is in front of it.



AB = Size or field of object
A'B' = Size or field of image seen by eye

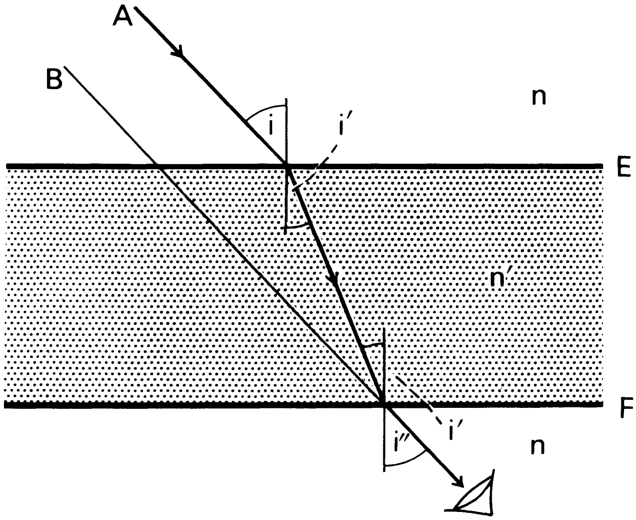
The field of view of a mirror is determined by its aperture and the distance the eye is from the mirror.



1 and 2	=	Mirror change of position
a	=	Angle of incidence to normal of plane of mirror
a'	=	Reflection angle
b	=	Angle of change by mirror
2b	=	Change in angle of reflected ray

The reflected ray changes its deviation by twice the angle of rotation of the mirror. This affects the speed of reflected image movement.

THE LAW OF REFRACTION (SNELL'S LAW)

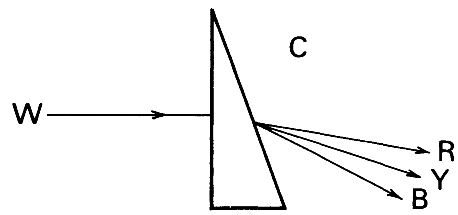


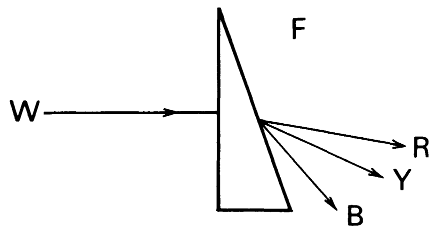
A	=	Incident ray
i	=	Angle of ray to normal
i'	=	Refracted ray angle to i
i"	=	Emerging ray angle to i
AB	=	Displacement of object
n	=	Refractive index of air = 1
n'	=	Refractive index of optical media = 1.50 approx. for plastic and 1.523 for glass
EF	=	Plane surfaces of optical media, e.g. sheet of glass

The *Law of Refraction*: the sine of angle i of the incident ray to the normal of the surface separating two optical media of different refractive indices is related to the sine of the angle i' of the refracted ray to the normal by the refractive indices of the two media.

$$\text{Thus } \sin i = \sin i' \times \frac{n'}{n}$$

Therefore a dense optical medium will bend the light more than a rarer medium.





C = Crown glass (refractive index = 1.523)
F = Flint glass (refractive index = 1.62)
R = Red
Y = Yellow
B = Blue
W = White light

Dispersive Power: the refractive index of a medium is usually measured for the following colours

Yellow line	(D Fraunhofer line)
Red line	(C Fraunhofer line)
Green-blue line	(F Fraunhofer line)

The dispersive power or relative dispersion is the power of the medium to spread the deviated C and F lines about the deviation D. Flint glass has almost double the dispersive power of crown glass.

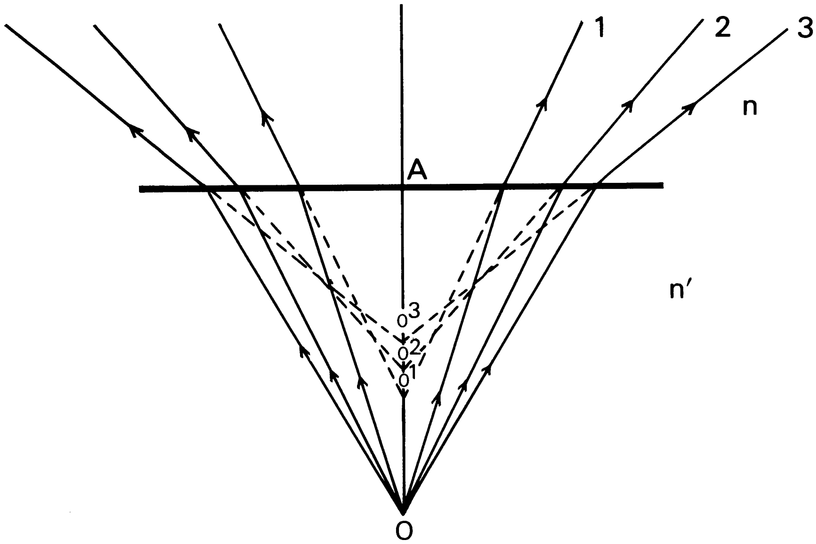
$$\text{Dispersive power } W = \frac{nF - nC}{nD - 1}$$

where n = refractive index for the various wavelengths.

Media of higher refractive indices are useful for making high-power lenses using flatter curves and therefore thinner lenses. The disadvantage would be chromatism or tinging of the image by colour.

Achromatic lenses and prisms can be made by combining lenses of different refractive indices but allowance must be made for a change in magnification values.

Reduced Vergence

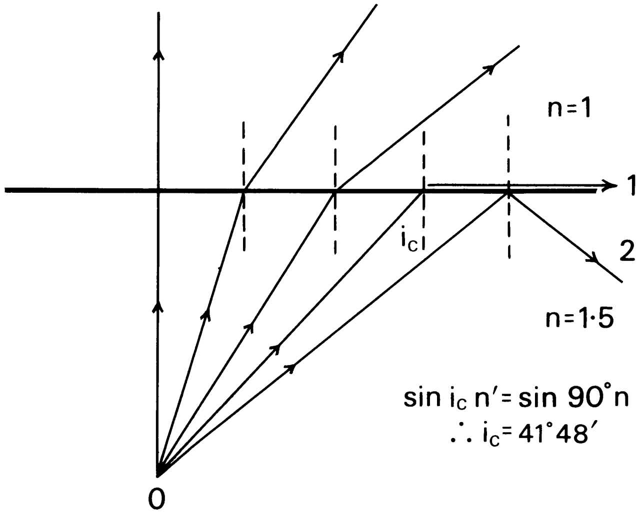


0	=	Object in denser optical media (n')
1, 2, 3	=	Emerging rays into rarer media (n)
0^1, 0^2 and 0^3	=	Virtual image 0^1 and aberrant images 0^2 and 0^3

N.B. $\frac{n'}{n} = \frac{A0}{A0'}$

The rays emerging from a point source in an optical medium and refracted to a rarer medium increase their angle to the normal (Law of Refraction). The divergent rays appear to have arisen from a virtual image of 0^1 for the axial (1) rays and at 0^2 and 0^3 for the paraxial rays (2 and 3). The diagram therefore shows image aberration and apparent nearness of the object 0. An example of reduced vergence or reduced distance is the apparent nearness of an instrument in the anterior chamber and how easy it is to misjudge its correct plane. Another example is a foreign body in the stroma.

The Critical Angle

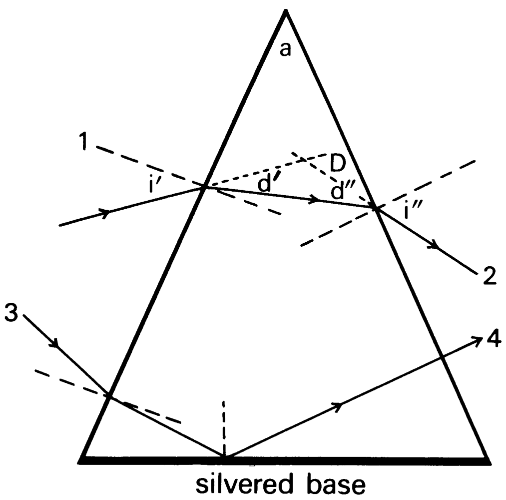


O = Object in denser medium
i_c = Critical angle
1 = Emerging ray parallel to surface
2 = Internally reflected ray when greater than i_c

Light passing from a denser to a rarer medium diverges until at a critical angle of incidence to the normal the divergent ray will be 90° to the normal. Rays of incident light greater than the critical angle will be internally reflected.

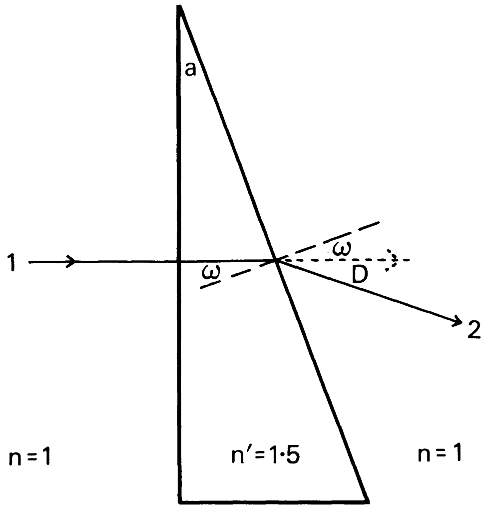
Internal reflection is seen in prism systems, e.g. prismatic binocular microscopes, ophthalmoscopes, the optical conduction in cones (directional sensitivity) (the Stiles-Crawford effect) (p. 9); it forms an important principle in fibre optics and cold light conducting instruments; it is the reason why the angle of the eye cannot normally be seen and why light cannot pass through equatorial parts of the crystalline lens from the retino-choroid (see the gonioscope, p. 172-175).

Refraction by a Prism



1	=	Incident ray
2	=	Emerging ray
i'	=	Angle of 1 to D
i"	=	Angle of 2 to D
a	=	Apical angle of prism
d' and d"	=	Deviations to D of internal ray
Total Deviation D	=	d' + d" = i' + i" − a
3	=	Incident ray producing internal reflection and emerging as 4 (reflecting prism)

The optical prism has a base, apex and three sides. The line from base to apex is the base apex line. A ray of light will be refracted by the first and second surfaces to become the emerging ray. Some rays will be internally reflected by the second surface, or base. There can be minimal and maximal angles of deviation (D). To ensure maximal internal reflection one surface (e.g. the base) can be silvered. Deviation of light by a prism will produce optical aberrations, and therefore front surface silvering of plane or curved mirrors is often preferable.



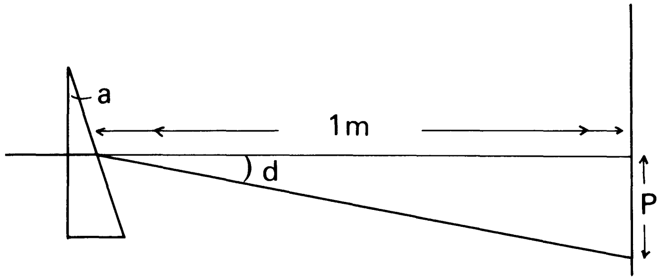
a = apex angle of prism
1 = Incident ray
2 = Emergent ray
ω = Deviation (D) = $\frac{a}{2}$

In refraction work the trial lens prism is called the *ophthalmic* prism with the front surface at 90° to the base. Half the apex angle = the deviation angle.

The flat surface of the prism should be placed in the spectacle trial frame with its surface facing the light.

The thick part is called the *prism base* and the line from angle to base the *prism axis*.

ISM DIOPTRE



lm a deviation of lcm is produced by a prism of prism dioptre.

viation (d, in degrees) = $\frac{\text{apical angle (a)}}{2} = \frac{\text{prism dioptres(p)}}{2}$

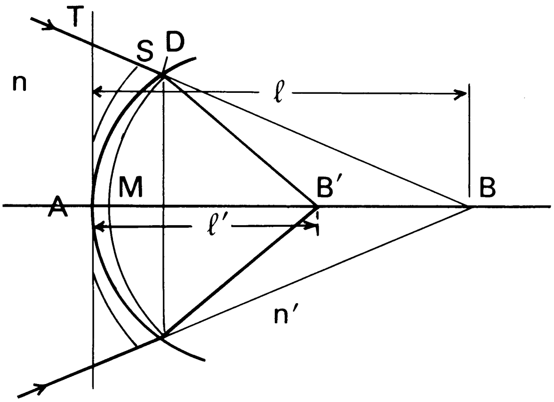
e deviation of a ray of lm from the prism can be asured in centimetres and gives the power in prism optres. A tangent scale marked in centimetres placed lm from a prism will read off the deviation in prism optres.

Deviation of 1^{o} = 1.75 dioptres
Deviation of 4^{o} = 7 dioptres

isms are used in ophthalmology for:

1. Diagnosis, e.g. orthoptics.
2. Treatment, e.g. prism lenses for hypertropia of small degree, Fresnel's prism for high degree (p. 196 and 197).
3. In instruments, e.g. prism binocular microscope (p. 156), stereoscopes (p. 184), applanation tonometer (p. 176).

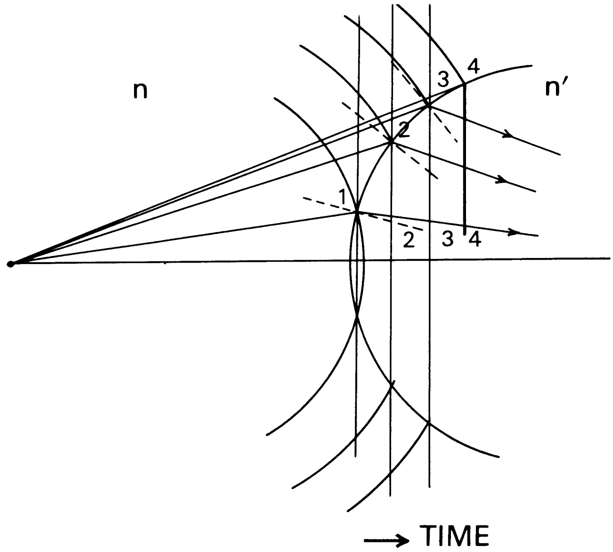
REFRACTION AT A CURVED SURFACE



$$nSD = n'AM$$

$$\frac{n'}{\ell'} - \frac{n}{\ell} = \frac{n' - n}{r} = \text{power of curved surface}$$

The incident rays are refracted at a curved surface. The sine law applies at the point of incidence. The normal is at right angles to the tangent at the point of incidence and the normal intersects the centre of curvature. A curved surface separating two media of different refractive indices produces a change in vergence. If TA is the wave front then the light energy will have traversed to M axially but only to S in the same time period. This change in wave front curvature produces a convergence of the light pathway to form an image B.



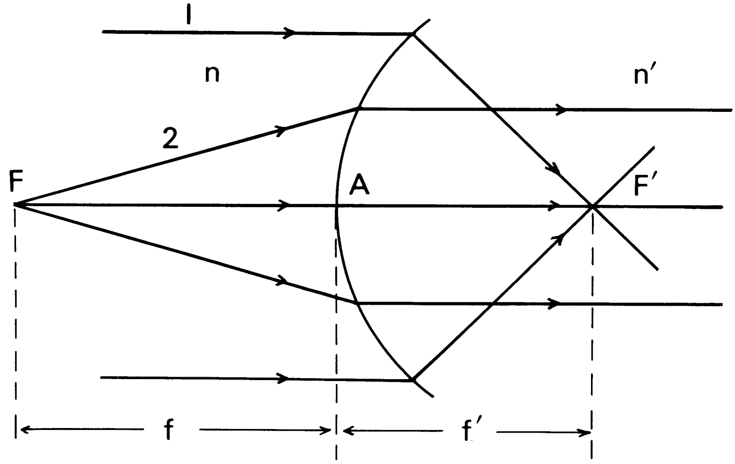
The change in vergence after refraction at a plane surface is in the same relationship as the refractive indices of the two media. Thus

$$\frac{n'}{n} = \frac{l}{l'} \text{ (in metres)} = \frac{L'}{L} \text{ (in dioptres)}$$

Refraction at a curved surface is not only due to the difference of refractive index but also to the power of the curved surface between the two media. The power (in dioptres) of a curved surface is

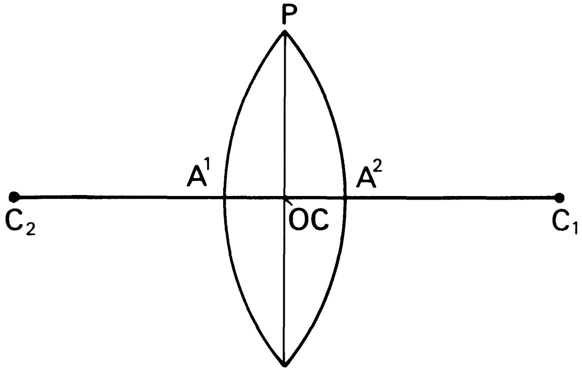
$$\frac{n' - n}{r}, \text{ i.e. } \frac{\text{difference between refractive indices}}{\text{radius of curvature (in metres)}}$$

Question: If the radius of curvature of the anterior corneal surface is 8mm and the refractive index of the cornea is 1.37, what is the power of this surface in dioptres?



FA (f)	=	Anterior focal length
AF' (f')	=	Posterior focal length
F'	=	Second focal point
F	=	First focal point
Example 1	=	Parallel rays incident to surface
Example 2	=	Divergent rays incident to surface

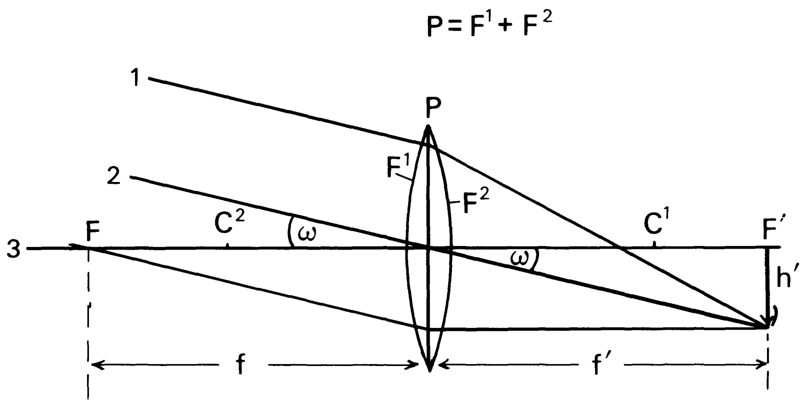
Rays from the anterior focal point will be refracted by the convex surface to become parallel to the axis. Stated differently: the divergent light from the anterior focal point is neutralised by the convergent power of the anterior surface and the refracted rays are parallel (with no vergence). Light of no vergence incident to this surface is refracted by the convergent power of the surface to form a focus at the second or posterior focal point. 'A' is the vertex or pole of the surface.



P	=	Principal plane
A^1 and A^2	=	Anterior and posterior vertices of lens
OC	=	Optic centre
C_2C_1	=	Optic axis joining the first and second focal points

The optical axis is the line joining the two centres of curvature. The lens has an anterior pole (or vertex) and a posterior pole (or vertex). The optical centre should be in line with the eye's visual axis unless the prescriber indicates otherwise. Tilting of lenses to the plane of the face can produce aberrations due to oblique astigmatism. This is less evident for near fixation and can be overcome by vertical decentration for distance fixation. It is a real problem with deep bridge and eye distances, and especially with bifocal high-powered lenses (see p. 102).

Image Formation

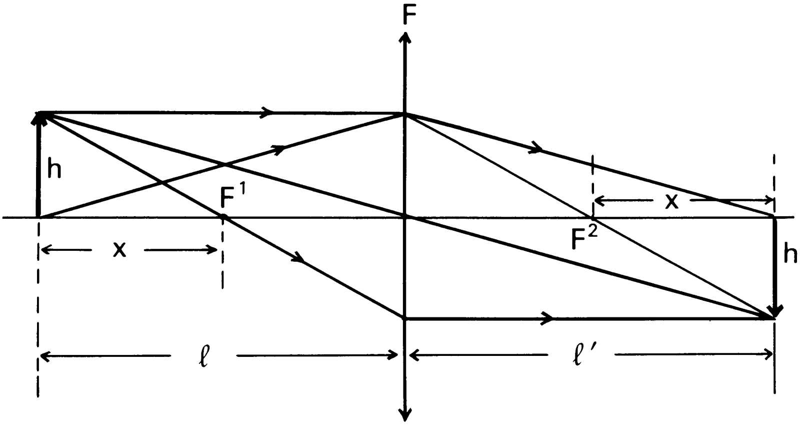


1, 2 and 3	= Parallel rays
1	= Ray incident to peripheral lens
2	= Ray incident to optic centre (no deviation)
3	= Ray incident to first focal point
ω	= Ray incident angle to optic centre
P	= Principal plane power
	= $F^1 + F^2$
h'	= Image (inverted and real)
size of h'	= fω

Rays of light from a distant source subtend an angle (ω) to the anterior focal point and to the nodal point or optical centre of the lens. This angle determines the size of the image formed in the plane of the second focal point.

The nodal point (or optical centre) is at the intersection of the principal plane with the optical axis (a line joining the centres of surface curvatures). There is no prismatic deviation at this point. Image size h' = fω.

Rays from Extra-Axial Points



h	=	Object
h'	=	Image
F^1	=	Anterior focal point
x	=	Object distance (ℓ) - focal length
F	=	Power of lens
F^2	=	Posterior focal point

The object and image distances from the lens are related to the focal power of the lens as follows

$$\frac{1}{\ell'} - \frac{1}{\ell} = F = L' - L \text{ (in dioptres)}$$

This merely states that the divergence of light from the object (-L) will be altered by the vergence of the lens power (+F) to produce the convergence of light (L^1) emerging from the lens to produce the image.

The chief rays required to construct the diagram are

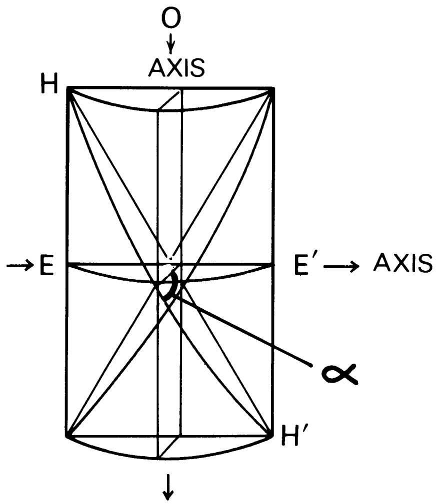
1. The ray passing undeviated through the optical centre.

2. The ray parallel to the axis passing through the second focal point (F^2).

3. The ray passing through the first focal point (F^1) and then emerging from the lens parallel to the axis.

If an object is outside the anterior (first) focal length of a positive lens, an inverted real image will be formed outside the posterior (second) focal length.

The Cylindrical Lens



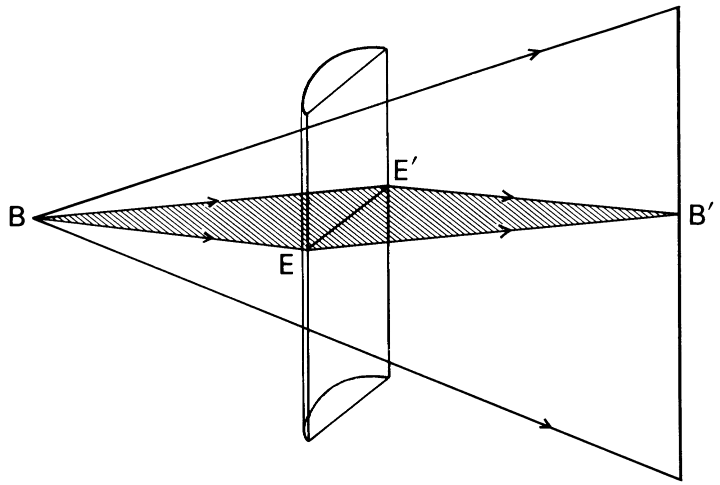
HH' = Oblique axis
EE' = Horizontal axis
O = Vertical axis of zero power

The plano-cylindrical lens has one axis of zero power (O), and at right angles to it, an axis of maximum power (EE').

The power at the oblique, HH' = EE'/sin α. This formula determines the power of any angle to this axis.

The resolution of powers in the oblique to the vertical and horizontal can, conversely, be calculated (prism powers can also be dealt with in this way).

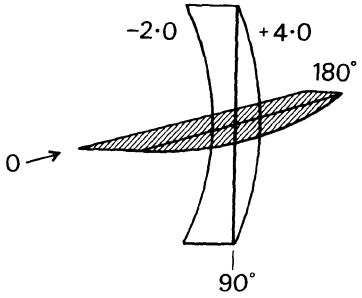
Refraction by a Cylinder



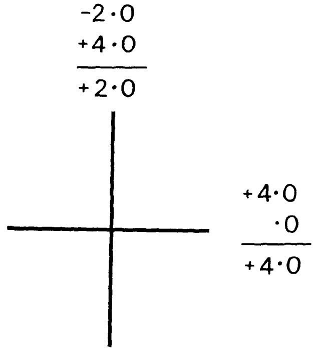
EE' = Horizontal axis of power
B = Object. Source of divergent light
B' = Image

Parallel rays of light incident to a plano-cylinder will form a line foci (B'). The rays of light at 90° to the cylinder axis are shown shaded in the diagram (see Maddox rod, p. 187).

The Sphero-Cylinder



=



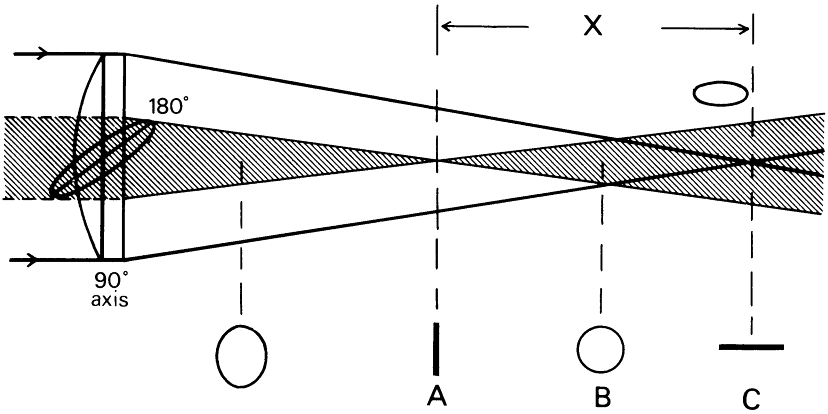
= +2·00s+2·00c×90°

A lens with a spherical surface on one side and a cylindrical surface on the other is called a *sphero-cylinder.*

The power of the lens in each axis is shown in the diagram. This Rx can be transformed by adding the cylindrical numerator to the sphere and changing the sign and axis (by 90^o) of the cylinder. Thus

+2.00s/+2.00c x 90^o
or +4.00s/-2.00c x 180^o

Stürm's Conoid



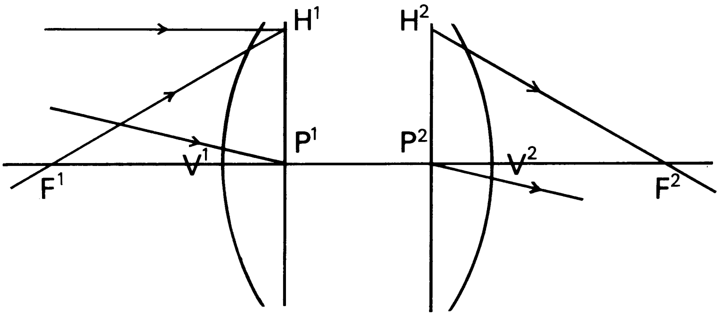
(A to C) X = Interval of Stürm
A = Line foci
B = Circle of least confusion
C = Line foci

The sphero-cylinder forms two line foci and an intermediate area of least confusion. In astigmatism the power of the eye in the principal planes may be of this form. The retina may be in any position relative to the Stürm's conoid so formed (see Astigmatism).

A spectacle lens, if oblique to the plane of the incident light, will result in oblique astigmatism.

'Best form' lens designs attempt to reduce this type of aberration. For aberrations see pages 84-87.

Thick Lens Principal Points



F^1 = First focal point
V^1 = Anterior vertex
H^1 = First plane
P^1 and P^2 = Nodal points

F^2 = Second focal point
V^2 = Posterior vertex
H^2 = Second plane

Front vertex power = $1/F^1V^1 = F_{FV}$
Back vertex power = $1/F^2V^2 = F_{BV}$

The chief ray passes through the nodal point (optical centre) of a thin lens undeviated. In the thick lens, however, there are two nodal points and the chief ray emerges from the lens in the same direction as the incident ray but displaced by the separation of the nodal points (P^1 and P^2). The other chief rays are shown.

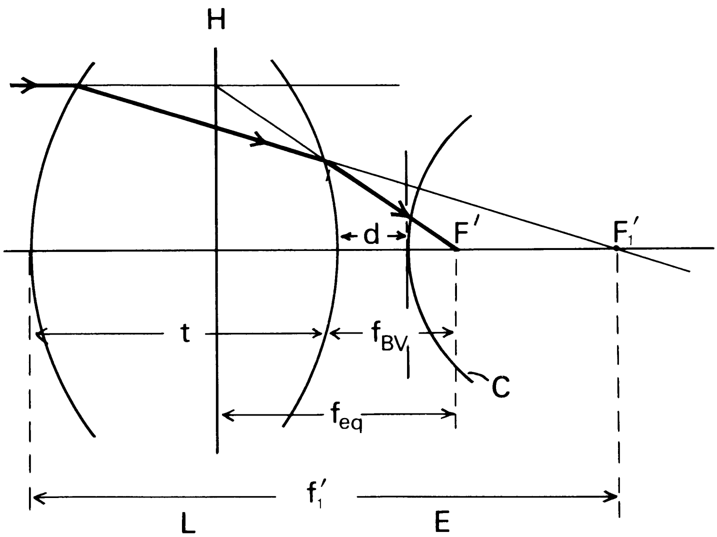
In 'best form' lenses the principal planes are not necessarily within the lens. The true focal lengths are measured from the principal planes to the focal points. They are not the same as the easily measured distances just described. Thus in high-powered lenses the anterior-vertex and back-vertex powers are not necessarily the same but the anterior and posterior focal powers are.

The use of very steep curvatures, even with low powers such as in contact lenses, will also require the same considerations even though the lens is thin at the vertex.

SECTION III

Clinical Optics

BACK VERTEX POWER



L = Lens
H = Equivalent power plane
t = Lens thickness
F^1 = Second focal point of lens
d = Back vertex distance (spectacle distance)
E = Eye
C = Cornea
f_{BV} = Back vertex focal length
$\frac{1}{f_{BV}}$ = Back vertex power (F_{BV})
f_1' = Focal length from anterior vertex

The following definitions should be noted.

1. *Back vertex focal length.* This is the distance from the back vertex of the lens to the second focal point. This distance can be measured easily.

2. *Back vertex distance* (or spectacle distance). This is the distance of the back vertex of the lens from the principal plane of the eye (see Effective power, p. 89).

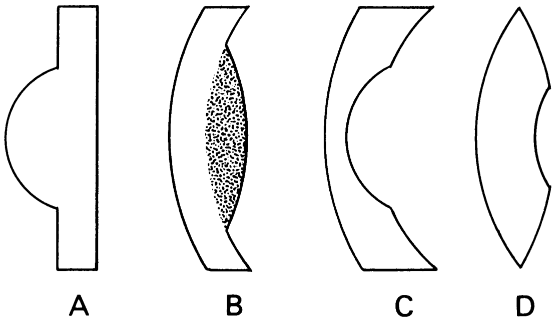
3. *Anterior vertex focal length* and *anterior vertex focal power.* These should be self-evident.

4. *Equivalent lens power.* This is the power in the single plane H shown in the diagram. Equivalent focal lengths can be determined from this plane.

In practice, using a focimeter, it is the back vertex power that is measured.

For all lenses over 5 dioptres it is necessary when writing a prescription to state the back vertex distance (d).

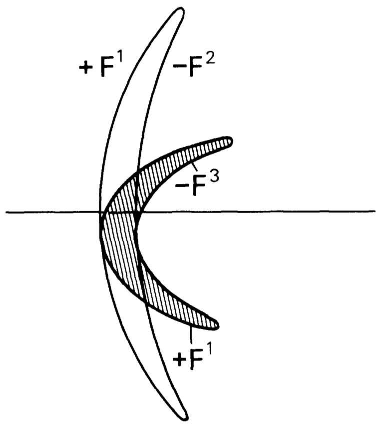
THICK LENS SHAPES OR FORMS



A and B = Positive lenses
A = Front reduced optic (lenticular)
B = Back reduced optic (lenticular) fused aspheric
C and D = Negative lenses
C and D = Back reduced optic
C = 'Best form' with periphery negative

To reduce the weight, thickness and aberrations of a high-power lens the optical aperture is reduced. This is called a *lenticular* lens and can take different forms. This principle is also used in high-power contact lenses. Using fused materials of different refractive indices for the central optic and peripheral carrier, it is possible to design aspheric high-power lenses with large fields and little aberration.

The diagram (not to scale) shows the various basic lens forms.

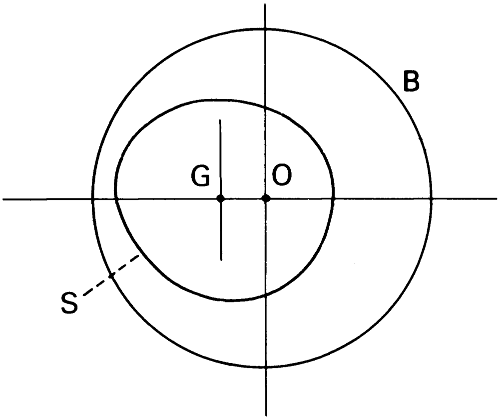


F^2	= Base curve
Front surface	= $+F^1$
Back surface	= $-F^2$ @ 90° and $-F^3$ @ 180°
Power in chief meridians	= F^1-F^2 @ 90° and F^1-F^3 @ 180°

The toric lens is the 'bent' or 'best form' of a sphero-cylindrical lens. The toric surface is formed by the rotation of a curve about an axis which is a curve but of different radius.

There are various base curves available. The base curve is the numerically smaller power of the toric surface; 3, 6 or 9 are commonly supplied. A change of toric base curve or even a change of toric surface from the front to the back of a lens can affect tolerance. An example of such a lens is given in the diagram.

PRISM-INDUCED EFFECT



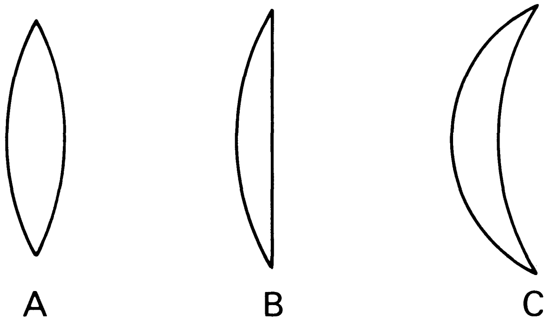
B = Manufacturer's blank (uncut)
S = Spectacle shape
O = Optical centre
G = Geometrical centre of spectacle shape

The spectacle lens has a geometric centre at the intersection of the greatest diameters. The optical centre is at the point of no prismatic deviation. The geometric centre should be at the optical centre for correctly centred distance glasses. The distance between the optical centres of the right and left lens is equal to the inter-pupillary distance. The inter-pupillary distance varies for distance and near fixation and the centering of spectacles ordered for distance and reading purposes should be accurate. The prescriber can do this measurement himself and specify it on the prescription if he so wishes.

The lenses can be decentred as shown in the diagram. This produces a prismatic effect P = F x Decentration (in cm, where F = the power of the lens (in dioptres)). The prismatic effect can therefore be obtained by decentering the optical centre relative to the geometric centre. The correction of phorias (especially vertical) can be treated in this way when surgical and orthoptic methods are inadvisable. Prismatic spectacle correction greater than 6 dioptres in association with normal refraction errors is not always clinically successful.

THIN LENS FORMS

Positive Lenses

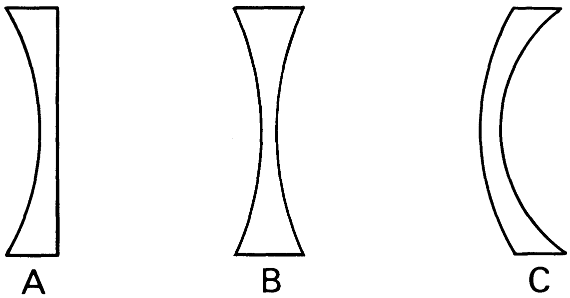


A	=	Biconvex
B	=	Plano-convex
C	=	Convex meniscus

A thin lens has a thickness of less than 2mm and with the normal spectacle aperture this can include powers of +5.0 to -6.0 dioptres and over.

The biconvex and plano-convex forms are not the best optical forms because of optical aberrations. The meniscus 'best form' lens reduces aberrations to a minimum.

Negative Lenses

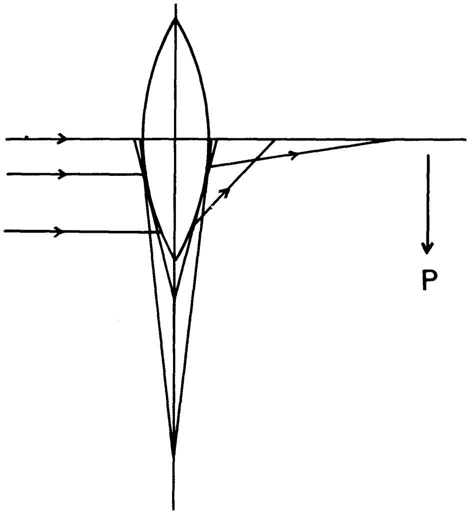


A	=	Plano-concave
B	=	Biconcave
C	=	Concave meniscus

These are plano-concave, biconcave and concave meniscus. Myopes can sometimes distinguish a difference in base curves in lenses of the same focal powers. Alterations in lens thickness will cause changes in image size and also in prismatic effects.

REFRACTION BY A LENS

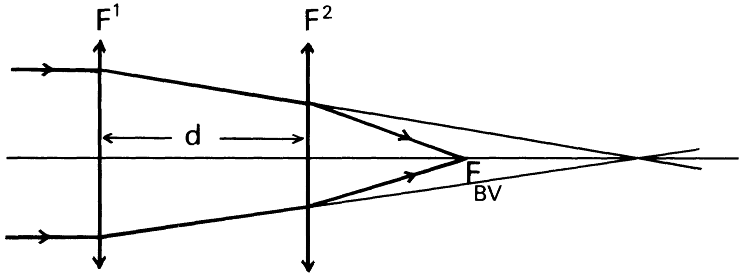
Using the Principle of Tangents and Prisms



P = For positive lenses, the prism effect increases towards the apex

The tangents to the surfaces at the points shown produce a prismatic effect, but there is none at the vertices of the lens. The prismatic effect for the positive lens increases towards the periphery of the lens. Consequently peripheral rays are refracted to a focus nearer than the axial rays (another explanation of spherical aberration).

Refraction by Two Lenses



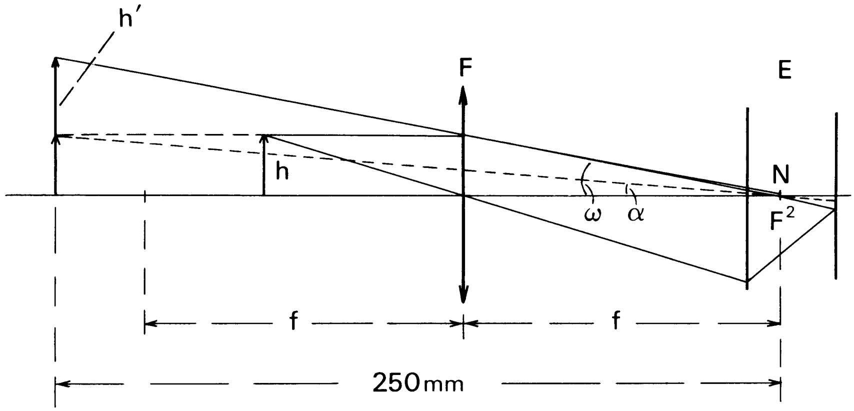
$$F_{BV} = \frac{F^1}{1 - dF^1} + F^2$$

The final vergence of light from the back vertex of the second lens is not the simple addition of the two focal powers. The effective power of the first lens in the plane of the second lens must be taken into account.

The power of the cornea cannot therefore be added to the power of the crystalline lens to find the back vertex power of the system without making an allowance for the distance between the back of the cornea to the front of the crystalline lens (the anterior chamber depth) and the refractive index of the aqueous humor must also be taken into account.

MAGNIFICATION OF OBJECTS

Simple Microscope



α = Angle subtended by object from near point (250mm)
ω = Angle subtended by image from near point (250mm)
F = Positive lens power
h = Object
h' = Virtual image projected by eye
E = Eye
N = Nodal point of eye
F_2 = Second focal point of positive lens (coincident with nodal point)

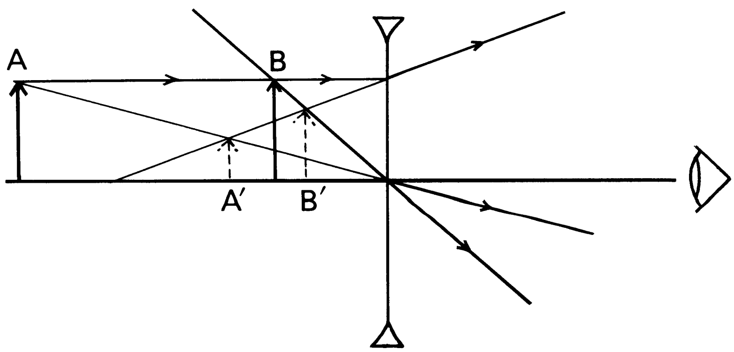
An object at the anterior focal plane of a positive lens will form an image at infinity. The size of the image as projected by the eye is determined by the angle subtended at the nodal point (or anterior focal point) of the eye. This is the principle of the simple magnifying loupe.

The object is therefore held within the anterior focal distance. The lens is held as near as possible to the viewing eye to increase the field of view. Both eyes are open and relaxed for distance so that the image can be projected to a distance and give maximum magnification (see p. 193).

The magnification at 250mm from the eye is F/4 (a x8 loupe has an equivalent power of +32.0 dioptres). (*N.B.* 250mm is the near point of distinct vision.) The refraction of the eye will also affect image size and is ignored in the above description.

$$\text{Magnification} = \frac{\text{Angle subtended by image at eye}}{\text{Angle subtended by object at near point of distinct visio[n]}}$$

IMAGE FORMATION WITH A NEGATIVE LENS

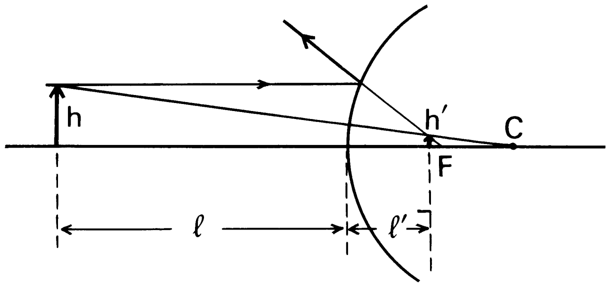


A = Object
B = Object moved towards lens
A' = Image (virtual and erect) formed by A
B' = Image (virtual and erect) formed by B

With a negative lens the image will always be erect and minified.

REFLECTION

From a Curved Convex Surface

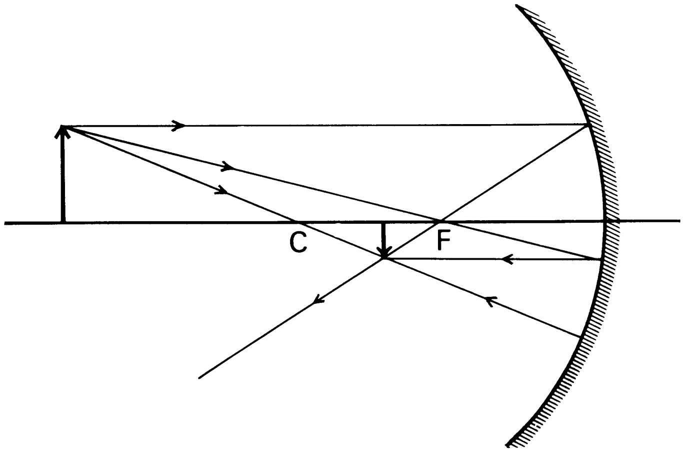


ℓ	=	Object distance
ℓ'	=	Image distance
C	=	Centre of curvature
F	=	Focal point
$\frac{r}{2}$	=	Focal length
h	=	Object height
h	=	Image height

The convex mirror is like the negative lens in that incident light of no vergence becomes divergent. A mirror has little chromatic aberration, and if aplanatic or conoidal, the spherical aberration will also be corrected.

The diagram shows that the focal length is half the radius of curvature.

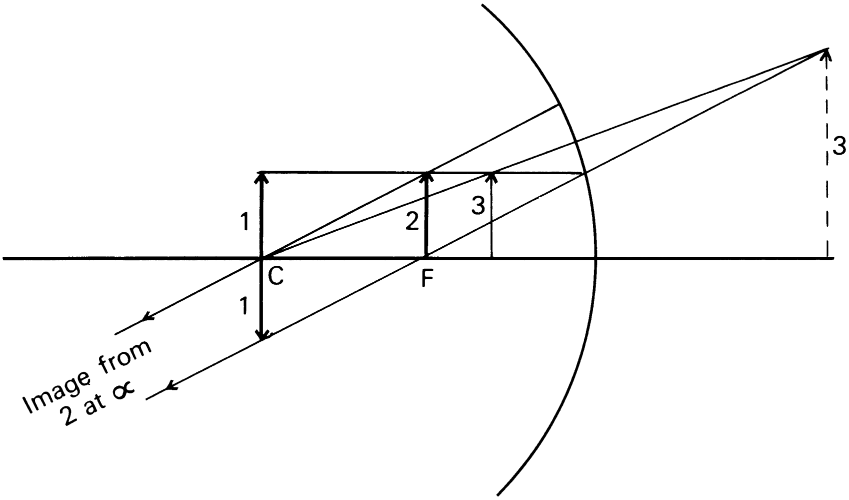
The object h will form a virtual image h'. The construction shows that a ray incident to the centre of curvature is reflected upon its own pathway.



See Key to Previous Diagram

The concave mirror is similar to the convex lens. The object outside the focal point forms an image between the centre of curvature and the mirror.

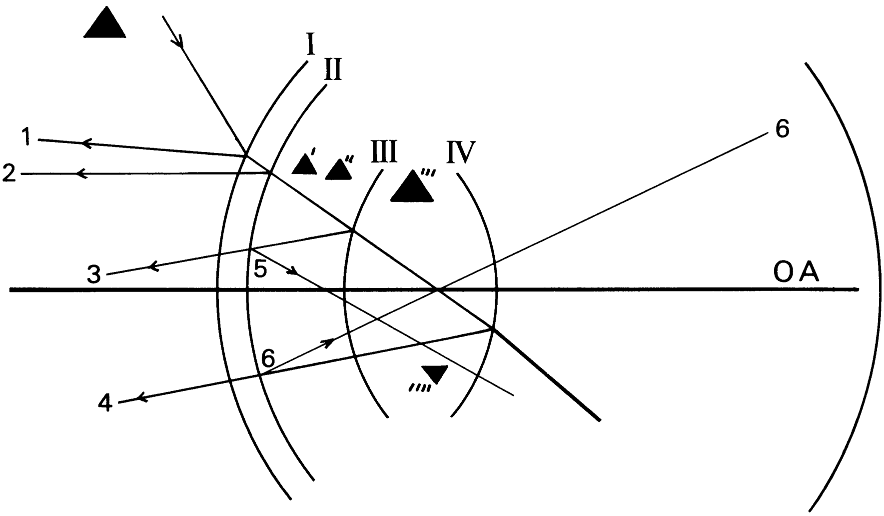
From a Curved Concave Surface



1 = Object at centre of curvature plane
2 = Object at focal point plane
3 = Object between mirror and focal point
Image 1 in same plane as object
Image 2 at infinity
Image 3 virtual, erect and behind mirror

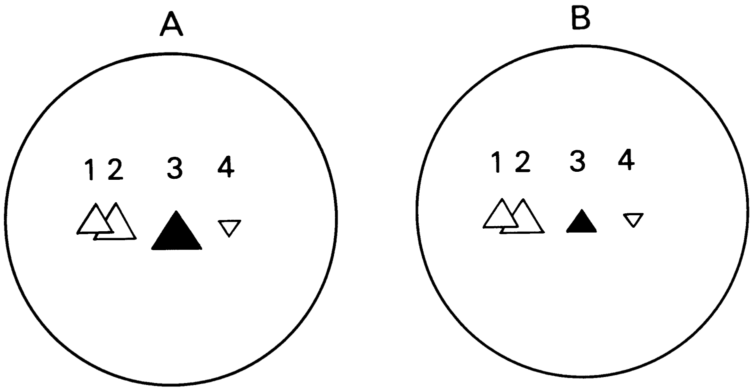
An object at C forms an image in the same plane (this can be used to find the centre of curvature, e.g. the radiuscope, p. 170). The object at the focal point F will form an image at infinity. The object between F and the vertex of the mirror will form a virtual, erect and magnified image.

From the Eye's Curved Surfaces



1. Reflected from corneal anterior surface
2. Reflected from corneal posterior surface
3. Reflected from lens anterior surface
4. Reflected from lens posterior surface
5. Number 3 ray return ray reflected by posterior cornea
6. To posterior vitreous

Catoptric images of Purkinje Sansom are minified images formed by the anterior and posterior surfaces of the cornea (I and II) and the anterior and posterior surfaces of the lens (III and IV). They can be used to measure the radii of curvature of these surfaces and the relative positions of these surfaces.



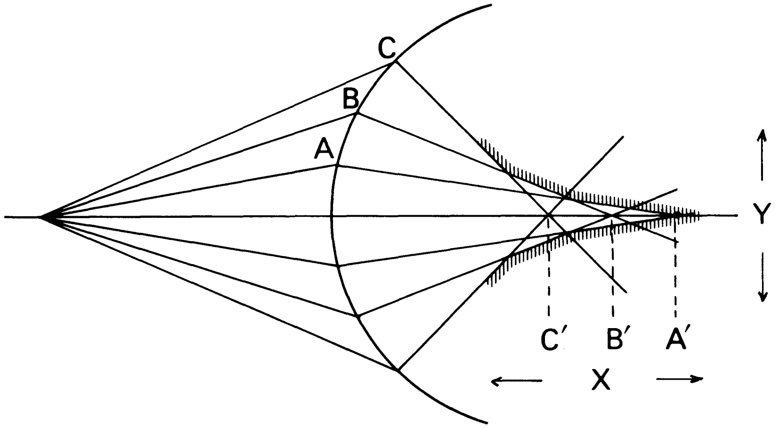
A = Eye at rest
B = Eye accommodated for new vision. *N.B.* Chief change is in image 3 from anterior surface of human lens

Images can be entoptic or catoptric. Entoptic images emanate from the central nervous system whereas the images formed by the surfaces of the eye are catoptric and are not necessarily seen by the subject.

The catoptric image behaviour indicates the part played by the crystalline lens surfaces in accommodation. It should be noted that the only image which has changed its form is that of the anterior surface of the crystalline lens. This image is shown in the diagram as black and is formed by the anterior surface of the crystalline lens.

N.B. As the crystalline lens surface becomes more convex the image becomes smaller.

From Curved Surface Refraction — Spherical Aberrations



A, B and C	= Paraxial rays
C', B' and A'	= Focal points
X	= Axial aberration
Y	= Lateral aberration

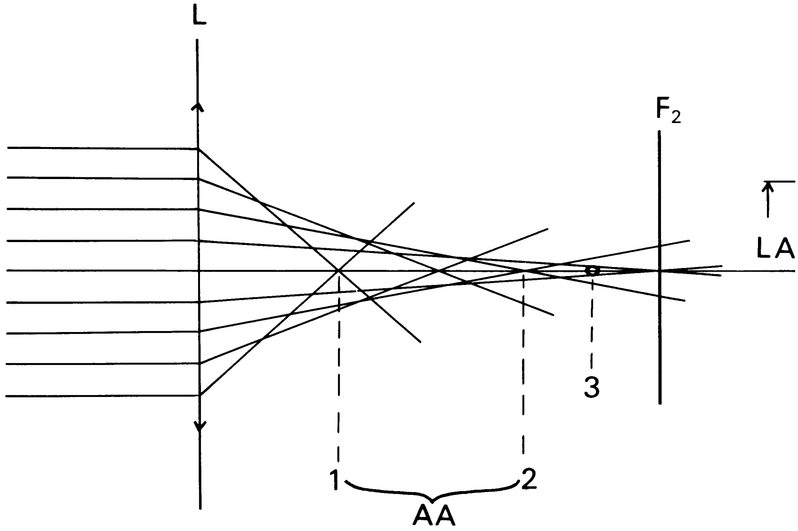
Paraxial incident rays will be refracted by a curved surface to form a point focus. Peripheral rays of light will, because of the sine law, be refracted and intersect at different foci on the axis. The intersections of the rays form aberrations which can be axial or lateral.

The concentration of intersected rays forms a caustic curve in section or a caustic surface in spacial conception (like a trumpet). This is called *spherical aberration*. This type of aberration can be corrected by restricting the rays to the axial region by using occlusive diaphragms (e.g. the pupil of the eye) or by flatter paraxial curves in the case of a convex surface (e.g. the cornea). The latter method permits the formation of a brighter image because axial and paraxial rays form the image.

From Lenses

Lens Material

Aberration can be due to the defects in the optical media or the dispersive power of the media (see p. 49).



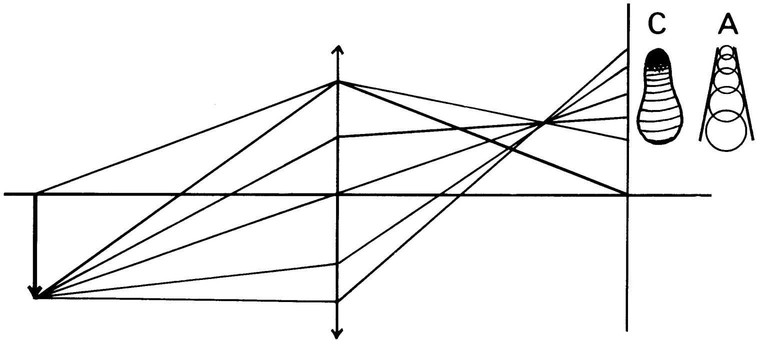
L	= Lens of toric or sphero-cylindrical form
F_2	= Second focal plane
1 and 2	= Line foci of principal power meridians
3	= Circle of least confusion
AA	= Axial aberration
LA	= Lateral aberration

Lens Form

The spherical aberration of a lens is similar to that produced by a single surface, as shown previously (p. 84). It can be reduced by occluding the peripheral rays, by using a 'best form' lens and by using aspherical surfaces.

In the human eye the pupil reduces the aberrations produced by the non-optical peripheral cornea and limits the rays of light to the axial portion of the crystalline lens. The spherical aberration of the human eye is of the order of 0.75 dioptres of longitudinal aberrations.

Oblique Astigmatism

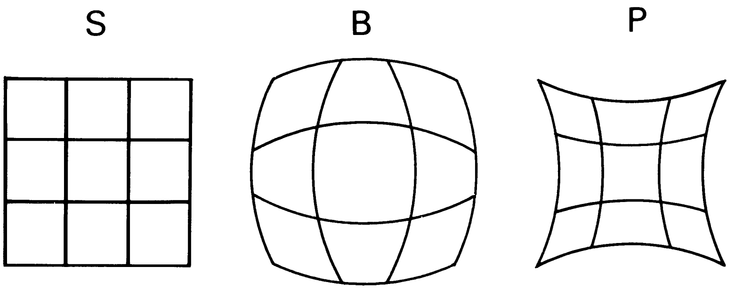


A = Overlapping of images from a point source — diagrammatic
C = Fused images in the focal plane forming a coma effect

Study once again Stürm's conoid (p. 65). In the diagram above, the axial rays form a focus further away than the paraxial.

Oblique astigmatism results from the plane of the lens being other than at right-angles to the incident rays of light. Examples of this are when the eye rotates to view an object through the peripheral part of the spectacle lens, or more commonly when the spectacle, contact or implant lens is tilted relevant to the plane of the eye. *Coma* is due to different-sized images being formed in several planes. The 'best form' lenses reduce this effect to a minimum.

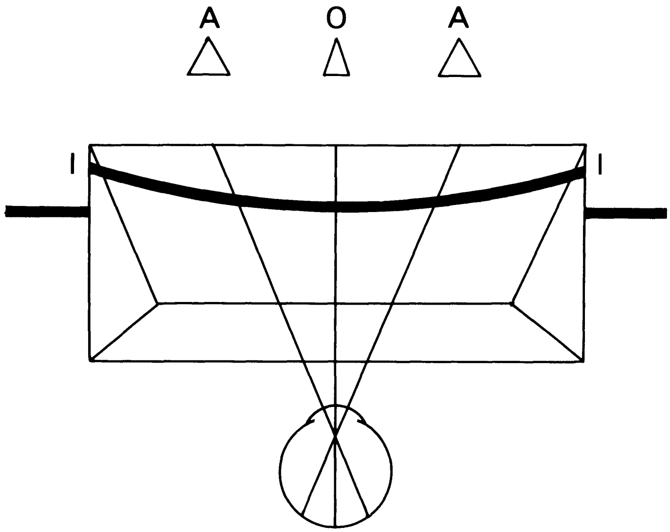
Magnification Distortion



S = Grid (squares) target
B = Barrel distortion
P = Pin-cushion distortion

Distortion of the image is difficult to eliminate if the full aperture of the lens is used. Its effects upon a square object are shown for a negative and a positive lens. The reasons for this form of distortion are to be found in the different magnification effects present in each part of the lens. It is commonly found in high-powered lenses of poorly designed microscopes and telescopes.

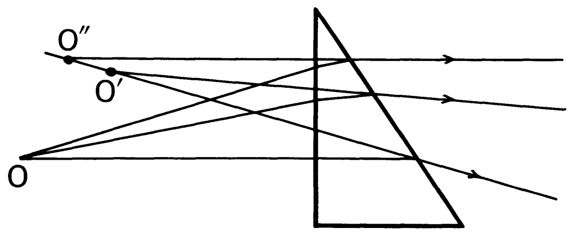
Prism Aberration



O = Primary eye position
A = Secondary eye positions and oblique fixation gives increased apical angles of prism
I = Image

This can be illustrated by viewing a straight edge or line through a prism.

A straight line seen through a prism will appear curved because the optical sections of the prism through which the rays pass to the eye have different apical angles — and therefore different angles of deviation (see distortion of images produced by lenses).

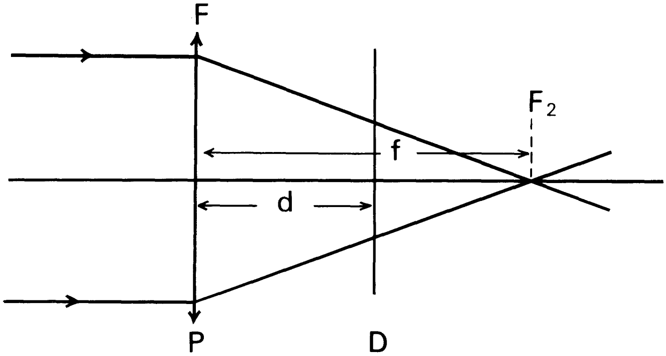


O = Source of light
O' and O" = Image formation in different planes

Divergent rays from a point source will be incident to the prism at different angles. The refracted rays will not therefore appear to arise from a single virtual image. This results in image aberration. Therefore large degrees of prism in a lens will result in aberration of the image.

EFFECTIVE POWER

<u>Power in Different Planes</u>



F = Lens power
D = Plane to measure effective power
f = Focal length of lens
F_2 = Second focal point
d = Distance from lens to effective power plane
P = Plane of lens

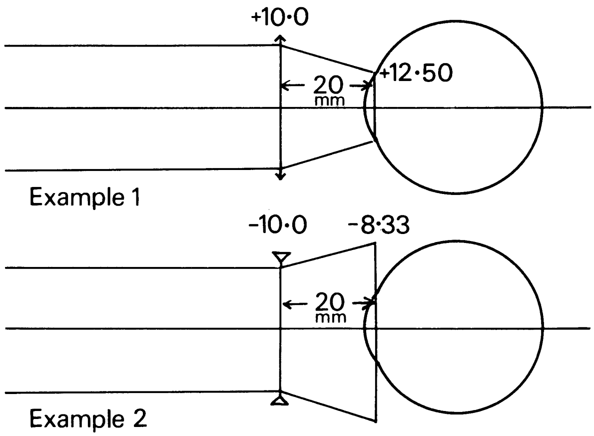
The focal power of a lens is the power in its principal plane. It is in this plane that the incident light changes its vergence. The effective power F_{eff} of the lens in any other plane, such as D, can be calculated if distance d is known.

$$F_{eff} = \frac{1}{f-d} = \frac{F}{1-dF}$$

where F is the focal power of the lens.

Thus a spectacle lens of F dioptres has an effective power of F_{eff} at the eye; the distance d is that between the posterior vertex of the lens and the principal plane of the eye (usually from the lens to the lid, and allow 2mm).

Power of a Lens



Example 1

$$F_{eff} = \frac{F}{1 - dF} = \frac{+10.00}{1 - (10 \times 0.02)} = +12.50 \text{ dioptres}$$

Example 2

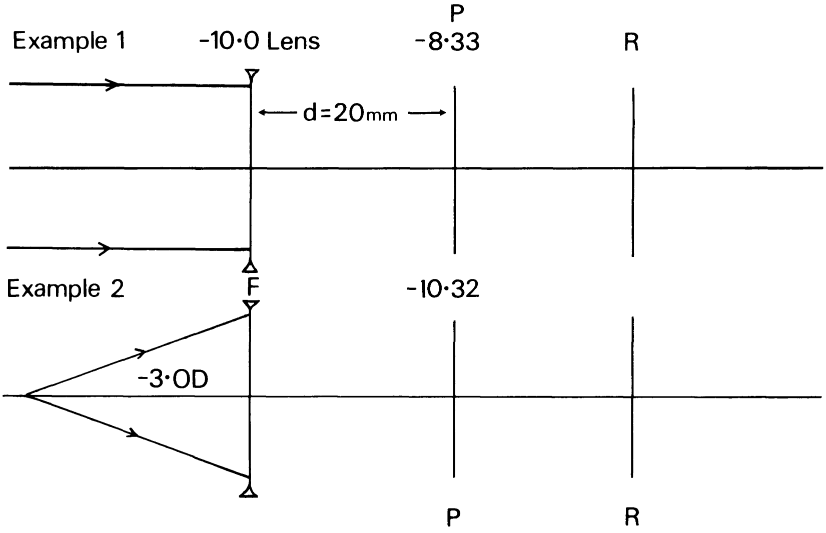
$$F_{eff} = \frac{-10.00}{1 + 0.02} = -8.30 \text{ dioptres}$$

To find the power of a correcting lens (spectacle refraction) in the principal plane of the eye, the effective power formula, $F_{eff} = F/(1 - dF)$, must be applied. In the examples given the +10.0 lens has an effective power of +12.50 dioptres at the eye (ocular refraction), and a -10.0 dioptre lens -8.33 dioptres at the eye (ocular refraction).

The distance d is called the *back vertex* or *spectacle distance* of a correcting lens. It must be specified in prescription lenses over +5.00 dioptres and over -6.00 dioptres, otherwise dispensing inaccuracies will occur. This distance will also be required in contact-lens practice and for ordering anterior-chamber implants Use either calipers (distometer) or a millimetre rule to measure d. A thin millimetre rule (Rayner's) placed in the slit of a stenopaeic occluder placed in the trial plane can also be used.

NEAR AND DISTANCE FIXATION AND OCULAR REFRACTION

Myopia

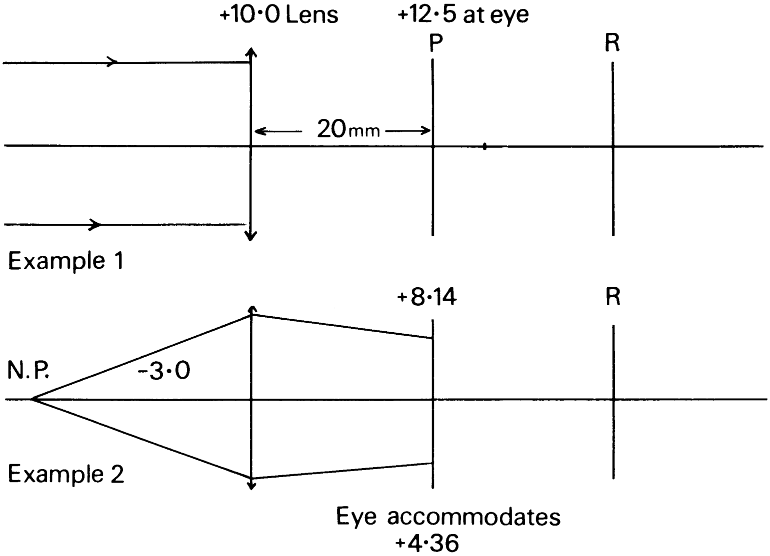


Example 1	Myope -8.33 dioptres ocular refraction Distance fixation correcting lens = -10.00 dioptres at 20mm
Example 2	Above myope as corrected but near fixation at $\frac{1m}{3}$
	Divergence of light at eye = Effective power of lens - Divergence (-3.00) = -10.32 at eye
Accommodation	= Ocular refraction (-8.33) - Effective power at eye (-10.32) = +1.99 dioptres
P	= Plane of eye
R	= Retina

In the first example the ocular refraction is -8.33 dioptres and the correcting lens at 20mm from the eye is -10.00 dioptres.

The effective power of a spectacle lens will vary as the light vergence incident to the spectacle lens alters. Thus if the incident light is -3.00 dioptres (near point), only 1.99 dioptres of accommodation are required. This is especially useful to the patient if the myopia is under-corrected. (The 'base in' effect of negative lenses will decrease the amount of convergence necessary; see p. 184 and 188.)

Hyperopia



Example 1 Hyperope +12.5 dioptres ocular refraction

Distance fixation correcting lens = +10.00 dioptres at 20mm

Example 2 Above hyperope fixates to $\frac{1}{3}$m

Effective power at eye is +8.14 dioptres

Accommodation = Ocular refraction (+12.5) - Effective power at eye (+8.14)

= +4.36 dioptres

The effective power at the eye for incident light to the spectacle lens of no vergence (distance fixation) is +12.5 dioptres. Therefore the patient with a spectacle correction of +10.0 dioptres would have to accommodate 4.36 dioptres for a near point -3 dioptres (33cm distance) away.

Consequently the hyperopia requires a relatively greater near correction than the myope.

(In practice the BVD given above as 20mm is much less.)

MULTIVISION SPECTACLE LENSES

The bifocal or two-vision lenses are of the following types.

1. Benjamin Franklin (obsolete) now available in the modern optical form as the monocentric (Tillyer Executive) bifocal (see p. 99).

2. Cemented bifocal (obsolete; see p. 95).

3. Fused bifocal; higher refractive index glass is fused to crown glass. The bifocal is 'invisible' but has a near segment with a higher dispersion power (see p. 97). *Note:* Small insets (Univis) can be made to bifocal and trifocal forms.

4. Solid bifocals, made from one piece of glass (see p. 98). The position and size of the segment is shown in the diagram on p. 102. The exact dimensions are usually left to the dispenser. Setting the segment too hight or too low, and the incorrect angling to the face of high-power bifocal lenses, are common causes of trouble. In special cases (especially for occupational reasons) the prescriber must indicate the size and height of the segment.

Indications for bifocals are

1. Age (presbyopia).
2. Occupation.
3. Aphakia.
4. Esophoria
   (a) With hypermetropia.
   (b) With full myopic correction (bicentric alternative in young persons).
5. Accommodative weakness or paresis.

Contra-indications are

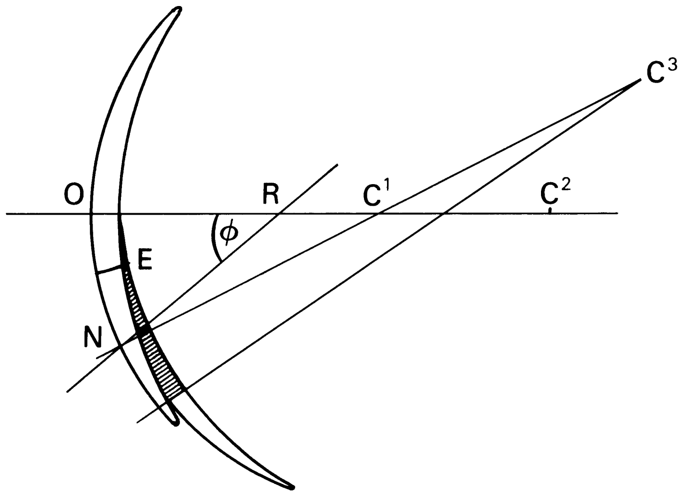
1. Age and physical infirmities.
2. Occupation, e.g. sailor, building-site worker.
3. Anisometropia.
4. High oblique astigmatism.
5. Heterophoria — uncompensated by low prisms (under 4 dioptres horizontal).

Intolerances

1. Segment size.
2. Segment height (limitation of visual field).
3. Chromatism in fused bifocals.
4. Non-relative prismatic effects on versions.
5. Prismatic 'jump'.
6. Loss of binocular single vision (B.S.V.) on head tilt.
7. Sudden change of focal power.
8. Varifocal has advantages but some patients are unable to tolerate limited fields of gaze in the lower half of the lens.

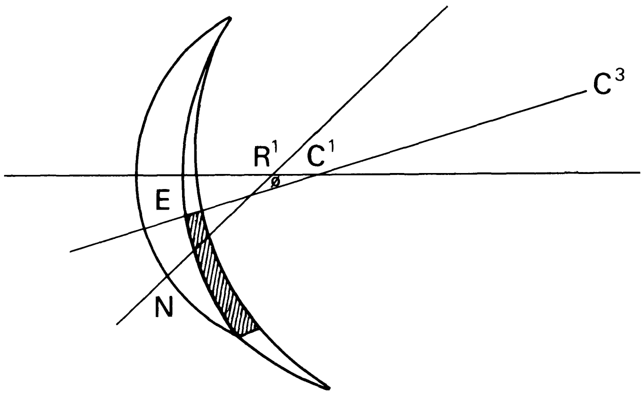
Bifocals

The Principle of the Prismatic Effect



C^1 = Centre of front lens surface
C^2 = Centre of back lens surface
C^1C^2 = Optic axis
O = Distance point on lens (optic centre)
E = Top of new segment
R = Centre of eye rotation
C^3 = Centre of new segment back curve
N = Near visual position of gaze
ϕ = Angle of depression from distance to reading (N) position

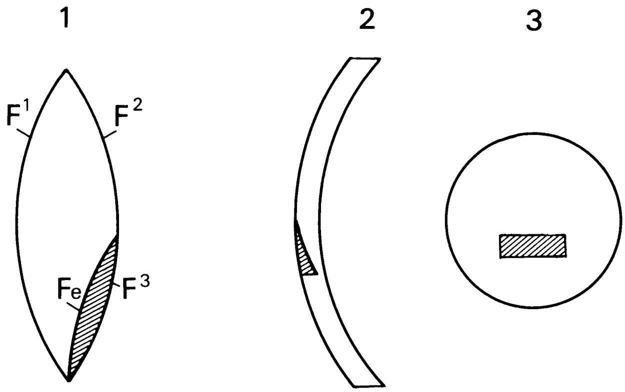
In this type of bifocal a prismatic change ('jump') is noticed as the visual axis passes from the distance to the near segment. The visual axis NR is oblique to the optical axis NC^1 of the near segment. This produces astigmatism aberrations.



Key as Previous Diagram

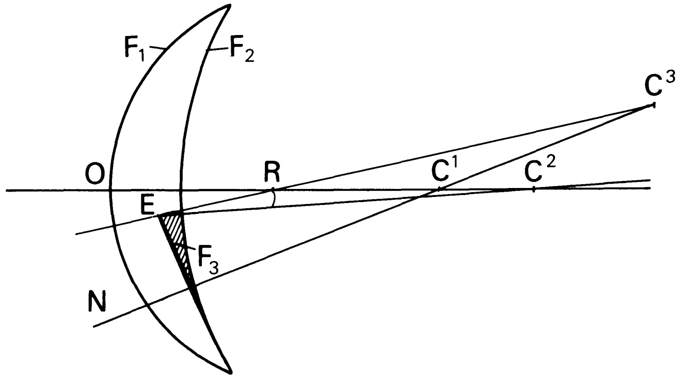
The segment, when designed as shown, reduces the prismatic jump effect but increases the oblique astigmatism. These effects are minimised with monocentric bifocals.

The Fused Segment



1 = Fused segment (shaded) of higher refractive index than lens
2 = Segment in a convex meniscus lens
3 = Note shape of segment. Other shapes are available

The round fused segment Fe is often used for low-power additions; the prismatic effect and chromatism are disadvantages. The inset types can control the prismatic 'jump effects and permit some distance correction below (Univis).



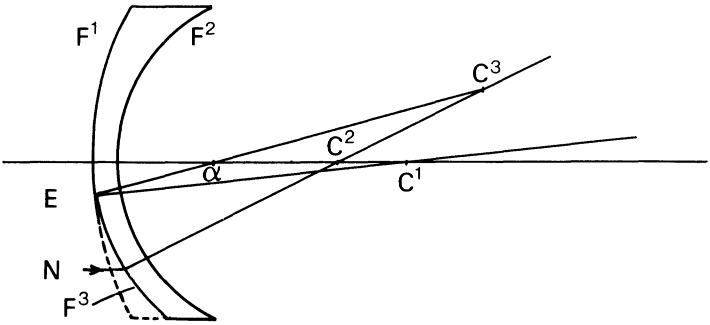
Key as diagram on p.95

This bifocal is cut or moulded from one solid piece of material.

Solid bifocals allow some control of prismatic effects and also variable sizes of segments.

This lens shows the lower segment power obtained by working a flatter curve on the back surface.

The diagram shows a positive lens form.

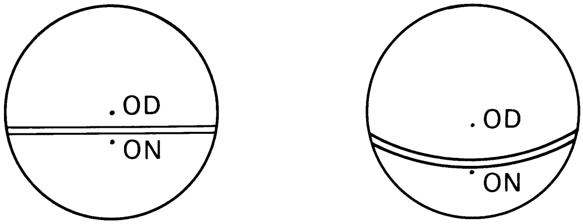


Key as diagram on p.95

In this negative-power example a different method of obtaining the near add effect is used.

In this example of a solid bifocal the anterior surface is used to obtain the increased positive power for near vision.

Monocentric Axes (Split Lenses)

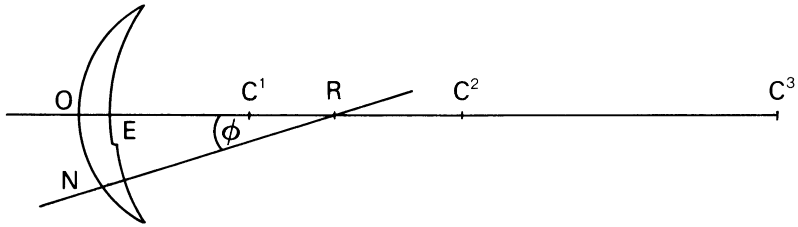


OD = Optic centre for distance
ON = Optic centre for near

A two-vision lens is made by placing two separate lenses in one frame.

This diagram shows the first type of two-vision lens used by Benjamin Franklin and possibly made for him either in London or Paris. It is possible to obtain a monocentric effect by this method.

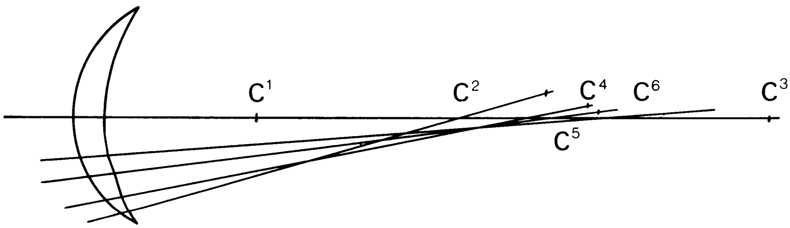
Monocentric Optical Axis



φ = Rotation angle through O to N
without prism change at E

A lens with all the optical centres in the same axis avoids the prismatic effect.

The monocentric and multifocal lenses with principal axes are shown. A gradual change of power can be obtained with a paraboloidal surface (Varilux).

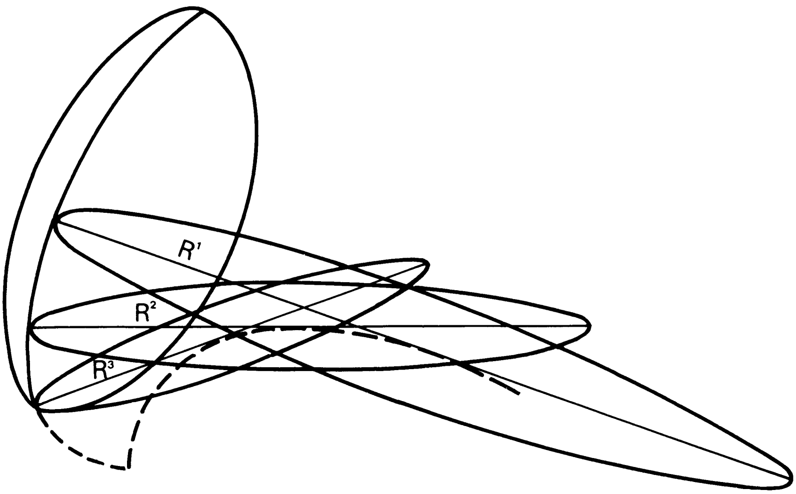


C^1 to C^6 = Progressive change of radii

Multifocals

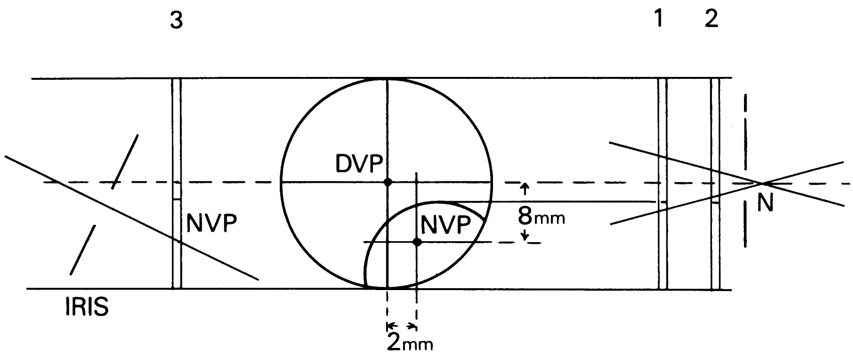
Several powers can be cut or inserted in the forms described. The intermediate power is usually +1.00 dioptre added to distance. The example shown (see also p. 101) is of a gradual changing curve — Varifocal.

Along the vertical meridian of the lens a series of curvatures of progressive change occurs with a locus of centres describing a curvature which provides an increase add effect for reading in the lower segment of the lens.



R^1-R^3 = Variation in curvature to produce change in power
- - - = Locus of centres of curvature in varifocal-type lens

Fitting



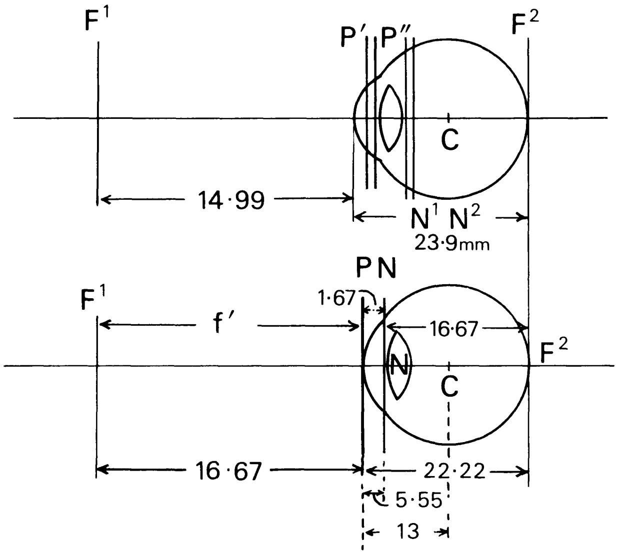
N = Nodal point of eye
I = Plane of iris and pupil
Bifocal Lens and Segment Position
Example 1 = Segment height correct
Example 2 = Segment height too high
Example 3 = Segment correct for reading
DVP = Distance vision point
NVP = Near vision point

There must be accurate fitting when bifocals are advised. The diagram illustrates how such factors as rotation of the visual axis, size of the pupil and reading segments, and the spectacle distance, can affect tolerance and acceptance of the bifocal lens-

SECTION IV

Visual Optics

THE SCHEMATIC (AVERAGE) EYE



The 'Schematic' Eye (Top Diagram)

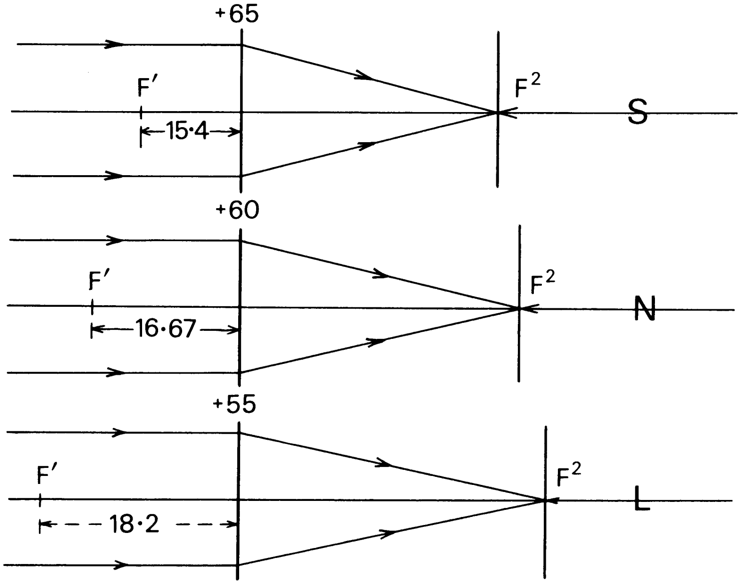
F^1 = Anterior focal point
F^2 = Posterior focal point
P'P" = Principal planes
N^1N^2 = Nodal planes

The 'Reduced' Eye (Lower Diagram)

μ = 1.33
Single front curve r = 5.55mm
P = Single plane
N = One nodal plane and point

The 'schematic' eye is the average optical data for the human adult eye. It has two principal planes and two nodal points.

The 'reduced' eye ignores the lens and has one principal plane and one nodal point. The measurements are given. The refractive index for the whole reduced eye is 1.33 and the power is +60 dioptres. This is the optical form used in subsequent diagrams. The true anterior corneal surface is $1^2/3$mm in front of the principal plane. The radius of curvature of the front surface of the reduced eye is 5.55mm (using the formula $\frac{n - n'}{r}$).



The Emmetropic State

N = normal
S = short eye and higher power
L = long eye and smaller power

Two variables determine the emmetropic state. They are the total dioptric power of the eye and the axial length of the eye. In the reduced eye, F_e (the power of the eye) is complementary to F_{ax} (the axial length expressed in dioptres as a vergence power). Emmetropia can exist, therefore, in eyes with the axial lengths outside accepted normal limits.

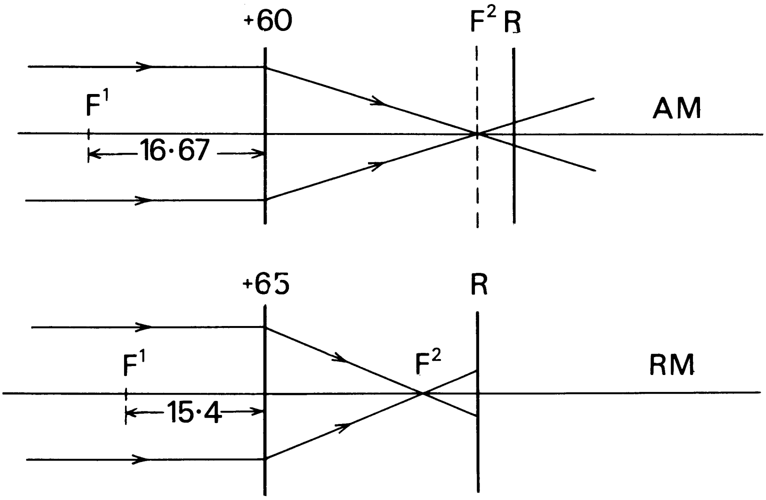
(The above examples have arbitrary powers.)

Ametropia (F_{am}) is a state where the total dioptric power of the eye does not equal the axial power (F_{ax}). Thus

$$F_{am} = F_{ax} - F_e$$

Ametropia

Myopia



AM = Axial myopia = Power normal, long eye length

RM = Refractive myopia = Power high, normal eye length

Aetiology

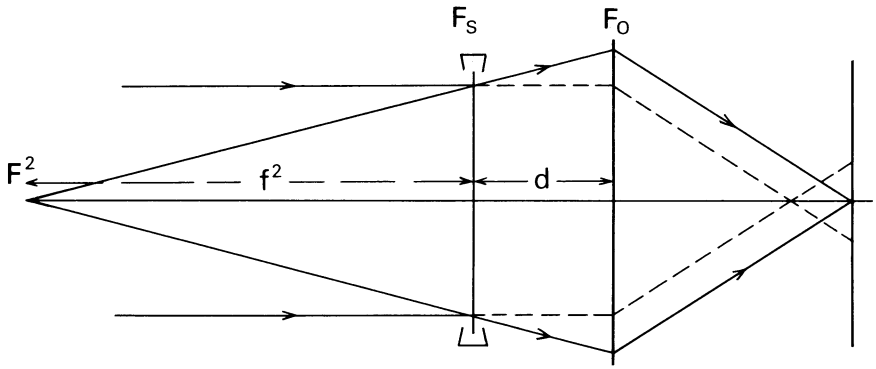
1. Congenital — present at birth and usually of high degree.
2. Developmental — racial incidence in Caucasians usually up to -6 dioptres.
3. Acquired. Corneal disease, e.g. interstitial keratitis.
4. Degenerative. Usually axial and of high degree — associated with chorioretinal degeneration and other eye changes.

Myopia is that state where the second focal point of the eye is in front of the retina. It may be due to an eye length that is greater than normal — axial myopia.

Refractive or 'index' myopia is caused by a higher than normal dioptric power of the eye. It can be caused by:

1. Cornea curvature.
2 (a). Abnormal crystalline curvatures or position of the crystalline lens.
   (b). Spasm of accommodation (pseudomyopia).
   (c). Convergence — accommodation anomaly as in space myopia.
3. Refractive index increases, e.g. senile lens changes due to diabetes mellitus, sulphonamide toxicity and steroids.
4. Night myopia (illumination and sensitivity confined to shorter wavelengths). Occurs because of chromatic aberration.

Correction of Ametropia



d = Spectacle distance or back vertex distance

F_S = Spectacle refraction (back vertex power of lens)

$$= \frac{1}{f^2}$$

F_0 = Ocular refraction (power in plane of eye) $= \dfrac{1}{f^2 - d}$

$$= \frac{F_S}{1 - dF_S}, \text{ and } F = \frac{F_0}{1 + dF_0}$$

Methods of Correction

1. Using accommodation power in hypermetropia.

2. Reducing the diameter of blur circles, e.g. stenopaeic occluders or closing of the palpebral fissure.

3. Spectacle lenses. The focal point of the correcting spectacle lens is in the plane of the far point of distinct vision of the eye. (The vergence of light from the far point of the eye will, when incident to the eye, result in the light forming a focus at the fovea.) The effective power of the correcting spectacle lens in the plane of the eye is called the *ocular refraction*. The ocular refractions may be obtained as follows

$$F_0 = \frac{F_S}{1 - dF_S}$$

4. Contact lenses. The effective power of the spectacle lens at the cornea is the power of the contact lens in air. The outside curvature of the contact lens is determined from a knowledge of the keratometry, the refractive index of the contact lens, the choice of the inside curve of the lens and its thickness. The fluid thickness between the cornea and the lens must also be considered when it is thicker than 0.5mm.

5. Anterior chamber implant. The power is calculated from a knowledge of the spectacle correcting lens and the approximate plane the implant will occupy (see p. 121 and 122).

6. There are various experimental surgical methods which include keratectomy, corneal implants, shortening of the eye and lens extraction. The latter is applicable for high myopia.

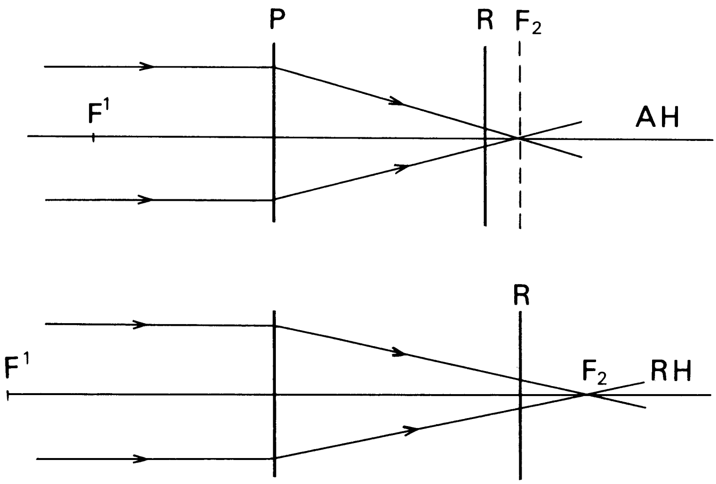
7. Dietary methods in myopia.

8. Galvanic stimulation of extra-ocular muscles.

9. 'Eye exercises'.

N.B. Numbers 6-9 are methods not in general acceptance.

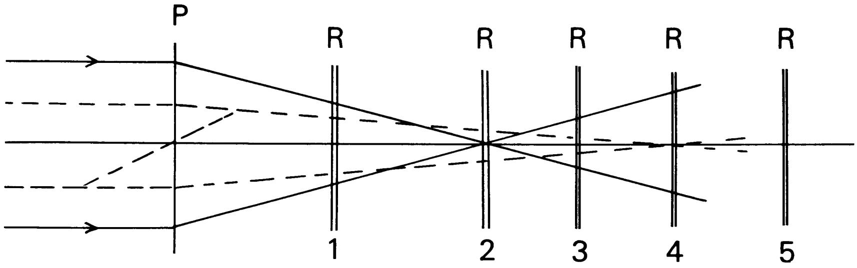
Correction of Hyperopia



AH = Axial hypermetropia
   = Short eye and normal power
RH = Refractive hypermetropia
   = Normal length eye and low power

In axial hypermetropia the eye length is shorter than normal and it is usually congenital or developmental in aetiology. The second focal point of the eye is behind the retina.

Index (or refractive) hypermetropia is found in the acquired state of aphakia (see p. 117-120).



P = Plane of eye
R = Five positions of retina relative to line foci
1 = Compound hyperopic astigmatism
2 = Simple hyperopic astigmatism
3 = Mixed astigmatism
4 = Simple myopic astigmatism
5 = Compound myopic astigmatism

Total astigmatism = Corneal + Residual (crystalline lens)

Astigmatism can be regular or irregular.

Irregular astigmatism due to corneal disease can not be adequately corrected with spectacles. If contact lenses are of no use, corneal grafting may be necessary. The stenopaeic occluder will give useful information as to the best acuity possible.

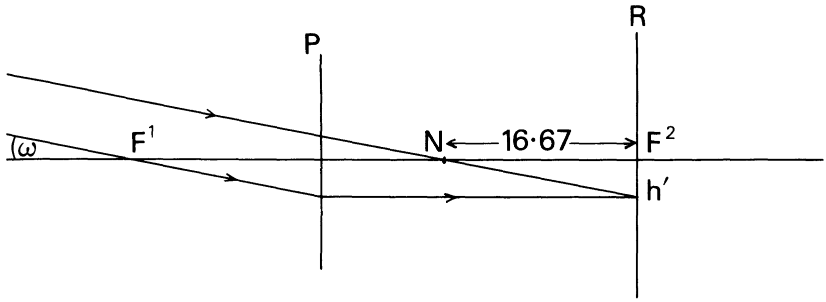
Regular astigmatism can be corneal or lenticular in aetiology. The parallel rays of light incident to the plane (reduced eye) of the eye from a distance source will form a Stürm's conoid in the eye. The diagram shows the several planes in which a retina could be placed relative to the line foci and the designation of the types of astigmatism.

The region of 'least confusion' may give an acuity of $6/_{18}$ even with high degrees of astigmatism. Such patients may not wish to wear spectacles until they begin to lose accommodation (R_3).

The spectacle correction of regular high astigmatism should be full in young patients, but the cylinder reduced if ordered for the first time in adults. It can gradually be increased to the full amount.

The full correction of uniocular astigmatism over 4 dioptres in anisometropia may cause heterophoria and is best treated with contact lenses.

RETINAL IMAGE SIZE (R.I.S.) (SPECTACLE MAGNIFICATION)



$h' = \tan\omega \times 16.67$ = Image size

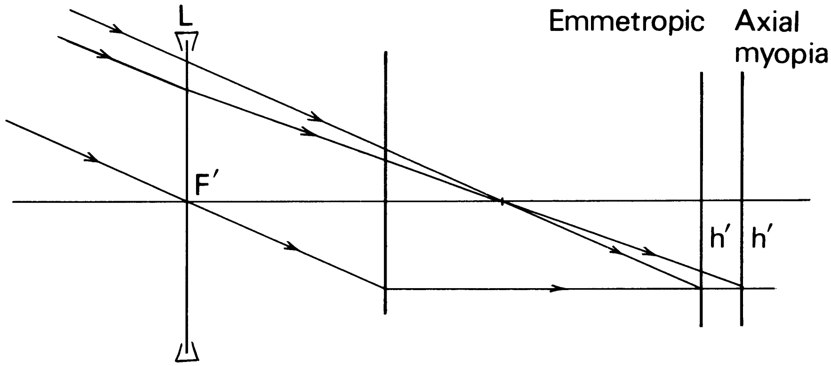
Absolute image size = $\dfrac{\text{Corrected image size}}{\text{Uncorrected image size}}$

Relative image size (to emmetropia) = $\dfrac{\text{Corrected image size}}{\text{Emmetropic image size}}$

N = Nodal point of eye

The correction of visual acuity by optical appliances is associated with a change in magnification. The corrected image size can be compared with the image size of an emmetropic eye or that of the blurred image size of the uncorrected eye. The spectacle magnification is termed 'relative' in the first instance. It must be admitted that a blurred image has no finite size and the psychological perception may bear no mathematical relationship to the corrected image size. The actual image size is determined by the position of the anterior focal point and the angle the incident rays subtend to this point. The image size in emmetropia is determined by the tangent of the angle subtended at F^1 (16.67mm from the principal plane, anterior focal length or NF^2).

AXIAL MYOPIA AND MAGNIFICATION OF IMAGE

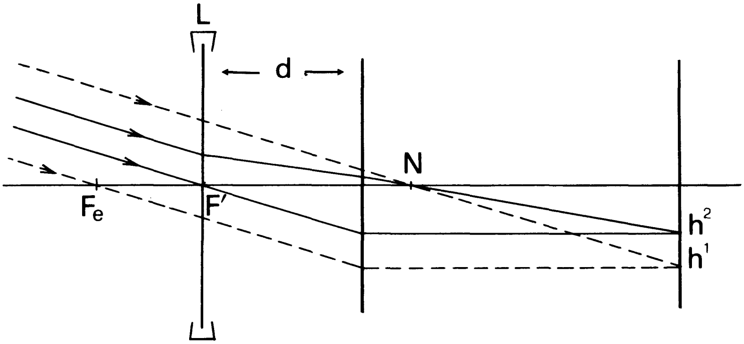


L = Lens in anterior focal plane of the eye for emmetropia and axial myopia

h' = Image size same for emmetropia and axial myopia when lens is in F' plane, i.e. relative magnification = 1 (see previous figure)

In axial ametropia, if the correcting lens is placed in the plane of the anterior focal point of the eye, no magnification will occur.

In axial myopia, movements of the correcting lens towards the eye will increase the size of the image. If the correction is placed between the anterior focal point and the principal plane the image will be larger than in emmetropia (a contact lens will, in axial myopia, perform the function of a visual aid by giving a magnification effect).



L = Lens
d = Lens distance from the eye
---- = Rays for emmetropia when F is anterior focal point of eye
—— = Rays for corrected refractive myopia when F' = Anterior focal point of eye
$\frac{h^2}{h^1}$ = Image ratio less than one = RM less than 1

The spectacle lens in refraction myopia will minify the retinal image. The greater the spectacle distance the smaller the image.

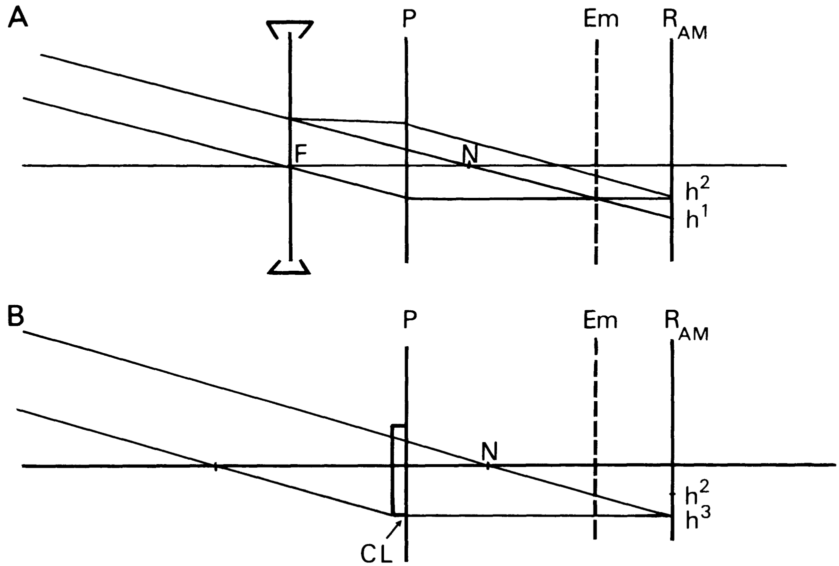
A formula for spectacle magnification is

$$M = \frac{1}{1 - dF}$$

where d is the distance of the lens from the plane of the eye. Therefore if d = 0, the spectacle magnification = 1.

In refractive myopia the correcting lens will only give the emmetropic image size when the correction is placed in the plane of the eye. The negative lens in myopia will still give a reduced image in the plane of the anterior focal point of the eye.

MAGNIFICATION OF IMAGES IN MYOPIA

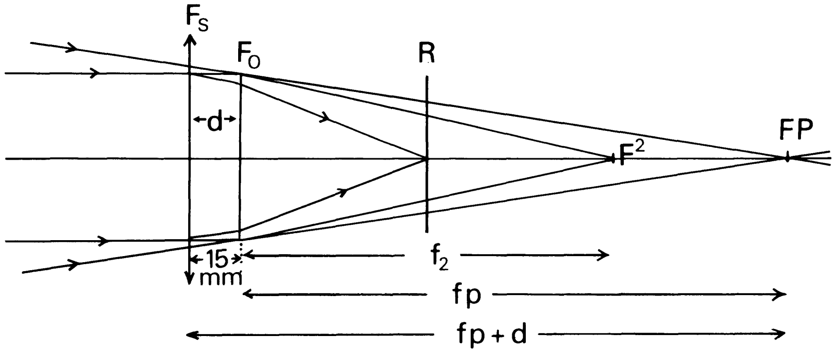


F = Anterior focal point of eye
R_{AM} = Retina of axial myopia
Em = Retina of emmetropia
h^1 = Uncorrected myopia image size
h^2 = Corrected spectacle image size
h^3 = Contact lens corrected image size

In the upper diagram the myopic eye is corrected by a spectacle lens and the retinal image is smaller than the uncorrected.

In the lower diagram the contact lens changes the total power of the eye so that the image formed is larger. The greater the degree of axial myopia the larger will be the size of the image produced by the contact lens.

Bringing the spectacle lens closer to the eye will permit a reduction in power (see Effective power, p.89) and increased image size.



FP = Far point of eye
F^2 = Second focal point of the eye
f_p = Focal length of the eye
f_2 = Second focal length of the eye
F_0 = Ocular refraction
F_s = Spectacle refraction
d = Spectacle vertex distance

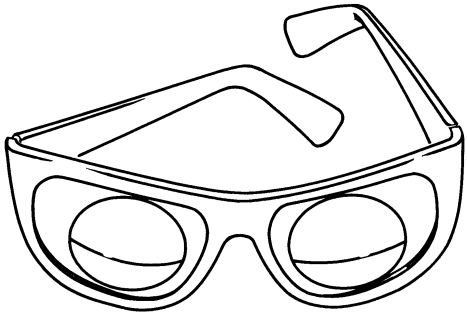
A hypothetical case is shown.

The far point FP = 70mm (approximately +15 dioptres). The power of the eye F_0 is approximately +45.0 dioptres. The spectacle lens distance d = 15mm. Thus the spectacle lens focal length = 70 + 15mm = 85mm. (The second focal length of the spectacle lens = FP of the eye and the spectacle distance.)

The spectacle lens (F_S) power = 1000/85 = +11.75 dioptres, in the example given.

Aphakia ametropia is therefore determined by two factors: (1) the power of the front surface of the cornea and (2) the vergence power as determined by the axial length of the eye ($1.333/\ell$) and the refractive index of the media. The difference between the two gives the ametropia.

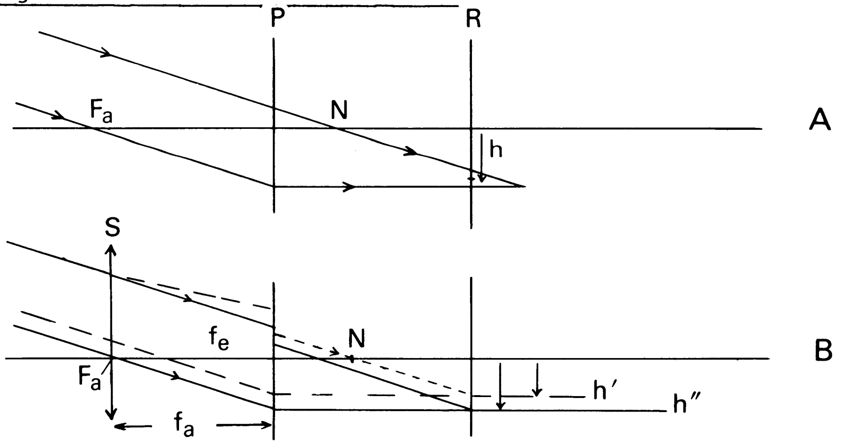
Temporary Aphakia Spectacles



A plastic reduced-optic bifocal spectacle for post-operative use after cataract extraction.

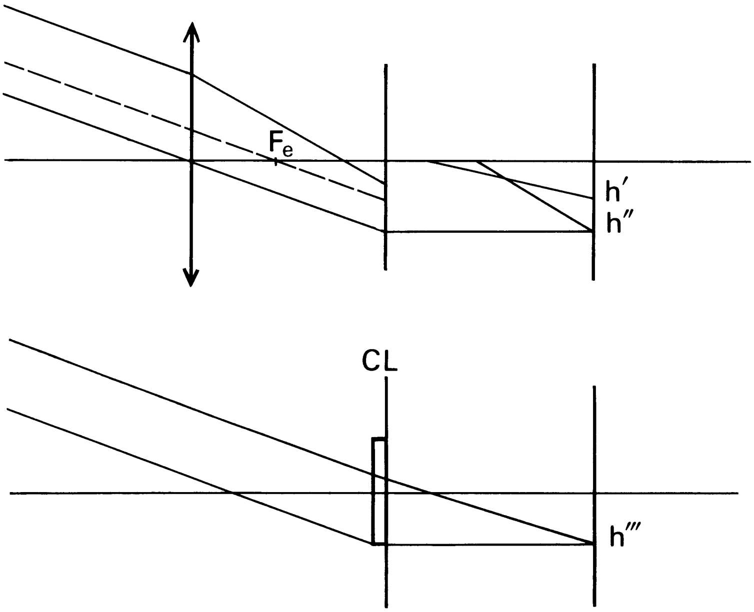
It is usually available in +11.00 to +16.00 dioptres; distance powers with +1.0 dioptre intervals and +3.00 dioptres reading addition. Some designs have side protective shields.

Magnification with Correction



A.	h	=	Uncorrected aphakia image size
	h'	=	Emmetropic eye
	h"	=	Spectacle corrected size
	F_a	=	Anterior focal point of aphakic eye
	P	=	Plane (ocular refraction = 15 dioptres)
B.	S	=	Spectacle lens in plane of F_a
	— — —	=	Emmetropic ray formation
	-----	=	Construction rays
	———	=	Aphakic ray formation
	R.M.	=	$\frac{h''}{h'} = \frac{f_a}{f_e} = \frac{22.22}{16.67} = \times 1.33$

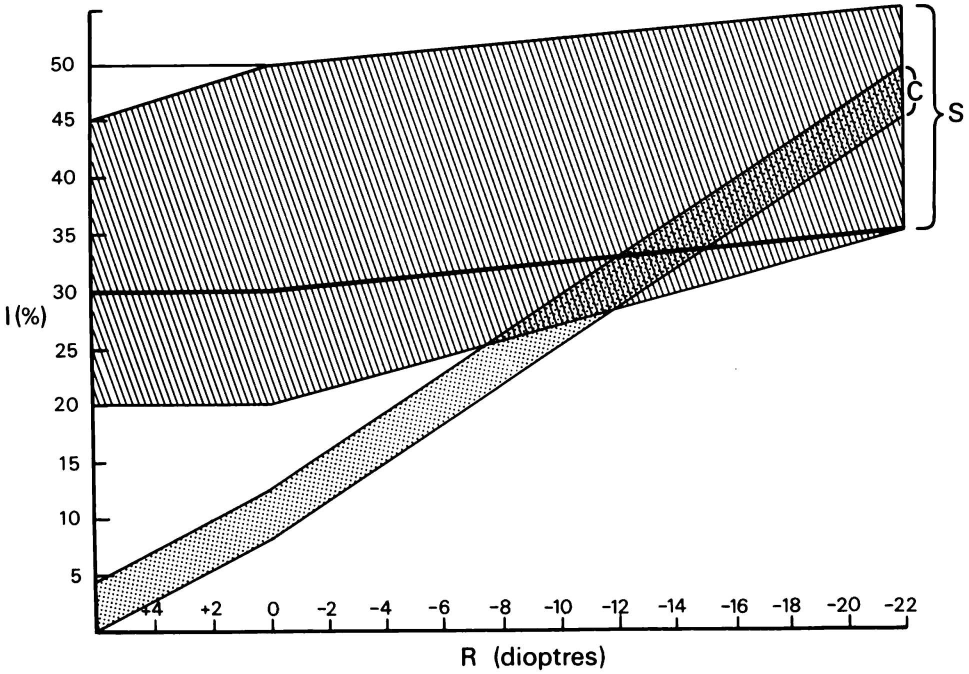
In hypermetropia of 'refractive' aetiology the spectacle correction will produce image magnification. A difference in magnification between two eyes of greater than 7% (x1.07) will be an obstacle to B.S.V. especially if acquired before B.S.V. is well established This is the case in unilateral aphakia. With a spectacle correction the aniseikonia is as much as 20 to 30% (x1.20 to x1.30). A contact lens reduces the aniseikonia to under 10% and the anterior chamber implant to under 5%. This presupposes the other eye to be of normal emmetropia.



h' = Emmetropic image size
h" = Spectacle corrected image size
h''' = Contact lens corrected image size
(h''' approx. 5% greater than h' and h" approx. 30% greater than h')

The spectacle lens corrects aphakia with magnification (see graph on p.120) but the contact lens reduces the image size especially if no axial abnormality exists.

The implant (pseudo-phakic) lens reduces magnification to a minimum and can even produce minification.



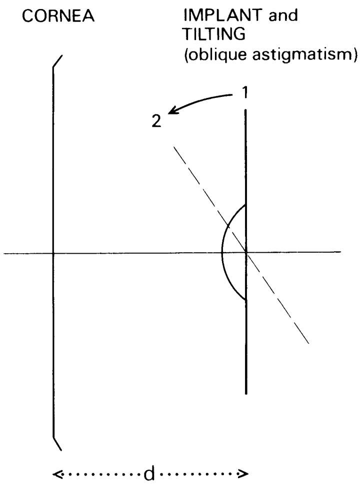
R = Pre-operation refraction
I = Retina image size (% normal)
S = Spectacle correction
C = Contact lens correction

The above graph taken from Bennett's figures* indicates that with spectacles after the operation, depending upon keratometry and axial length, the image size can vary from 20% to as much as 50%, but by an average of 30%. The shaded area represents the range.

With contact lenses the range is from 5 to 45% directly related to the degree of myopia. This effect is mostly due to high myopia being axial in aetiology (stippled area).

*From Ruben, M. (1975). Contact Lens Practice, Baillière Tindall, London.

Pseudo-lens Plastic Implant



C = Plane of cornea (power 38 - 48 dioptres)
I = Plane of implant
d = Cornea to implant distance
1 to 2 = Tilting of implant
Axial eye length (AEL) = 22 - 26mm
Variables = C, AEL and plane of I

Formulae to derive implant power

Given data: length of eye (L), average keratometry (dioptres) = K, and implant plane 5 mm from anterior cornea (or 5 - 1.67* = 3.33 from anterior plane)

Formula 1 Reduced eye length (see p. 105) = L - 1.67

Formula 2 Power of eye $= \frac{1.33 \times 10^3}{L - 1.67} = P$

Formula 3 Am (ametropia) = P - K

Formula 4 Implant power $= \frac{Am}{1 - 0.0033 \times Am}$

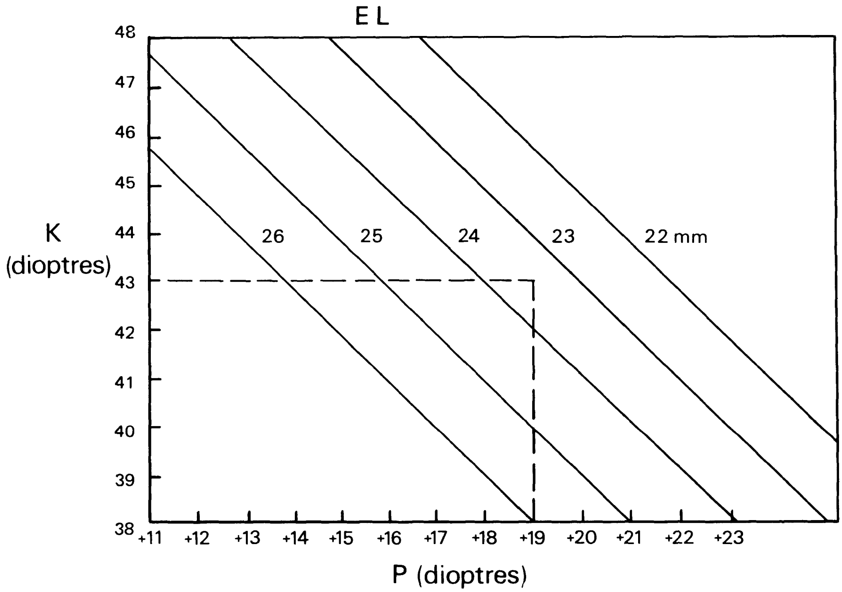
*Using reduced eye formulae (p. 105)

Example

	L = 23.5
	Average K = 43
Formula 1 and 2	P = 61
Formula 3	Am = 18
Formula 4	Implant P = 19 (power in aqueous)

(all to nearest 0.25 dioptres)

Pseudo-Lens Implant Powers



P = Power of implant for keratometry (if 5mm behind cornea)
EL = Eye length (mm) (found by ultrasound)
K = Average power of cornea (front surface) (in dioptres)
- - - - - - = Reading for normal average keratometry

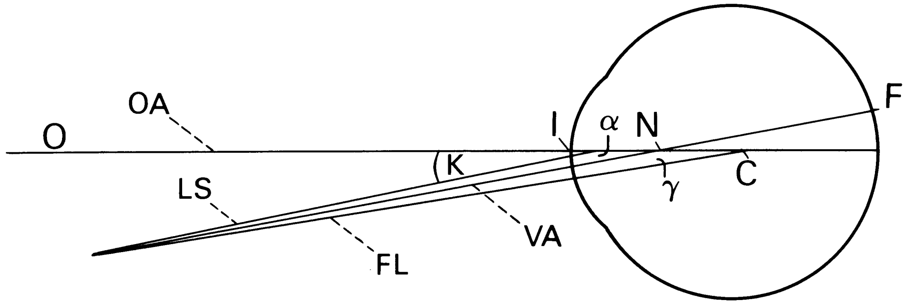
Given that the implant is at 5mm from the anterior corneal surface.

The graph gives the power of the cornea related to the eye length and the power of the implant. In the example shown above K = 43 dioptres and ℓ = 23.4mm. Therefore implant power is +19.0 dioptres (in eye) or

+57 dioptres (in air).

N.B. For every millimetre the implant is forward, add -1.0 dioptre.

FIXATION AXIS RELATIONSHIP TO OPTIC AXIS, ETC.



N = Nodal point of eye
C = Centre of rotation
I = Image from the anterior surface
O = Object
F = Fovea

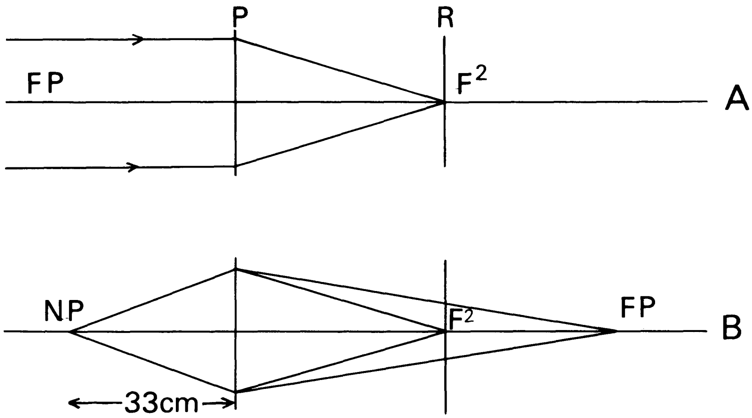
N is the nodal point, C is the centre of the eye's rotation and I is the image from the anterior corneal surface. ONC is the optical axis (OA) of the eye. The visual axis is FN.

The angles K, α and γ are shown and are formed by the optical axis and the line of sight (LS), the visual axis (VA) and the fixation line (FL), respectively.

The angle K is that studied by observing or measuring the point of fixation to the image formed by the cornea. Thus for a large angle K a pseudo-strabismus may be seen. Also large angles may result in the geometric centre of the cornea being at more than 0.75mm from the vision point of the cornea (the visual axis intersection with the cornea). These angles require consideration in the following measurements where fixation is required.

1. Keratometry.
2. Pachometry.
3. Ultrasonography and axial eye length.

ACCOMMODATION

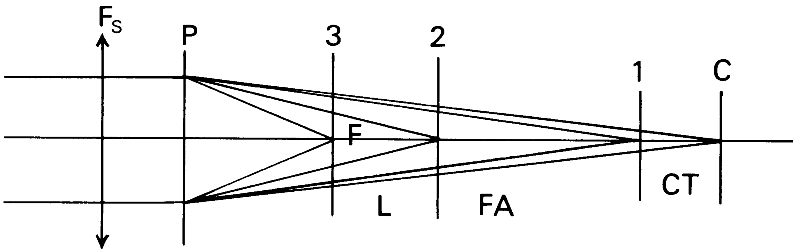


A Emmetropia	=	Unaccommodative eye state with distance fixation (FP = ∞)
B Hypermetropia	=	Accommodated for 33cm
Amplitude of accommodation	=	3 dioptres
Range of accommodation	=	33cm
F^2	=	Second focal point

The crystalline lens when the zonule is relaxed will add dioptric power to the eye. The maximum power it can add is the amplitude of accommodation. In hypermetropia some or all of this power is required to correct distance vision; any remaining power can be used for near fixation (see part B of the figure).

FP = Far point
NP = Near point
Amplitude of accommodation = $F_{FP} - F_{NP}$ (in dioptres)
Range of accommodation = FP-NP (in metres)

When the distance vision is corrected the FP becomes infinity and therefore the near point vergence is equal to the accommodative power.



F_S = Correcting spectacle lens
C = Focal point when cycloplaegiac is used
L = Least spectacle power required to correct acuity
FA = Full accommodative state
CT = Ciliary zone
F = Fovea of eye

Stages in Correction

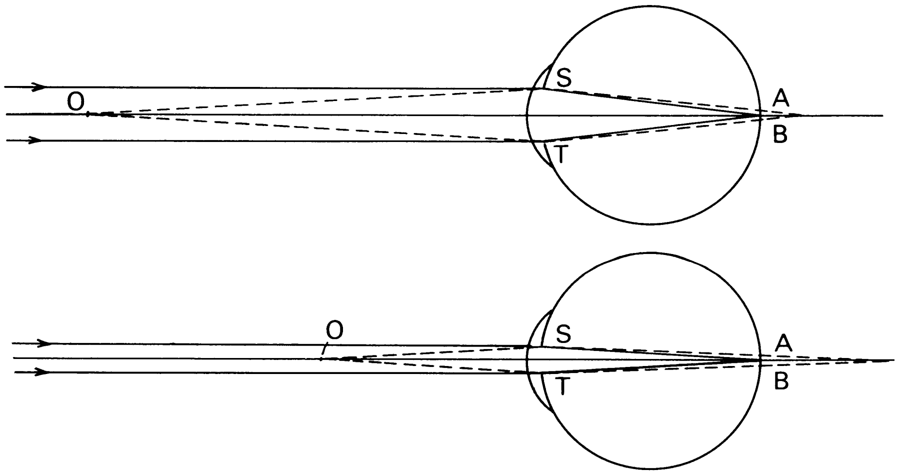
Physiological	to 1 =	Ciliary tone (latent)
	to 2 =	Accommodation (facultative)
by least added spectacle power	to 3 =	Absolute
		Total hypermetropia

The hypermetropic eye attempts to correct its ametropia. The normal ciliary tone is not more than +1.0 dioptres (latent). The accommodation (that is facultative) will correct or reduce the ametropia and in high degrees of error the ametropia will require an additional spectacle lens power (F_S). The facultative and absolute (minimum spectacle lens power) constitute the manifest hypermetropia. The manifest and the latent (found only after use of a cycloplaegic, e.g. cyclopentolate 1%) add up to the total hypermetropia. Therefore, the difference between the minimum and maximum spectacle correction giving the best acuity will be a measure of the facultative accommodation. A full correction of the manifest hypermetropia will allow the maximum accommodation to be used for near vision. This is necessary in the treatment of esophoria and tropia, but is otherwise rarely used.

The normal presbyope must be assessed as a binocular individual; the range and detail required for work are important factors.

It is usual after deciding the distance correction necessary to allow the presbyope to use two thirds of his remaining accommodative power and correct with spectacle lenses to obtain the near point required. Any phoria present will require a final adjustment in the near prescription. For distances closer than 33cm, prisms may be required. As a general rule the hypermetrope requires a greater near addition than the myope, and likewise esophoria more than exophoria. For example, if latent esophoria exists for near fixation (Maddox rod, Wing test or synoptophore) then prism base-out can be incorporated with the near addition.

DEPTH OF FOCUS



O = Object
AB = Blur circle on retina
ST = Pupil diameter

A distant source of light will form a point focus on the retina. Suppose one cone is stimulated. If the light source approaches the eye the image will form behind the retina and the retina will be stimulated by light patch AB. If light patch AB equals the area of the retinal cone then the distance source will still appear in focus. There is therefore a depth of field for any given object. The object can be moved without affecting the clarity of the image. This assumes that the dioptric power and the pupillary aperture remain constant.

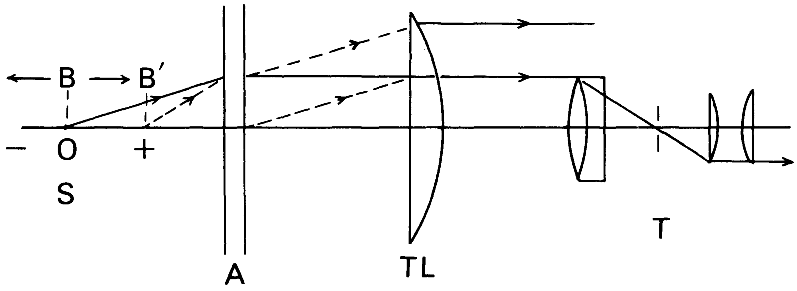
Alternatively, if the pupillary aperture ST becomes smaller the light patch AB will remain the same size although the object O is now nearer to the eye. A small aperture pupil will therefore give a greater depth of focus (but if the aperture becomes too small the retinal image is degraded by the diffraction effect (see pages 28 and 40)).

Therefore the depth of focus and field give the eye a range over which accommodation can lag — the paretic pupil is therefore a disadvantage to rapid changes of fixation.

SECTION V

Instruments

FOCIMETER TO MEASURE LENS POWER (THE LENSOMETER)

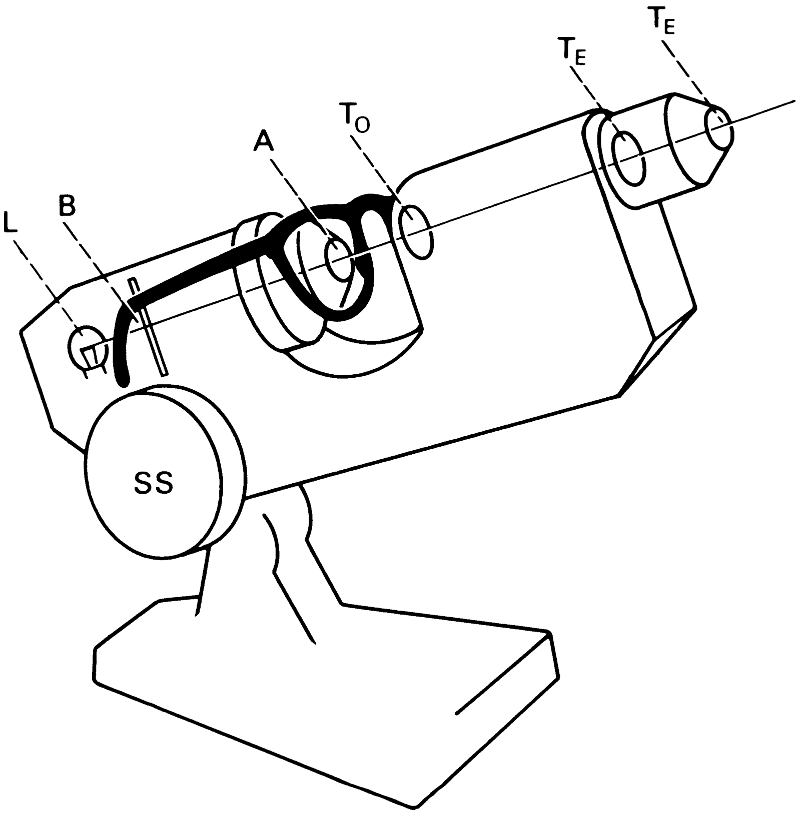


B - B'	=	Movement of target
A	=	Aperture and collimator
T	=	Telescope
S	=	Scale or 'read-out'

The focimeter has a movable illuminated target B. The emerging rays from the standard lens are neutralised by the spectacle lens being tested (the telescope is previously adjusted for the user so as to correct any refractive error of the operator). The target is then clearly seen.

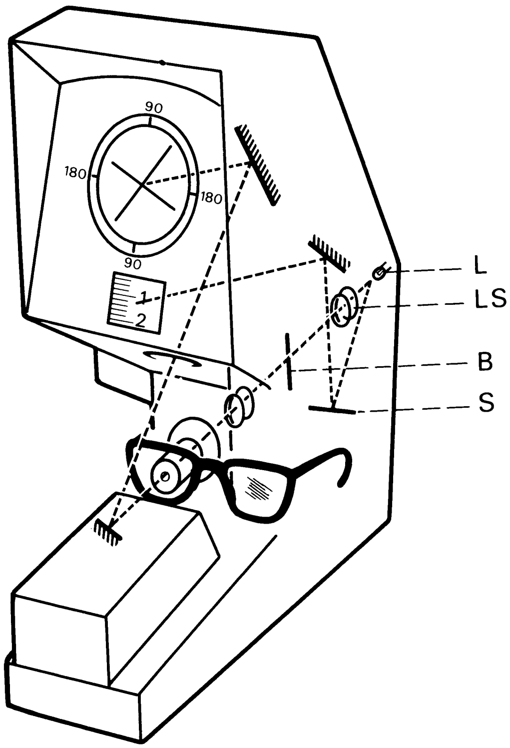
The position of the target B will then be read as the power in dioptres. The instrument can be used to measure astigmatism and prismatic power (if the lens is marked for centres). The spectacle lens is placed with its front surface facing the telescope to measure the back vertex power.

Using this instrument the optical centre of the lens can be found. If the geometric centre is marked and centred in the instrument, prismatic power and base direction can be measured.



A	=	Aperture of collimator
B	=	Target
L	=	Light
SS	=	Screw for changing B
T_O and T_E	=	Telescopic system

The above focimeter can be fitted with an optic-centre ink marker.

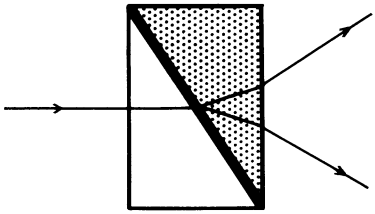


Projection lensometer (focimeter) (Grade Instruments Ltd)

L = Light
LS = Lens systems
B = Target
S = Scale

The above instrument projects the image on to a screen combined with a direct read-out for dioptres and a protractor to give the angle of the principal meridians.

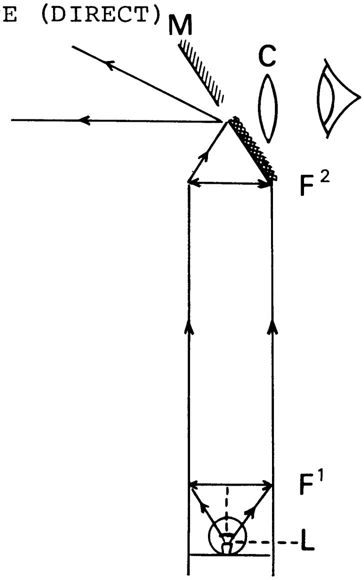
WOOLASTON PRISM USED FOR DOUBLING THE IMAGE



The Woolaston prism can double an image by a fixed amount. It is found in refractometers, keratometers (p.162) and pachometers (p. 157).

The formula for the length of a doubled image is $\ell = aP/100$, where ℓ = length of doubled image, a = distance of image from prism and P = power of prism (prism dioptres).

THE OPHTHALMOSCOPE (DIRECT)

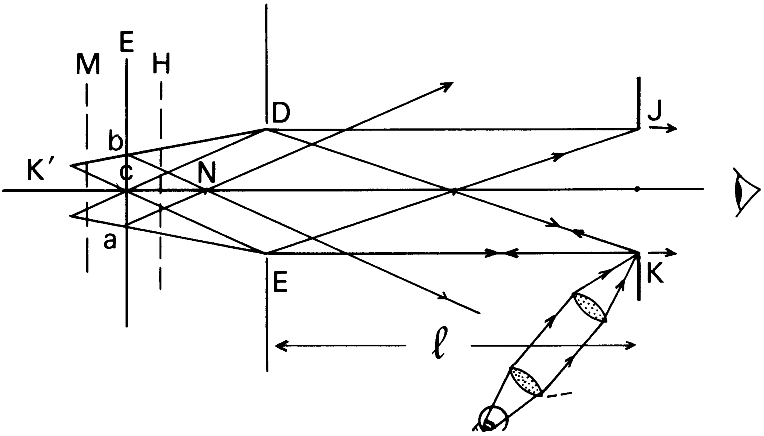


M = Reflecting system with aperture
C = Correcting lens battery
F^2 = Projection lens system
F^1 = Condensing lens system
L = Bulb

Variables are size of aperture, and size of light filament and position

The self-illuminating ophthalmoscope has several optical designs. The important points are: high illumination bulb; pre-centred bulb that does not move during use (when the instrument is shaken); wide aperture lenses; achromatic lenses of good design with stops to reduce aberrations; wide beam of reflected light from prism or mirror; and centre image of bulb filament below aperture with little diffraction of light. The corneal image of the reflected bulb image should be small and not in the visual pathway.

THE OPHTHALMOSCOPY OF THE EMMETROPIC EYE



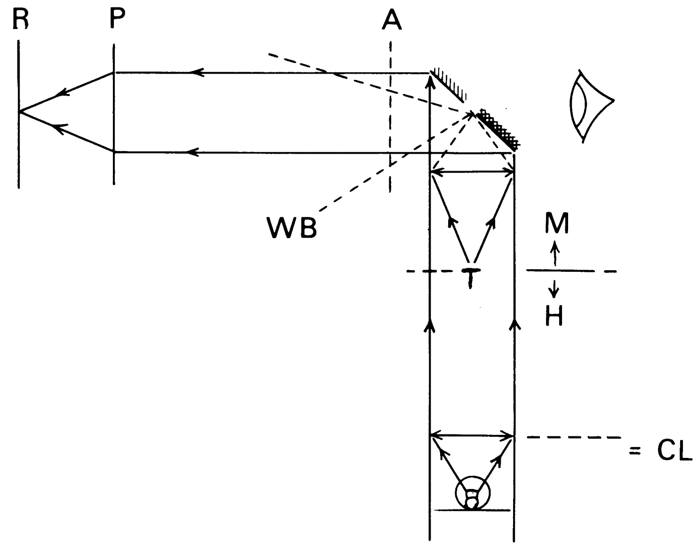
JK	=	Aperture in mirror
ℓ	=	Distance from mirror to patient's eye
DE	=	Pupil
N	=	Nodal point
H	=	Hypermetropic retina
E	=	Emmetropic retina
M	=	Myopic retina
bc and ca	=	Illumination areas
K'	=	Image of K

The self-illuminated direct ophthalmoscope forms a real image of the bulb at K and the reflected rays pass through the patient's pupil DE. The rays converge to form an image K' behind the retina. The area bc on the retina is brightly illuminated. The rays from J illuminate ca if an aperture mirror is used.

The rays of light emanating from ba will pass through the pupil DE and through the aperture JK. This determines the field of view which is usually 6.5°. In peripheral areas of the retina the inferior field of illumination is noted to be dark (ca). By internal reflection the equatorial region of the crystalline lens will also reduce the illumination of the retina by a dark band peripheral to the equator.

DIRECT OPHTHALMOSCOPY

Use as Visuscope and Optometer

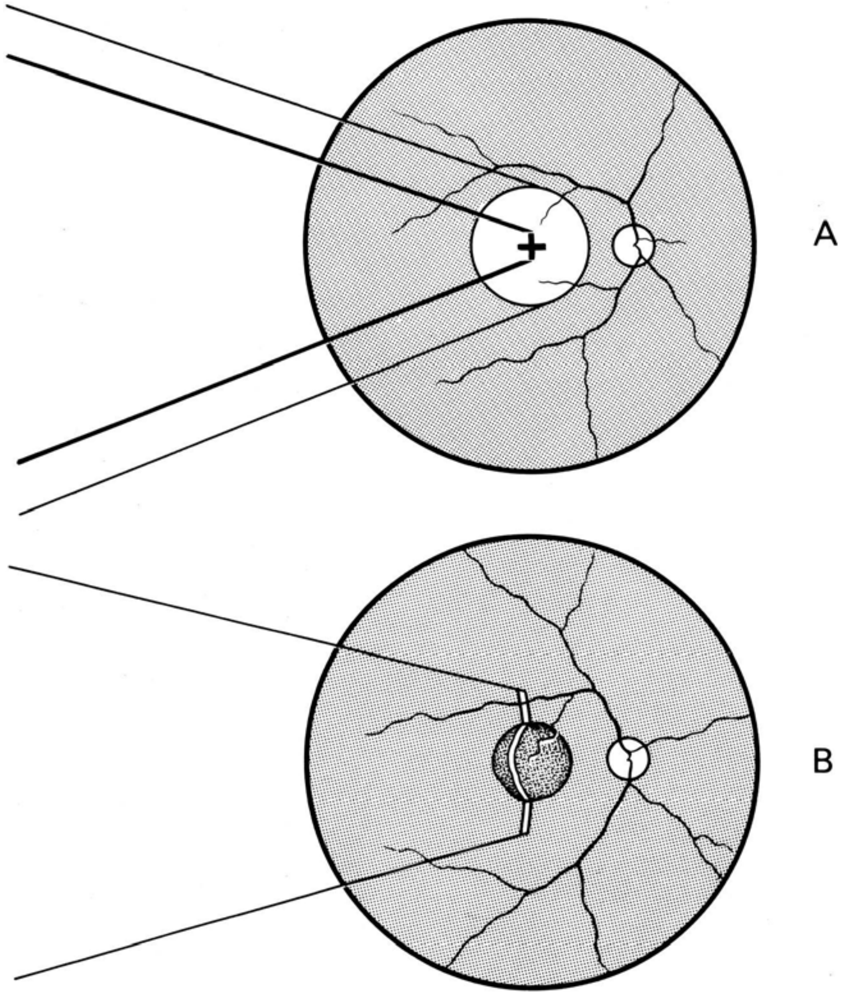


CL = Condensing lens
T = Target
M to H = Movement of target for measurement of myopia and hypermetropia
WB = Wide beam
A = Plane for ophthalmoscope lenses to correct retinal image
P = Plane of eye
R = Retina

The use of a target (i.e. graticule) at T provides a method of measuring ametropia. The fundus is viewed and T is moved until a clear image is projected on to the fundus. This method has been used in the design of the visuscope. Movement to M and H is made to produce clear images on the retina for myopia and hypermetropia.

If T is fixed in position, then the correcting lenses can be placed alternatively in plane A. It will then serve a double function: to project the target and also allow the fundus to be seen clearly. A wide beam (WB) system is used.

Use for Fixation Location and Slit Beam



A = Pleoptoscope target projected into macula
B = Slit beam of ophthalmoscope projected into retina to show elevated macular lesion

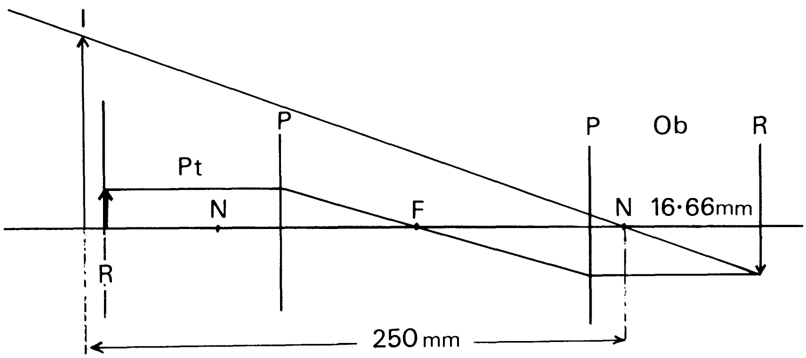
Pleoptoscope

Projection of an image on to the retina or macular area for diagnostic purposes (visuscope) or treatment (pleoptoscope). (See the upper diagram on p. 137).

Slit-Beam Projection

To estimate the elevations of the fundus, e.g. the optic nerve and the macular oedema. (See the lower diagram on p. 137.)

Optical Magnification in Emmetropia



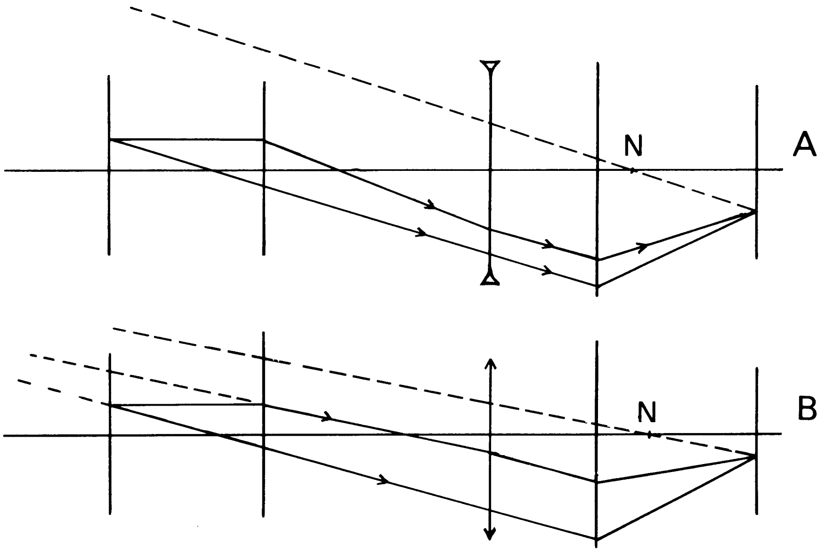
$$\text{Mag.} = \frac{250}{16 \cdot 66} = \times\ 15 \text{ (approx.)}$$

Pt = Patient
Ob = Observer
I = Virtual magnified image

This diagram assumes that the anterior focal points of the subject and examiner are in the same plane F. The subject and examiner are both emmetropic. The examiner projects the image (at 25cm). The magnification is approximately x15.

N.B. This magnification is related to the observer's retinal image size and not the object size at 250mm (see p. 77). The observer's refraction must therefore be considered.

Magnification in Myopia

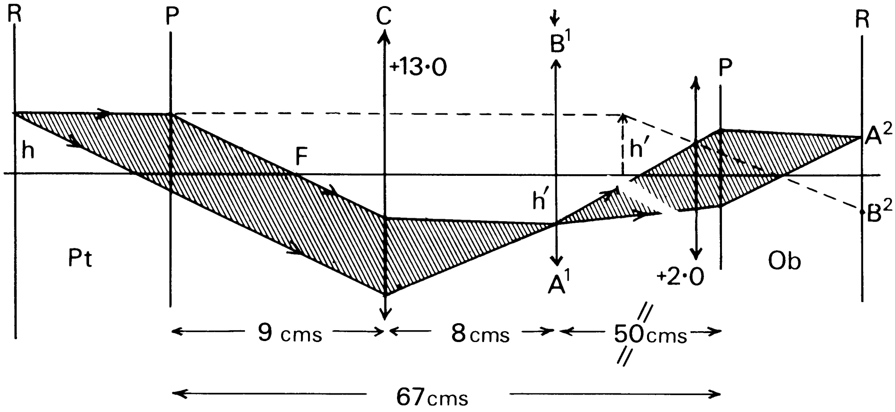


– – – – = Virtual image rays

The emerging rays from the illuminated chorio-retina of the myope (diagram A) are convergent. The correcting lens of the ophthalmoscope neutralises the vergence; the parallel rays subtend an angle to the examiner's nodal point which determines the image size. The retinal image formed in the near fixation plane is larger than that in emmetropia.

In hypermetropia (diagram B) the rays leaving the eye are divergent. The image projected by the examiner is smaller than in emmetropia. A line drawn from the virtual image formed by the divergent rays to the optical centre of the correcting lens (ophthalmoscope) will determine the angle eventually subtended to the examiner's nodal point and thus the image size. Thus in aphakia the retinal image seen by the examiner is smaller than that of emmetropia.

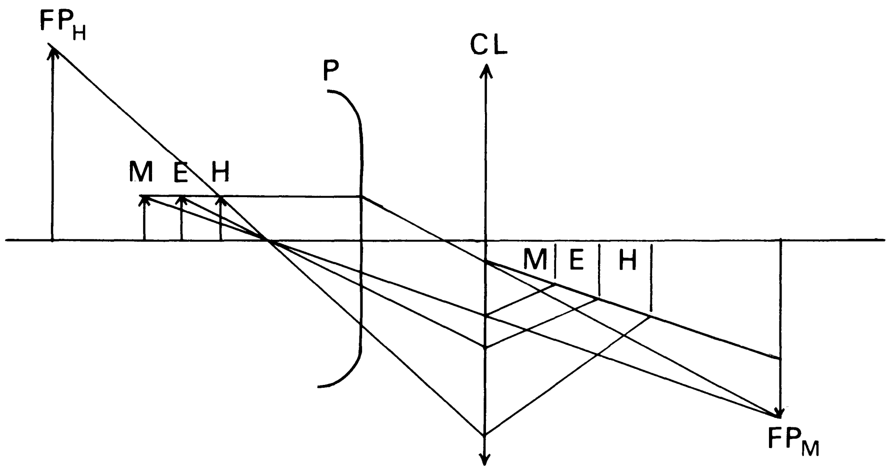
The Observation System and Magnfication



Pt = Patient
Ob = Observer

$$\text{Magnification} = \frac{h'}{25} \times \frac{67}{h} = \frac{67}{25} = 2.68$$

The illuminated chorio-retina is the source of light rays from the eye. They leave the eye as parallel rays in emmetropia. The condenser lens C forms a real inverted image of the fundus in space (B^1A^1). A +2 dioptre lens in the mirror aperture or accommodation of the examiner allows the image to be focussed by the examiner. The magnification by this method is approximately x3. It is determined by the ratio of the angle the image and the object subtend at the observer's eye. The image h' distance is at the near point of clear vision (25cm). Condensing lenses are usually +13.0 dioptres. The peripheral fundus is best examined by this method and a larger field of view is obtained. The smaller magnification allows the highly myopic fundus to be examined. Remember that the pupillary plane of the subject's eye, the condensing lens and the concave mirror (F = 25cm) should be conjugate (i.e. object, lens and image positions).

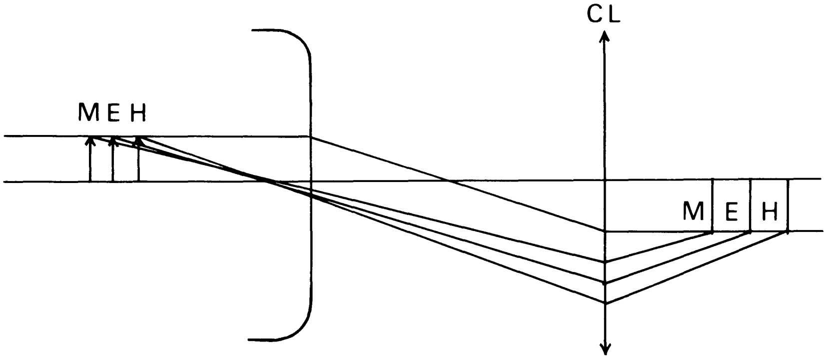


P	=	Plane of eye
CL	=	Condensing lens
M, E and H	=	Positions of image in myopia, emmetropia and hypermetropia
FP_M	=	Far point of eye for myopia
FP_H	=	Far point of eye for hypermetropia

The movement of the condensing lens away from the eye will result in the hypermetropic image becoming smaller and the myopic image larger.

The condensing lens near to the eye

The diagram below shows how the images change size as the lens is moved away from the eye.

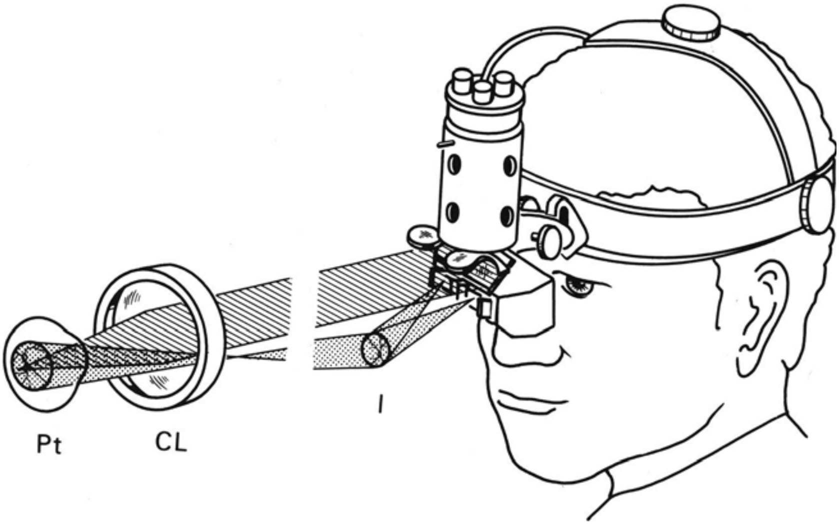


Key as for Previous Diagram

The condensing lens moved away from the eye

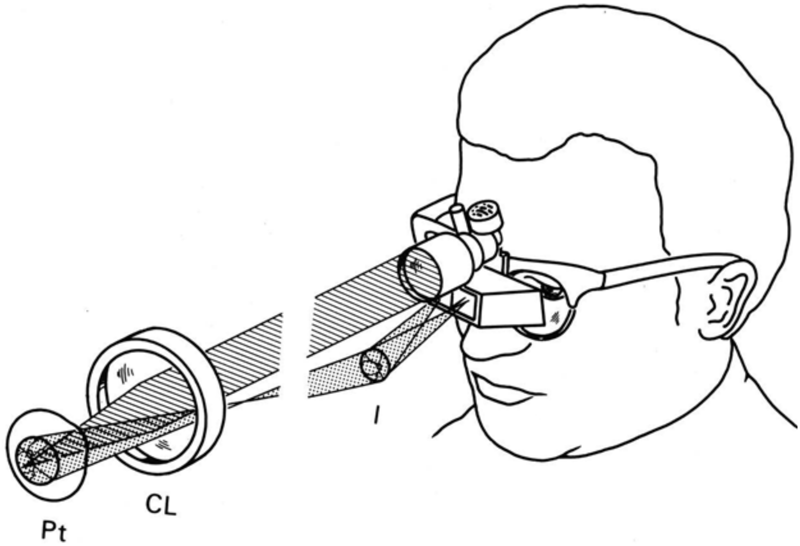
The hypermetropic image of the retina becomes larger, and if the eye is myopic it will become smaller.

Self-Illuminated Binocular Instrument



Pt = Patient's eye
CL = Condensing lens
I = Inverted real image of retina

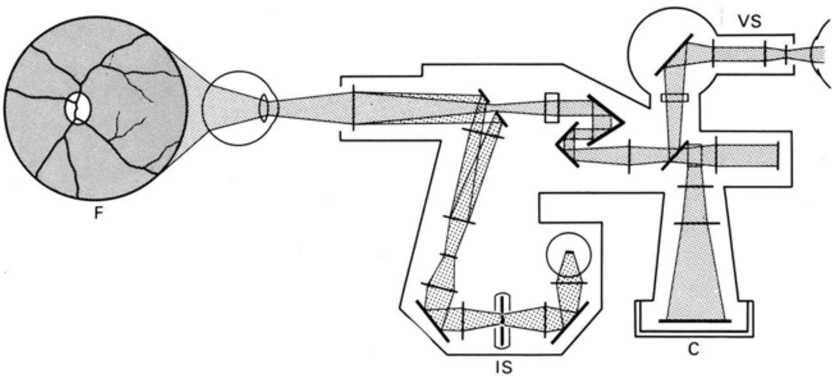
The binocular indirect opthalmoscope uses the classical method of forming a real erect image between the observer and the condensing lens. Binocular vision is used with the aid of prisms and the illumination is mounted on the head.



Key as Previous Diagram

A spectacle-mounted instrument (after Crock).

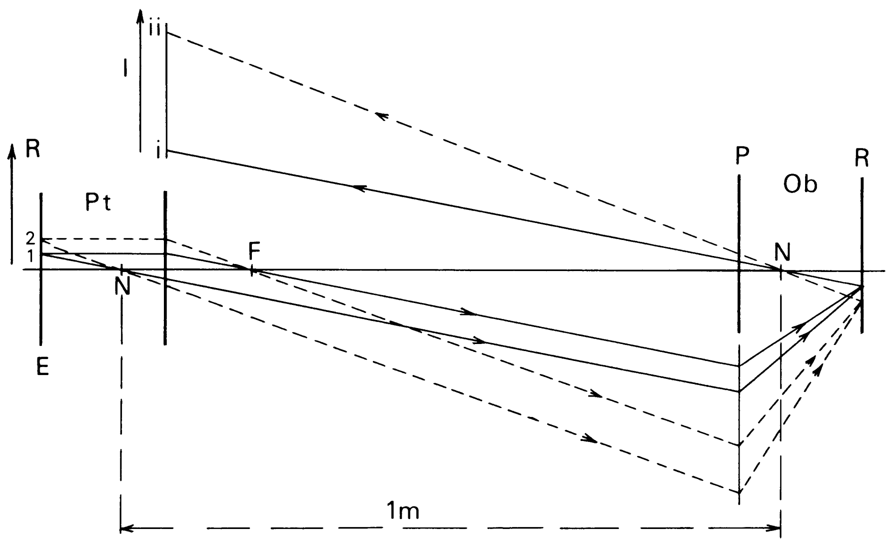
FUNDUS CAMERA



VS = Viewing system
C = Camera
IS = Illuminating system
F = Solid angle of approximately 40°

The system is divided into two for illumination and observation, the latter being reflected to a camera. One level of illumination is used for observations, but flash is used for photography (after Nikkon).

Retinoscopy



Note: Illumination and mirror not shown

N	=	Nodal points of the eye
F	=	Anterior focal point of patient
Ob	=	Observer
I	=	Plane of projected image by observer
1 and 2	=	Illumination areas on chorio-retina moving from 1 to 2 by illumination system
i and ii	=	Projection of image and direction of movement as seen by observer
E	=	Emmetropia
R	=	Movement direction of light on retina

In retinoscopy the chorio-retina is illuminated. The area of illumination moves as the mirror is rotated. The light leaving the eye is divergent in hypermetropia and convergent in myopia, and of no vergence in emmetropia. The examiner is fixating the plane of the patient's pupil. It is usual for the nodal plane of the examiner and the patient to be 1m apart. The examiner notes the direction of light movement in the patient's pupil and its velocity.

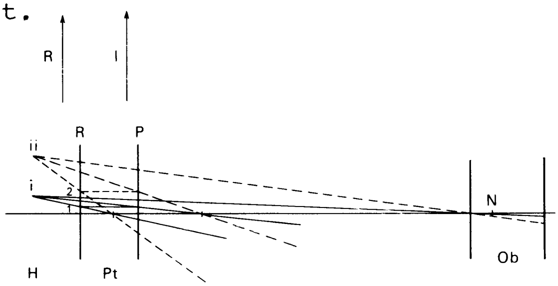
The direction of light movement will be the rotation of the mirror when the vergence from the patient's eye has a focus in a plane other than between the principal planes of the patient and examiner (that is in all cases of hypermetropia and myopia of less than -1.0 dioptres). The light movement will be opposite (against) the mirror rotation when the vergence of light from the patient's eye forms a focus between the two principal planes (that is in any case of myopia greater than -1.0 dioptres).

The velocity of light movement will be most rapid in low refractive errors (that is as the vergence of light leaving the patient's eye forms a focus nearer to the nodal plane of the examiner).

The light movement will only indicate the refraction in the meridian chosen. Broad beams of light will show a scissor movement in high astigmatism due to the different velocities and often opposite directions of movement of the emerging rays (due to the different powers along the co-ordinates of the axis of mirror rotation).

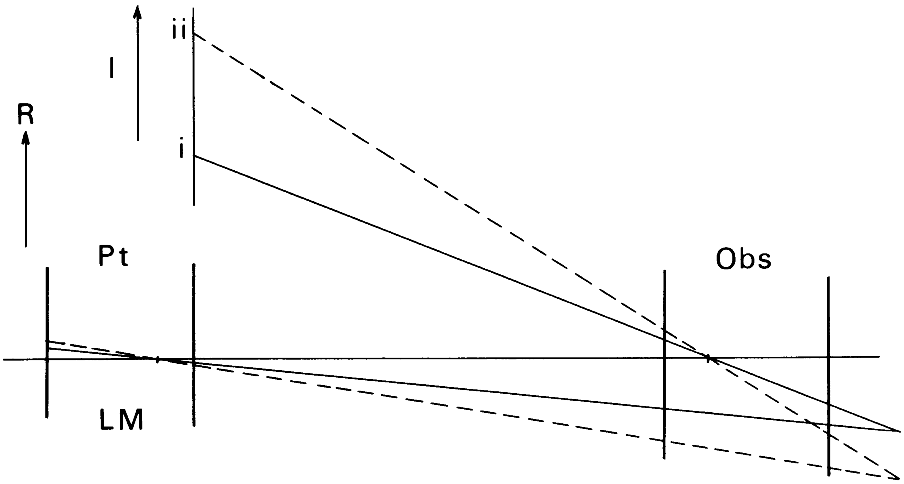
The end-point or point of reversal is when the patient's refraction has been made -1.0 dioptres of ametropia (by adding trial lenses). The vergence of the emerging rays will have a focal plane in the nodal plane of the examiner's eye. In this state the emerging rays from the patient cannot subtend an angle to the examiner's retina. The rays emanating from 3 will stimulate the examiner's retina but not those from 1 and 2. Thus the mirror rotation will only produce a 'light on' effect but no light movement.

The following diagrams illustrate the movement of the projected image by the examiner into the plane of the patient's pupil. The light patches 1 and 2 should be traced from the subject to the examiner and then to the subject.



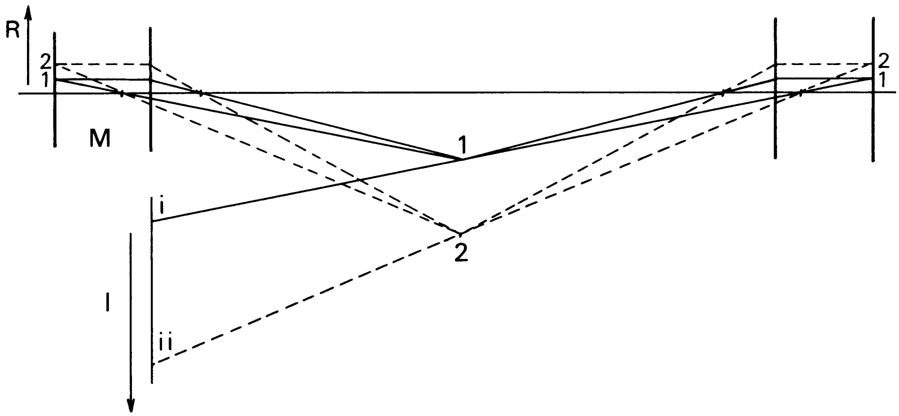
Key as Previous Diagram

In Hyperopia



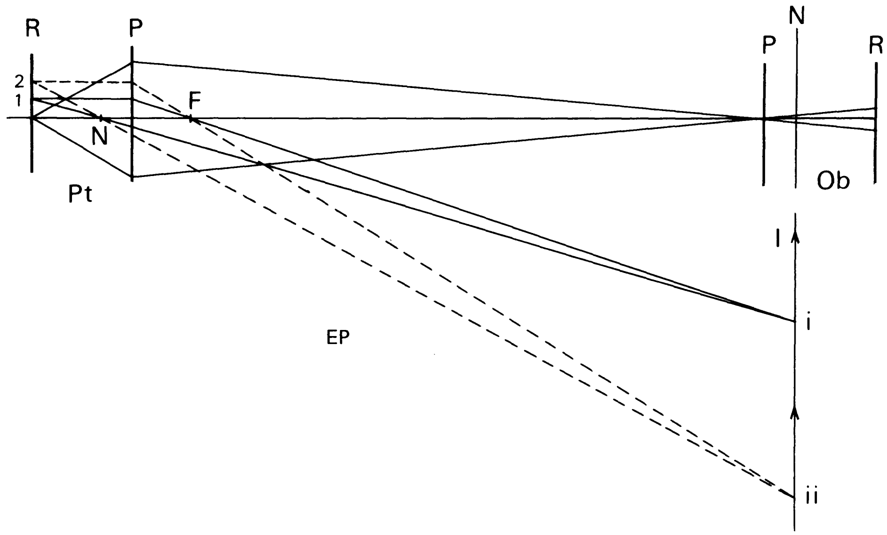
Symbols as for diagram on p. 144, but:
LM = Low myopia (under -1.0 dioptres) with far point behind observer's eye

Myopia (Less than -1.0 Dioptres)



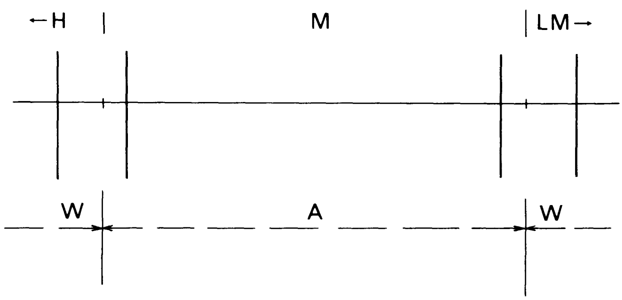
Symbols as for diagram on p.144 , but:
M = Myopia over -1.0 dioptres with far point between observer and patient's eye

Myopia (Greater than -1.0 Dioptres)



EP = End point or point of neutralisation when image of retina is projected on to observer's nodal plane. The correcting lens (not shown) in front of the patient's eye has now produced a state of -1.0 dioptres myopia. Therefore the subjective test and result must add -1.0 dioptres

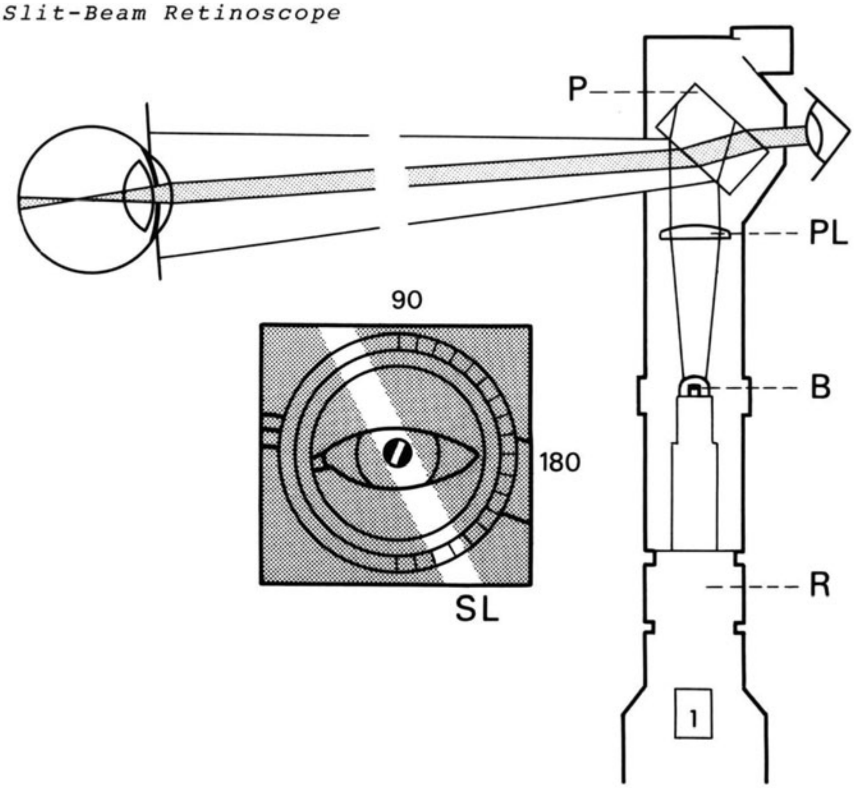
End Point (Ametropia of -1.0 Dioptres)



LM = Width (W), -1.00 to 0 dioptres
M = Against (A), over -1.00 dioptres myopia
H = Width (W), hypermetropic

Summary of Light Movement

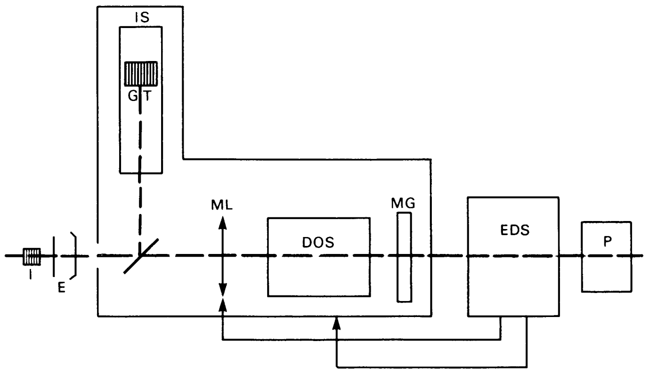
Slit-Beam Retinoscope



The bulb can be moved into two positions, either the broad convergence beam forming a light object in front of the eye or a divergent beam of normal (plane mirror) retinoscopy. The beam can be narrowed to permit greater accuracy in the principal meridians.

Automated Instrumentation

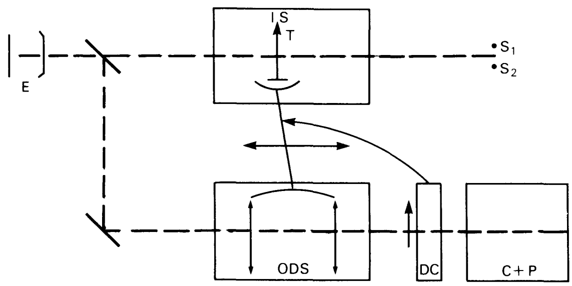
The Dioptron (Automatic Refraction System)



IS = Illuminating system (infra red)
GT = Grid target
I = Image of grid target
ML = Movable lens
DOS = Detection optical system
MG = Masking grid
EDS = Electronic detection system
P = Printing

Method
The target grid is projected on to the retina. When the image is in focus on the retina this is detected by the DOS because the emitted rays match the masking grid resulting in a maximal output signal.

When the source is not in focus the EDS moves the lens ML until focus is obtained. When sufficient data are obtained the machine rotates into six positions and repeats the recordings. The computer calculates and prints-out the refraction in standard notation.

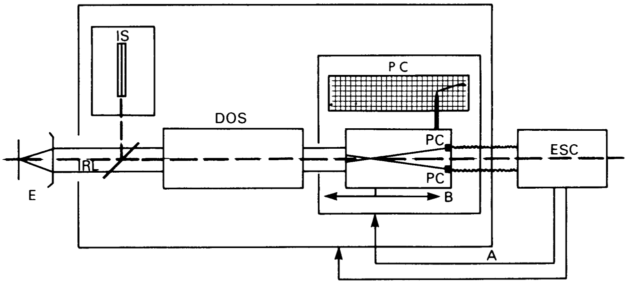


IS	=	Illumination system (infra red)
T	=	Target
S_1 and S_2	=	Source
ODS	=	Optical detection system
DC	=	Detection cells
C + P	=	Computer printing
E	=	Eye

Method

The target T is projected on to the retina, and the emitted light from the eye into the optical detection system and then the photo-sensitive cells. When the target is in focus on the retina the alternating stimulus from source S_1 and S_2 does not alter the signal produced by the detection cells. If out of focus, the detection system commands the lenses (ODS) and target to move until focus is obtained.

This automatic process is repeated in three meridians and the computer-printer gives the result in standard notation.

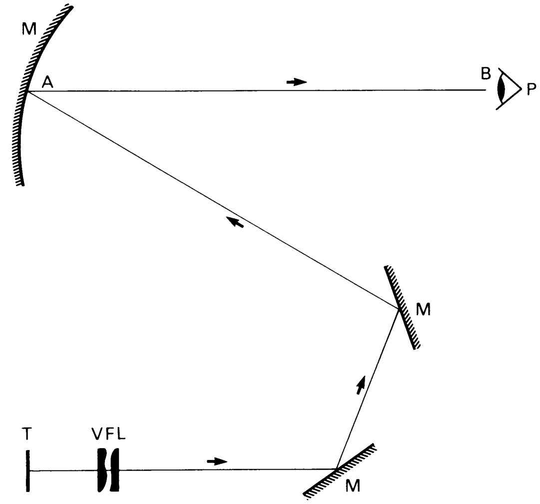


IS = Illumination system (infra red)
IRL = Infra-red light
E = Patient's eye
DOS = Detection optical system
PC = Photo-electric cells
ESC = Electronic servo control
A = Displacement carriage (for automatic focussing)
B = Rotating mechanism to record through 180°

Method
Infra-red light falls on to the retina, and the emitted rays are focussed by the detection optical system on to the photo-electric cells which record when an equal stimulus is obtained from each cell. The electronic servo-control system displaces the carriage A until equal stimulus occurs and recording commences.

The carriage B rotates to give readings over 180° rotation.

HUMPHREY'S SUBJECTIVE REFRACTOMETER



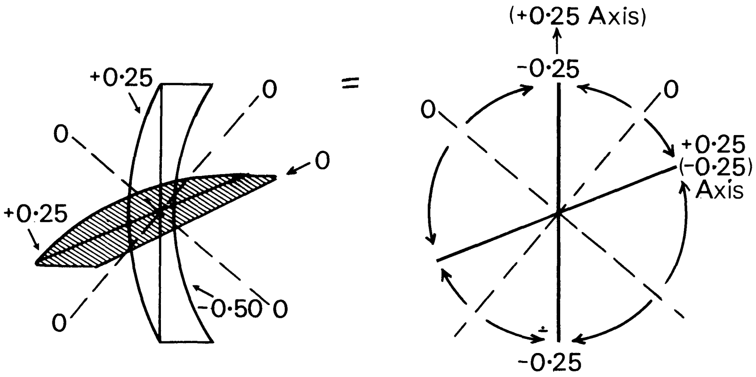
T = Target
VFL = Variable focus lenses
P = Patient's eye
M = Mirrors
AB = Radius of mirror

Instead of a trial spectacle lens a variable-focus lens system which produces convergent or divergent light from a target (T) to the patient's eye is used. The system is referred to as a *phantom lens*.

The astigmatism is corrected by the patient viewing an oblique and vertical line, and the movement of the variable-focus lenses produces a power change in the X and Y co-ordinates. The results are computerised to give the best spherical and cylindrical combination and the equivalent axis.

Objective refractors have already been described (see p. 149-151) and their accuracy depends upon clear media, relaxed accommodation and no distortion of refraction surfaces. The objective refraction using automated instruments can, in many instances, give either no results at all, or else results that are misleading. This is especially true for patients who have abnormal lesions of the cornea and crystalline lens. Therefore the Humphrey system is particularly useful in eyes likely to give no result with infra-red autorefraction.

Jackson's Cross-Cylinder



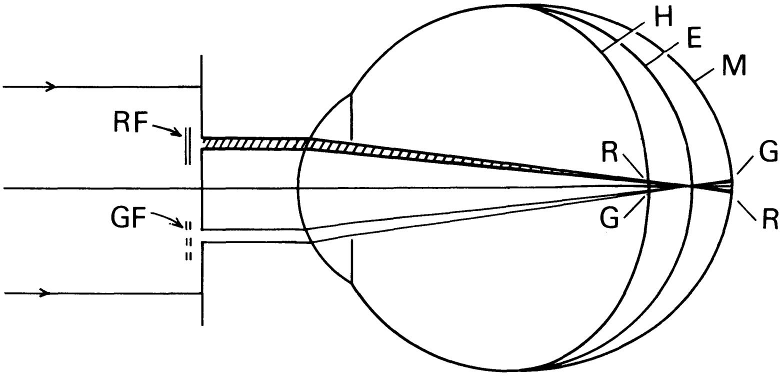
— — — = Axis of cylinders
———— = Power distribution

The Jackson's cross-cylinder is used to measure axis direction accurately, to add or subtract cylindrical power.

The cross-cylinder is formed by a lens with a spherical power on the one side, and a cylinder of double that power (but of opposite sign) on the other side, of the lens. This gives equal and opposite cylindrical powers at 90° with an intermediate neutral axis. The neutral axis of the cross-cylinder is placed along the axis of the trial lens cylinder and the preferred position indicates whether the trial cylinder should be rotated towards the negative or positive area of the cross-cylinder. (Movement of a negative trial lens cylinder is towards the negative area of the cross-cylinder, and vice versa for positive.)

Cross-cylinders are available from 0.25 to 1.5 dioptres. Note that the placing of a cross-cylinder in an axis of power will also alter the power in the opposite axis. Lower power cross-cylinders are mostly used to decide axis direction within 5° accuracy and power to 0.25 dioptres.

The Pin-Hole and the Scheiner Disc



RF	= Red filter over stenopaeic (pin-hole)
GF	= Green filter over stenopaeic (pin-hole)
R	= Red blur circle
G	= Green blur circle
H, E and M	= Hypermetropia, emmetropia and myopia

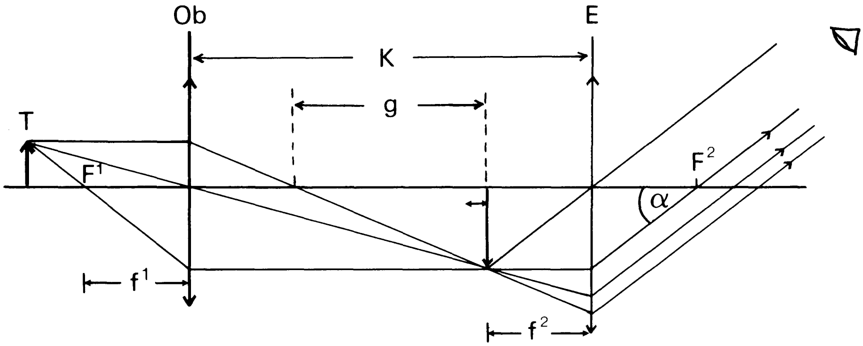
In principle, a 1mm hole forms a narrow beam or pencil of light. Even in high degrees of ametropia the narrow pencil of light will be refracted as a ray of light. The single stenopaeic aperture, if centrally placed, will form blur circles of light which are smaller than those formed by the ametropic eye. The image will appear clear and defined but of reduced illumination. Corneal opacities which are the cause of visual loss by diffraction of light can be avoided by placing the pin-holes over a clear portion of cornea.

Scheiner's disc has two small holes. The distance between the holes must not exceed the diameter of the pupil. The pencil of light is refracted by the eye as peripheral rays; in emmetropia these will form a focus at the fovea, but in myopia and hypermetropia they will form two images. The position of the projected images in space (identified by different colours) will determine whether the patient is myopic or hypermetropic. Correcting lenses can be placed in front of the disc until only one fused image occurs.

This is therefore a simple optometer.

The principle can be used in automatic refraction instruments. It is commonly used as a focussing device.

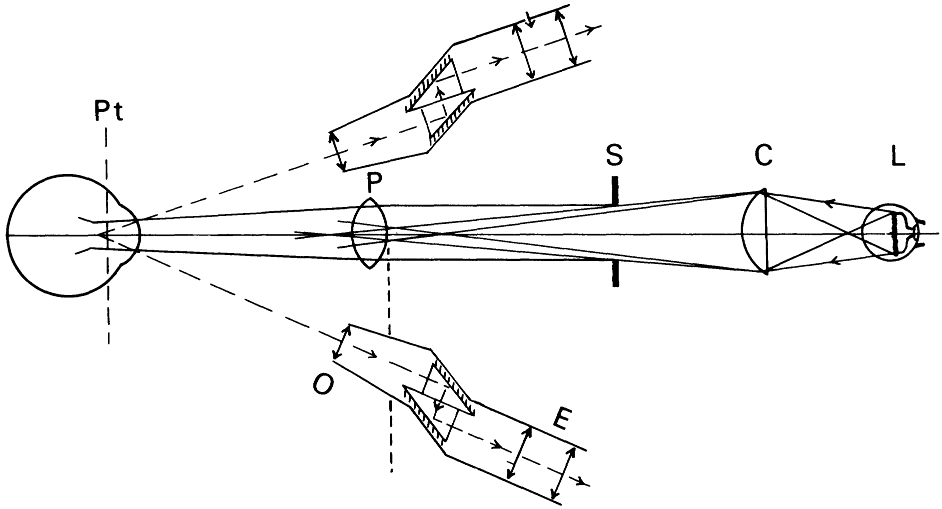
COMPOUND MICROSCOPE



T = Object being examined
F^1 = Anterior focal point of objective-lens system
Ob = Objective-lens system
g = Tube length (between focal points)
K = Distance between lens systems
E = Eye-piece system
F^2 = Second focal point of eye-piece
α = Angle of virtual image to eye

The compound microscope consists of an objective-lens system and an eye-piece lens system. The object is placed outside the anterior focal point of the objective lens and an image is formed in the plane of the anterior focal point of the eye-piece lens. The emerging rays subtend an angle to the near point of distinct vision.

The magnification is determined by the power of the objective and the tube length $\frac{g}{f1}$, and by the magnification of the eye-piece, $\frac{250}{f^2}$ (see the simple loupe p. 77). Thus $M = \frac{-g}{f^1} \times \frac{250}{f^2}$

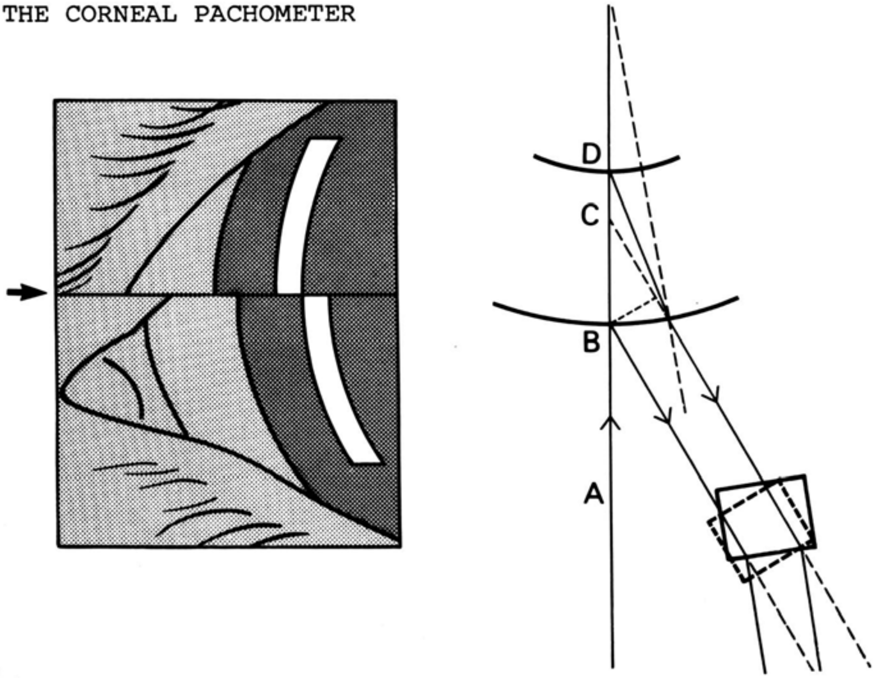


Pt	=	Patient's eye
O and E	=	Objective and eye-piece systems of binocular microscope
O	=	Anterior focal length of 65mm
E	=	x10 mag
S	=	Slit aperture
C	=	Condensing lens
L	=	Lamp with special filament
P	=	Projecting lens (for projecting the slit)

The illumination system shown has a condensing lens, slit and projecting lens. The light from the condensing lens forms a focus on the back vertex of the projecting lens. Therefore the lamp's filament does not form a real image in the eye. The slit aperture (object), the projecting lens and the slit (image) illumination are conjugate points. The magnifying systems are familiar low-power microscopes with prisms to reduce the tube length. Magnifications of x10, x16 and x40 are used (x100 is used for endothelial microscopes). In modern instruments low-power objectives are used combined with high-power eye-pieces.

The operating microscope is very similar. It has, in addition, a co-axial illumination and zoom-lens objectives. In modern instruments movement of the system is co-ordinated to keep the object in focus.

THE CORNEAL PACHOMETER



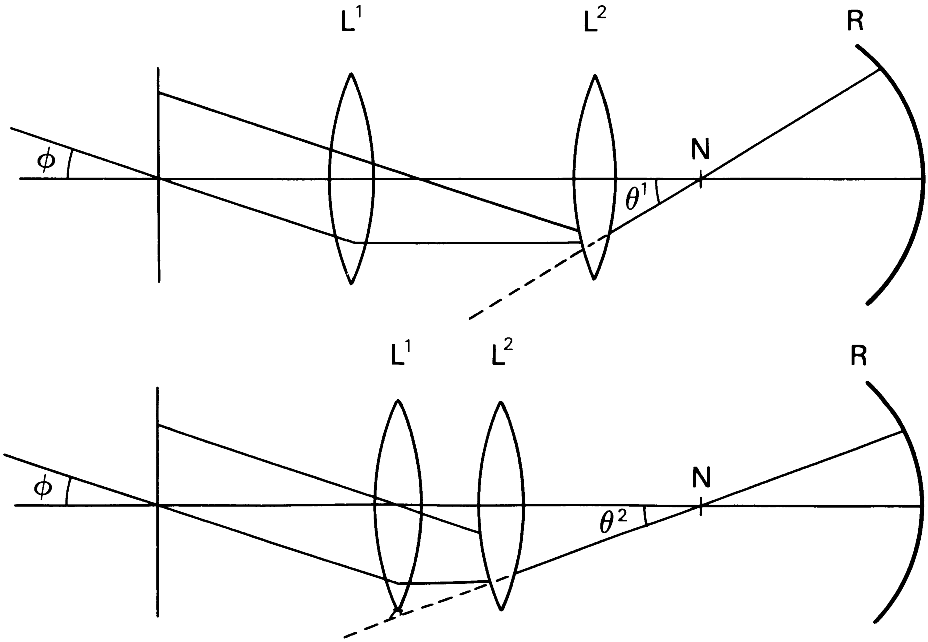
The corneal pachometer is used to measure the thickness of the human cornea *in vivo*. There are several ways of doing this but the method illustrated is the measurement of the apparent thickness of the optical section using the principle of Juillerat and Koby and available as an attachment for the Haag-Streit slit-lamp Model 900.

Light falls perpendicularly on the cornea having passed through a diaphragm at A which reduces the light of the slit-lamp to a smaller pencil. The optical section is now observed at an angle of 40^{o} and its thickness is measured by aligning the anterior and posterior corneal surfaces by means of a rotating plane parallel glass plate covering the lower half of the reflected light. This is aided by a split image eye-piece (not shown in the optical diagram but illustrated in the observer's view on the left). The angle of rotation has a direct relationship to the apparent thickness BC, but to obtain the real thickness BD a value must be assumed for the refractive index of the cornea.

In the Haag-Streit attachment this has been done and the rotatable glass plate is directly connected to a scale calibrated in millimetres. Some writers consider this unjustifiable in cases of corneal oedema where the refractive index of the cornea will have altered, and prefer to use the term 'pachometer units'.

With different glass plate thicknesses the instrument can be used to measure the depth of the anterior chamber (a combined instrument is available).

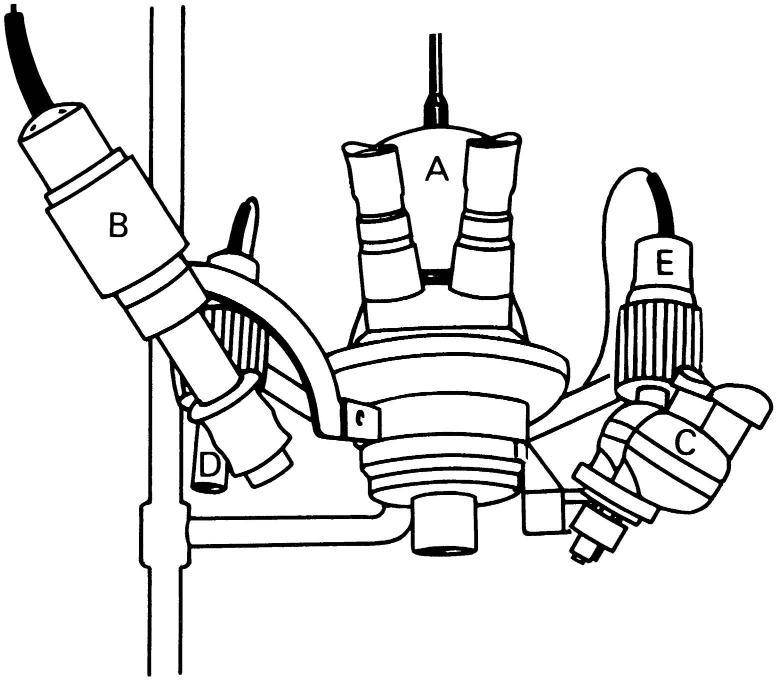
ZOOM-LENS PRINCIPLE



L^1 and L^2 = Objective-lens sytems
Θ^1 and Θ^2 = Angles subtended to observer's eye
ϕ = Angle subtended by object to lens system

By altering the position of the objective-lens system a change of magnification occurs without altering the conjugate points of object and image.

OPERATION MICROSCOPE (ZOOM)



A = Microscope
B = Slit beam
C = Assistant's microscope
D and E = Oblique beams

The microscope must have objective-lens systems that at the highest magnification allow a comfortable sitting and working distance for the surgeon.

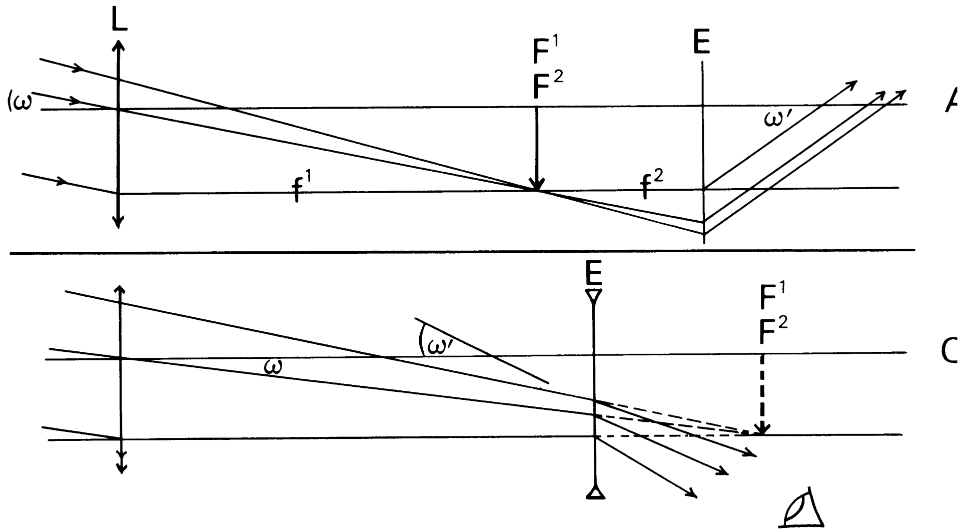
The microscope A can have either fixed magnification, or rotation of lenses to change the magnification. The use of zoom-lens systems (see p. 158) allows rapid change using foot-pedal controls.

The illumination can be co-axial (in the line of the vision axis), which is useful for vitreous and retinal work. The slit beam B and oblique beams D and E are of value for assessing depth and surface work. The slit-beam is useful for lens-capsule and corneal procedures.

Attachments include viewing telescope, assistant's microscope C and those for the camera.

Magnifications vary from x5 to x40. The depth of focus and illumination decrease as the magnification increases. Therefore the instrument should be set for the operator using the highest magnification and then zoomed down to the lowest magnification required to commence the operation. The inter-ocular eye-pieces are set wide and adjusted until binocular vision is comfortably obtained.

TELESCOPES



ω	=	Angle subtended by object to lens
L	=	Objective or field lens
E	=	Eye-piece lens
ω'	=	Magnified angle of image to eye
F^1 and F^2	=	Coincidence of focal points of both eye and objective lenses

Note: The upper diagram shows the astronomical telescope which produces an inverted image. The lower diagram shows the Galilean telescope which produces an erect virtual image.

The simple astronomical telescope (upper diagram) has two lenses (systems) — a field lens and an eye-piece lens. The telescope is afocal. The second focal point of the field lens is in the plane of the first focal length of the eye lens.

The magnification = F^1/F^2. Thus a weak field lens and a strong eye-piece lens will give maximum magnification, but will require a great tube length ($f^1 + f^2$).

The image formed is inverted. This type of telescope is used in instruments and for astronomy. The principle is not used for visual aids.

The Galilean system (lower diagram) has a negative eye-piece with its first focal point in the plane of the second focal point of the field lens. The image formed is virtual and erect.

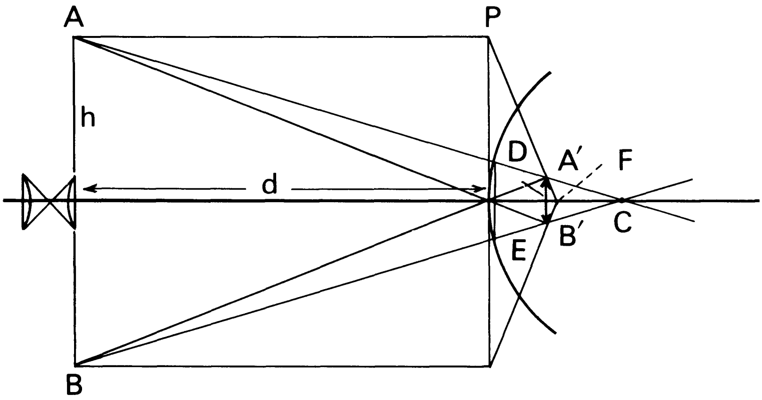
This system is used in visual aids. The limiting factors are

1. Apertures of lenses are small.
2. Tube length is short.
3. High magnifications of x4 and over can only be obtained by using very-high-powered lenses.
4. High-powered lenses are made of plastic and glass, and are of small aperture to avoid aberrations and great weight - but the field view is small, and so is the depth of focus.

The distance R_x (the spectacle prescription) and the telescopic magnification must be given when ordering a visual aid, and whether it is to be used for near or distance work must be specified.

N.B. The simple high positive lens (see simple loupe) can be used as a magnifying aid, $M = \frac{F}{4}$. The distance-vision correction must be taken into account. The reading chart is placed within the anterior focal point of the high-powered lens, and the spherical power is increased until the optimum clinical effect is obtained. High powers must be used, with good illumination. They can be prescribed in half-eye form, and to save weight as micromagnifiers or as contact lenses.

JAVAL SCHIOTZ 'KERATOMETER' (OPHTHALMOMETER)



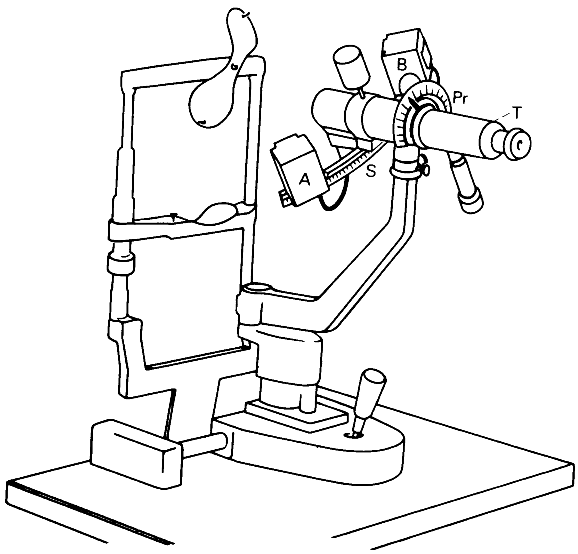
A and B	=	Illuminated targets (mires)
A' and B'	=	Images formed behind cornea (h')
F	=	Focal point of cornea (anterior surface)
C	=	Centre of curvature of cornea
P	=	Plane of cornea

The keratometer measures the radius of curvature r of the anterior corneal surface. It consists of a target h which may be fixed or of variable size AB. The distance of the target from the eye is d. The image is seen with the telescope, and there is a doubling device for alignment of the images and this eliminates the complication of fine eye movements and physiological nystagmus. The variables are h, h' (image) and d. Instruments utilise either a fixed size of target or of image.

$$r = \frac{2dh'}{h}$$

The area of the cornea measured varies with the design of the instrument. An average chord DE of 4mm of cornea is common. Peripheral areas of cornea are difficult to measure, because of image aberrations. The instrument can be used to measure corneal astigmatism. It is very useful in contact-lens practice. The use of micro-mires does allow small chords of cornea to be measured. This is useful in topographical keratometry.

N.B. The classical ophthalmometer gave dioptric readings which took into account the back surface corneal power.

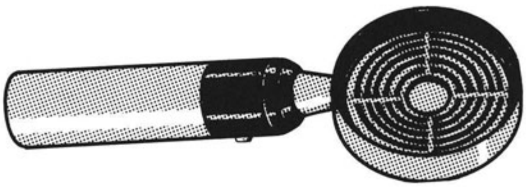


T	=	Telescope for sighting the images of the cornea
A and B	=	Illuminated mires
Pr	=	Protractor for image meridian measurement
S	=	Scale for radius and dioptre measurement of curvature

The stepped illuminated targets (mires) are attached to an arc which is calibrated with readings of corneal dioptric powers or radius of corneal curvature. The corneal images formed by the mires in the two principal meridians are made to align with one another, first by moving the instrument to form clear in-focus images as seen through the telescope, and then by moving the mires away or towards each other. A prism splitter in the tube of the telescope permits alignment, even with eye movement. The B and L ophthalmometer keratometer has fixed circular targets and a variable splitting prism to align the images.

The instruments vary greatly in design (see the P.E.K. below) and all measure over different chords of the cornea, but accuracy can be of the order of ±0.05%. It is less useful for intermediate cornea surface measurements unless topographical methods are used.

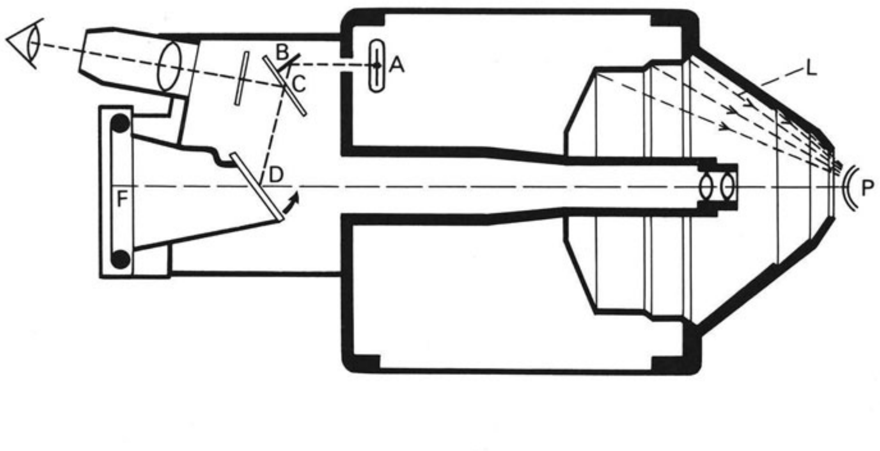
PLACIDO DISC KERATOSCOPE (KLEIN-KEELER)



The rings are illuminated and the corneal image viewed through the central aperture (usually +2.0 dioptres).

The central aperture can be used for a photographic system.

THE PHOTOKERATOSCOPE (THE WESLEY-JESSEN P.E.K.)



L = Light from target to rings
P = Patient's eye

The photokeratoscope produces a photograph which may be analysed to give the sagittal depth of the cornea at various chord lengths, from which changes in corneal radius may be deduced. As long ago as 1896 Gullstrand built a photokeratoscope using a placido disc-type target; this produces a curved image plane which means that on flat film the peripheral portions of the photograph are inevitably out of focus.

The Wesley-Jessen P.E.K., a simplified diagram of which is illustrated here, is designed to overcome this by using a target of concentric rings arranged to produce an ellipsoidal target surface which produces a flat image plane. Focussing and alignment are aided by light from a small tube source A reflecting from a mirror B through a small hole in another mirror C and reflecting in a third mirror D. When the photograph is taken the mirror A lifts as in a single-lens reflex camera and the film at F is exposed.

The photograph may be analysed to give a great deal of data on corneal topography, and if desired, also to design the posterior surface of a contact lens to fit the cornea and in any given manner. The amount of computation is enormous and only practical with a digital computer.

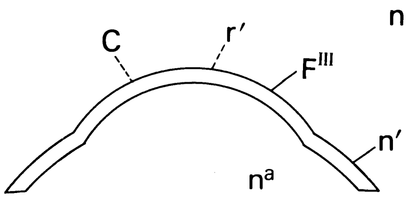
CONTACT LENSES

The fluid between the contact lens and the cornea optically neutralises the converging power of the anterior corneal surface. Corneal astigmatism and superficial irregularities are therefore corrected by this method.

To simplify the optics of the contact lens on the eye the thickness of the contact lens and fluid lens will be ignored. Furthermore, the problem will be that of the contact lens fitted with the same back curvature r'' as the anterior surface of the cornea r'. In practice, lenses fitted with back curves flatter than the cornea will produce a negative fluid lens, and when fitted steeper, a positive fluid lens. These factors are taken into account in contact-lens practice and are not within the scope of this text.

The ocular refraction (spectacle refraction in the plane of the eye - see Effective Power, p. 89) equals the power of the plastic contact lens in air.

The soft lens moulds to the corneal shape by lid pressure and therefore the corneal astigmatism is not corrected unless the lens is of toric form.



C	=	Cornea
CL	=	Contact lens
r'	=	Front central radius of curvature of cornea
r"	=	Back central radius of curvature of contact lens
n	=	Refractive index = 1 (air)
n'	=	Refractive index = 1.37 (for cornea
d	=	Back vertex spectacle distance
F_{SR}	=	Spectacle lens back vertex power
F_{OR}	=	Ocular refraction
n^2	=	Refractive index = 1.50 (plastic of contact lens
F^{I}	=	Front central surface power of contact lens
F^{II}	=	Back central surface power of contact lens on eye
F^{III}	=	Final surface power of cornea
F^{IV}	=	Back central surface power of contact lens in air
n"	=	Refractive index = 1.33 (tear lens)
n^{a}	=	Refractive index = 1.33 (aqueous humor)
F"	=	Power of contact lens posterior surface

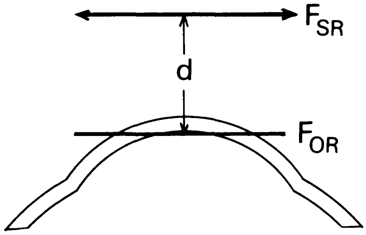
Given that the refractive index of the lens is 1.50, the cornea and tears are 1.33 and air is 1, the power P of the contact lens is as follows

$P = F^{I} + F^{IV}$ (see diagram below)

In this diagram, the power F^{III} of the corneal surface is considered

$$F^{III} = \frac{1 + 1.33 \times 10^3}{r'} = \frac{10^3 D}{3r'} \quad \text{(formula I)}$$

where r' is the radius of curvature of the corneal surface in a principal meridian.



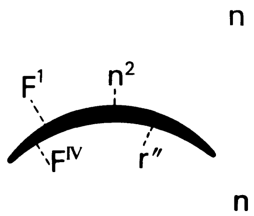
The lens of a hard material will either fit in parallel steeper or flatter than the cornea surface. The 'tear lens' (fluid between the back of the lens and the cornea) has therefore a lens form shape that is either plano, positive or negative. In general, fitting flatter produces a correcting effect for myopia, and steeper a correcting effect for hypermetropia.

If there is an 0.10mm difference in radius of curvature between the cornea and the back of the contact lens, 0.50 dioptres power change is induced.

The diagram explains the simple case of when the fit is parallel (back surface of lens *in situ*)

$$F^{II} = \frac{-1.50 + 1.33 \times 10^3}{r''} = \frac{10^3}{6r'} \quad \text{(formula II)}$$

where r'' = r'.



The power required by the contact lens to correct ametropia can be calculated from the spectacle refraction (at d mm from the cornea). This power is sometimes referred to as the *ocular refraction* (OR). Thus

$$F_{OR} = \frac{F_{SR}}{1-dF_{SR}} \quad \text{(formula III)}$$

If the cornea, tear lens and contact lens are now considered as a complex, it will be related to the spectacle lens correction in the following way

$$F^{III} + F_{OR} = F^{I} - F^{II} \quad \text{(formula IV)}$$

where F_{OR} is the effective power of F_{SR}

$$\therefore \text{ Formula I} + F_{OR} = F^{I} - \text{Formula II}$$

$$\therefore F_{OR} = F^{I} - \frac{10^3}{2r''} \quad \text{(formula V)}$$

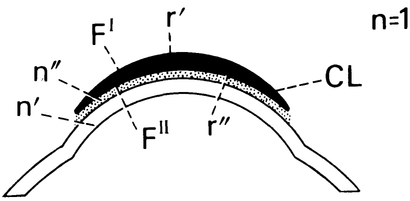
and

$$F^{I} = F_{OR} - \frac{10^3}{2r'} \quad \text{(formula VI)}$$

While formulae V and VI are of theoretical value, they are not used in practice since calculations of contact-lens formulae are based upon the following factors:

1. Spectacle equivalent spherical refraction.) (OR)
2. Back vertex distance.)
3. Back surface design of curvature plus peripheral curve (back central radius).
4. Average keratometry.

From this data a contact-lens power can be calculated.



The diagram shows a positive-powered contact lens where the back surface is of the same radius as the corneal surface. Thus

$$F = F^{I} - F^{IV} \quad \text{(formula VII)}$$

$$F^{VI} = -1 - \frac{1.50 \times 10^3}{r''} = \frac{10^3}{2r'}$$

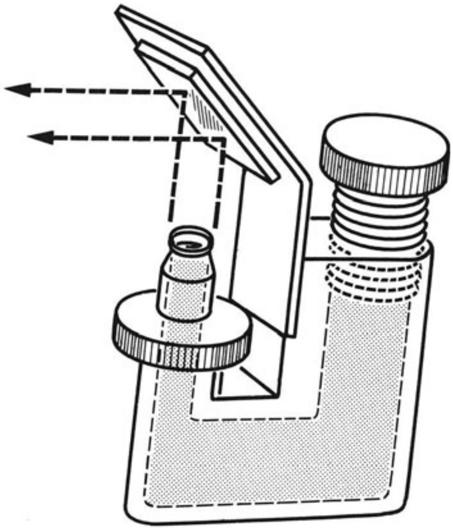
$$\therefore F_{OR} = F^{I} - F^{VI} = F \quad \text{(see formula VI)}$$

where $F^{IV} = 10^3/2r'$.

In soft-lens formulation the tear lens can be ignored except in special cases (see Ruben, M., *Soft Lens*, Wiley, 1978).

Measurement of Back Curves of Contact Lens

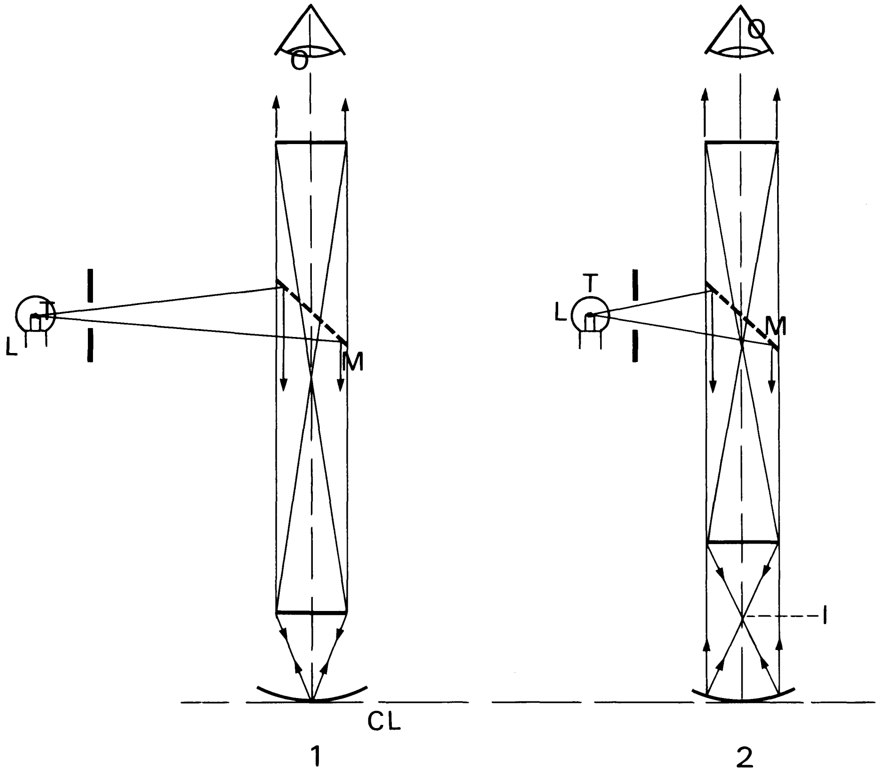
'Con-Ta-Check' attachment to keratometer



The mirror reflects the keratometer mires (target) into the instrument system. The back surface of the contact-lens image reflection is reduced by contact with water.

N.B. The keratometer (p. 162-163) is usually calibrated for convex surfaces and therefore a conversion table for concave surface measurements is necessary.

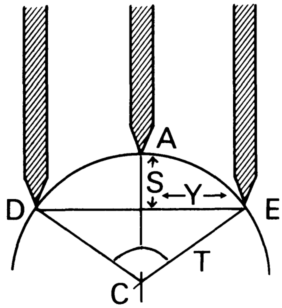
THE RADIUSCOPE (Using Drysdale's Principle)



L = Light
M = Mirror
T = Target
CL = Contact lens
1 = First position of image
2 = Second position of image formed at centre of curvature
0 = Observer

The first portion is such that the image of the target T is joined at the centre of the mirror and the rays are returned along the same pathway. At position 2 the rays are also returned in the same way since the image I is at the centre of curvature of the mirror. Twice the radius equals the focal length of the concave surface and the objective is now at the focal plane of the surface. Reflections from the front surface can be reduced by placing water beneath the lens. A dual guage reads the movement of the objective and expresses the resulting radius of curvature in millimetres. The instrument can also give readings to the front surface of the lens (dimmer image). The difference between these readings gives the lens thickness.

SAGITTA



DAE = Feet of lens measure
S = Sagitta
Y = Semi-aperture
T = Radius
C = Centre of curvature

The regular curve from D to E is an arc A and chord OE. This is related to the angle (a). Curvature can be expressed in relation to radius.

$$C = \frac{1}{r} = R$$

where r is expressed in metres.

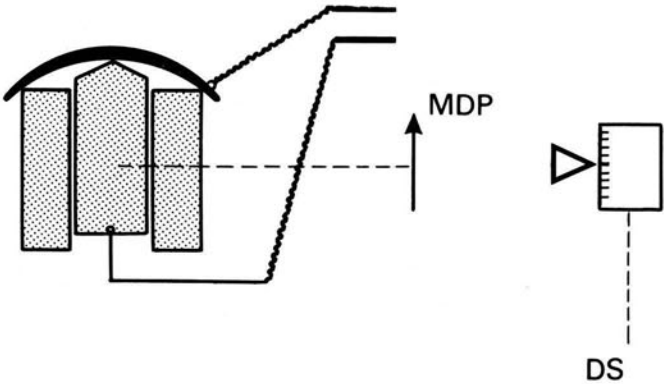
The sag S is related to the radius of curvature by

$$r = \frac{Y^2}{2S} + \frac{S}{2}$$

It can be measured with a three-footed lens measurer (Geneva) and the radius or power of the surface in dioptres read from a dial if the refractive index is known. The Geneva lens measurer can only be used on glass of refractive index 1.523. It is used to analyse spectacle lens curve and powers. Intolerance to spectacles can sometimes be due to change of lens form.

The sagitta depth is used to measure the radius of soft hydrophilic contact lenses — using a projection to obtain magnification.

Sagitta System Applied to Radius Measurement of Contact Lenses

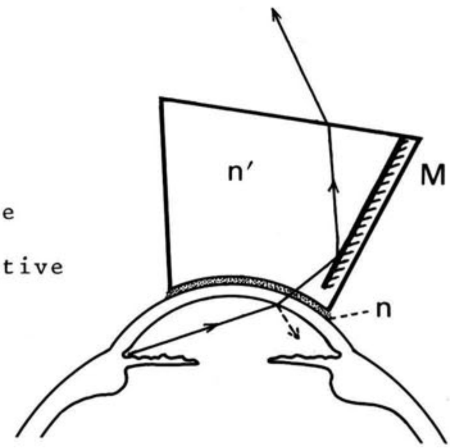


MDP = Motor drive piston
DS = Digital scale read-out and for radius in millimetres

The sagitta can be found by ultrasound and mechanical methods (see above). A digital computer can give direct read-outs of radii of curvature.

GONIOSCOPE CONTACT LENS

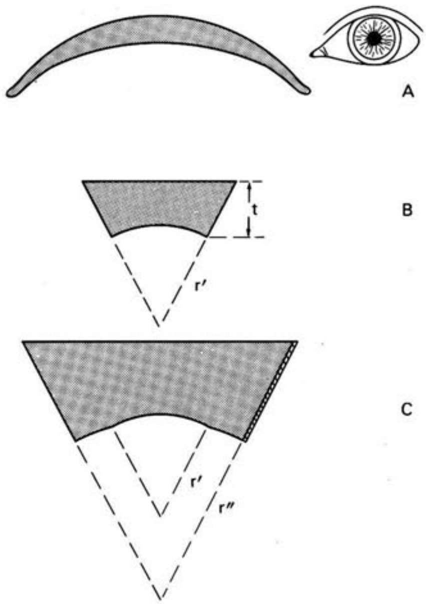
M = Mirror
n' = Plastic refractive index = 1.50
n = Tear fluid refractive index = 1.33



The gonioscope is a contact lens with a mirror, therefore light rays can pass to and from the angle of the eye. Rays pass from the rarer medium of the eye to the denser medium of the gonioscope and there is no internal reflection of light (see Critical Angle, p. 52).

For convenience the mirror is used so that the gonioscope can be used with the slit-lamp microscope. Operating microscopes can be used without the mirror principle for surgical procedures.

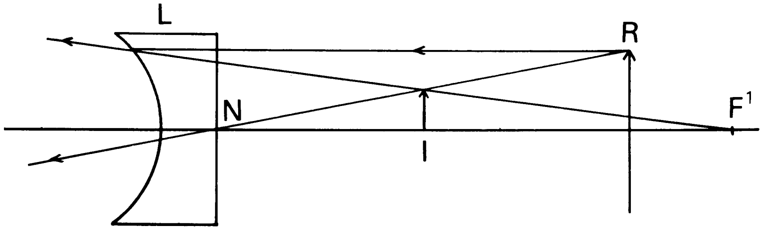
The angle of the mirror determines the area to be examined. Thus the Goldman three-mirror lens enables the posterior chamber and posterior segment (equator) to be visualised.



A = 13mm soft contact lens used as fundus-viewing lens; power = -40.00 dioptres
B = PMMA 12mm hard lens for fundus-viewing; power = -60.00 dioptres
t = 2mm
r' = 8.5mm (secondary curves not shown)
C = 14mm PMMA mirror gonioscope
r" = 12.50mm

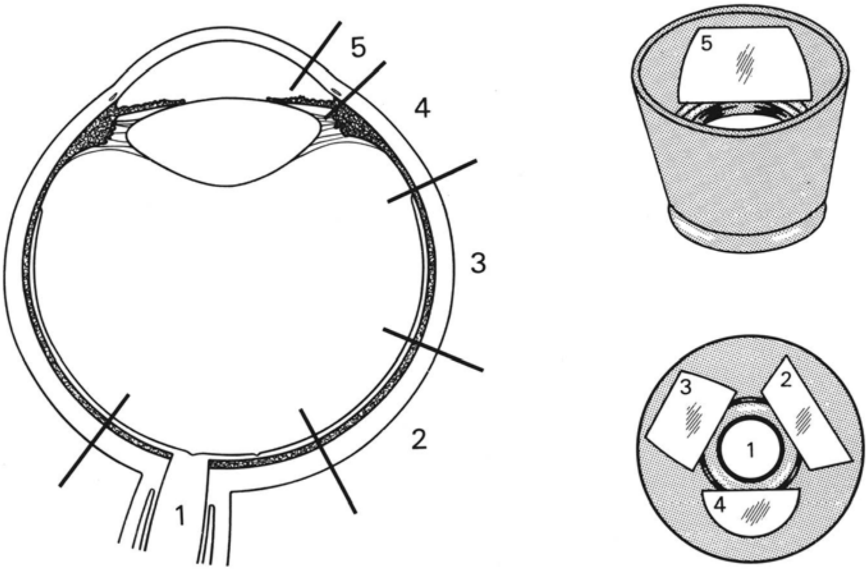
VARIOUS MINIATURE GONIOSCOPES AND FUNDUS-VIEWING CONTACT LENSES

Fundus-Viewing Contact Lens



L = High-negative-power lens in front of cornea (not in contact)
N = Nodal point of system
I = Image of retina (small erect)
R = Retina
F' = Far point of system

The negative contact lens will diverge the emerging light rays from the illuminated chorio-retina. The rays will form an image in front of the retina. The same principle applies to the H'Ruby lens but in this instance the high-powered negative lens is not in contact with the cornea.

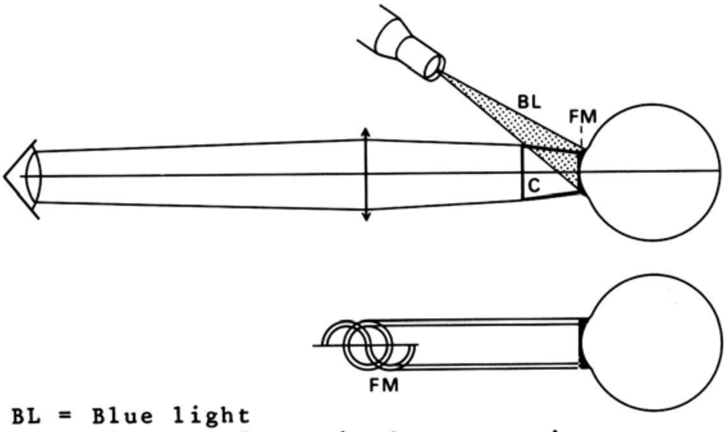


1 = Central aperture for optic-nerve viewing
2 = Mirror for foveal viewing
3 = Mirror for equatorial viewing
4 = Mirror for ciliary viewing
5 = Mirror for angles and posterior-chamber viewing

The combined Goldman gonioscope posterior chamber and fundus lens.

N.B. The angle of the mirror determines the part of the eye visualised (decrease the angle for the posterior segment).

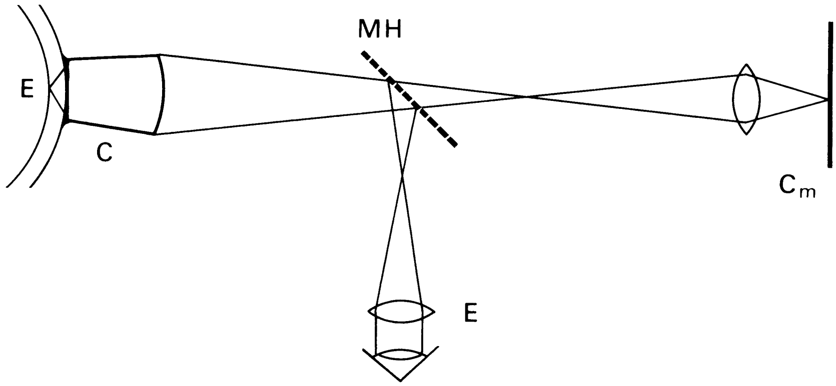
APPLANATION TONOMETER



BL = Blue light
FM = Fluorescein-stained tear meniscus around cone
C = Plastic prism cone (base to base)

The prism separation of the fluorescein meniscus is fixed and directly related to an applanation area of the cornea. The intra-ocular pressure is therefore measured by altering the pressure applied to the cornea by the face of the cone to produce a specified plane area.

SPECULAR MICROSCOPY



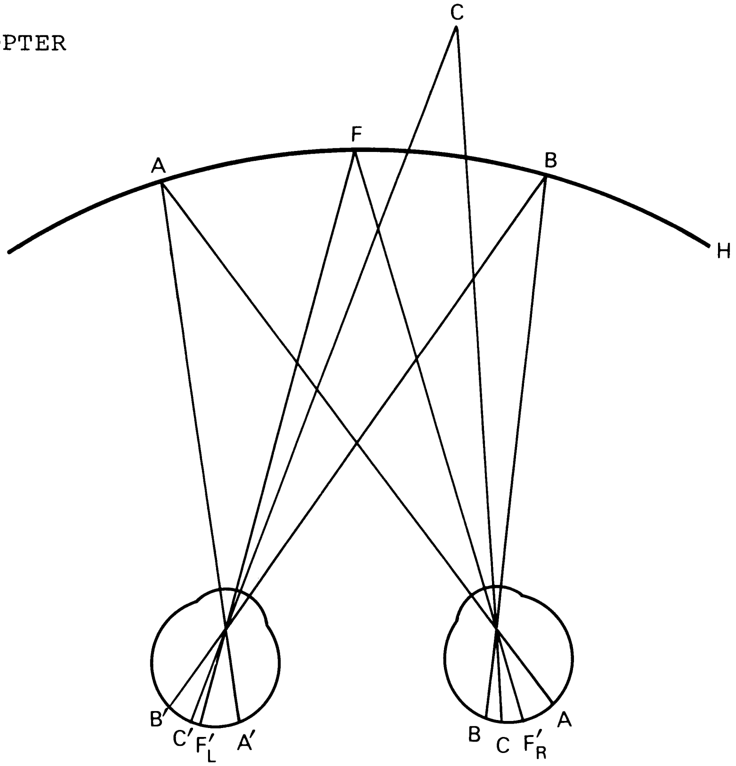
E = Endothelium of cornea
C = Applanation cone lens
MH = Half-silvered mirror
E = Eye-piece for observer
C_m = Camera

The objective of the microscope makes contact with the cornea or soft contact lens (if worn) and the object distance is adjusted to bring the endothelium into focus.

SECTION VI

Binocular Vision

HOROPTER



H	=	Plane horopter
A and B	=	Corresponding points on retina
C and C'	=	Non-corresponding points
A and A'	=	Area of correspondence (Panum's)
B and B'	=	Area of correspondence (Panum's)

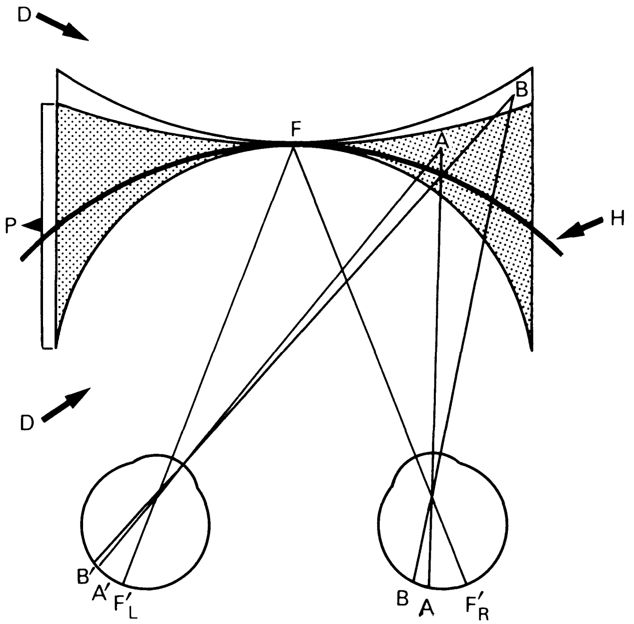
(see also key on p. 180)

The horopter is that portion of space in which objects will form images on the two retinae on corresponding photoreceptors.

In the diagram, points A, F and B, which lie on the horopter, are imaged on corresponding retinal points A and A', B and B', and F and F', respectively. C, lying outside the horopter, is imaged on non-corresponding points C and C'.

As shown in the diagram, the horopter is approximately a portion of a circle, but the shape of the horopter varies with the degree of convergence to form a toroid in space.

PANUM'S AREA



Key as Previous Figure Except for:

D = Diplopia zones

P = Panum's area (stereoscopic vision possible)

F = Fixation point

F'_R = Fovea right eye

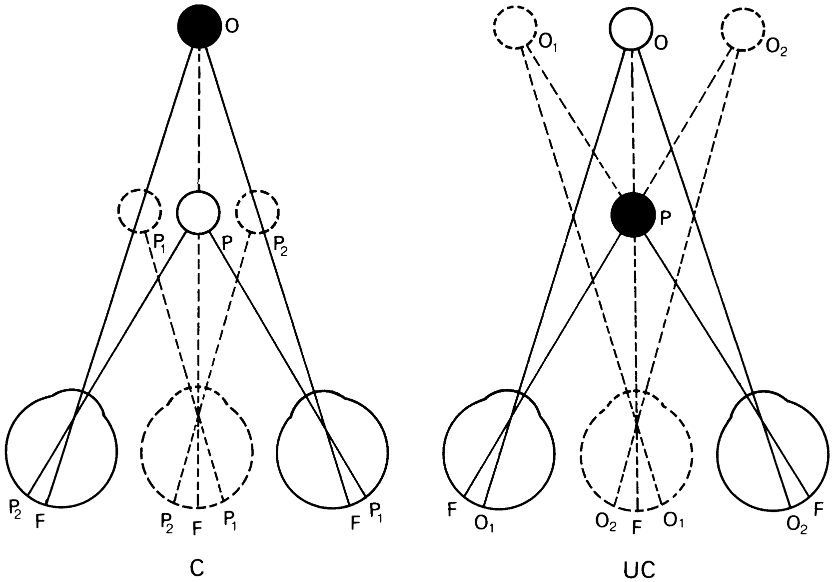
F'_L = Fovea left eye

Although the horopter is the only portion of space where an object will form images on corresponding photoreceptors in the two eyes, objects which lie away from the horopter may still be fused.

There is an area both slightly in front and slightly behind the horopter where objects can be seen as single. This area, determined experimentally, is known as *Panum's fusion area.*

Because objects in this area do not fall on corresponding photoreceptors, they have a slightly different directional value even though seen as single, and this is the basis of stereopsis.

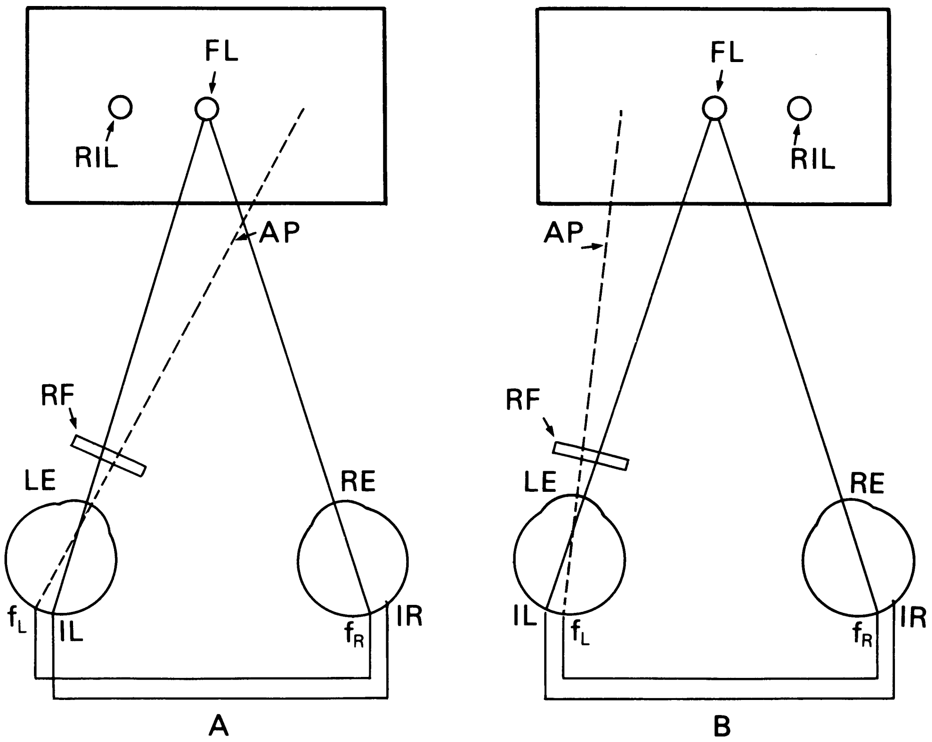
CROSSED AND UNCROSSED DIPLOPIA



Outside Panum's area objects will be seen double.

If a distant object 0 is fixated, a nearer object P falls on the temporal side of each fovea at P_1 and P_2. Image P_1 will be seen to the left of 0 and image P_2 perceived by the left eye will be seen to the right of 0. Thus the diplopia is crossed (C).

If nearer object P is fixated at both eyes, the images of further object 0 will fall on the nasal side of each fovea at 0_1 and 0_2. 0_2 will be projected to the right of P and 0_1 to the left. The diplopia is thus uncrossed (UC).

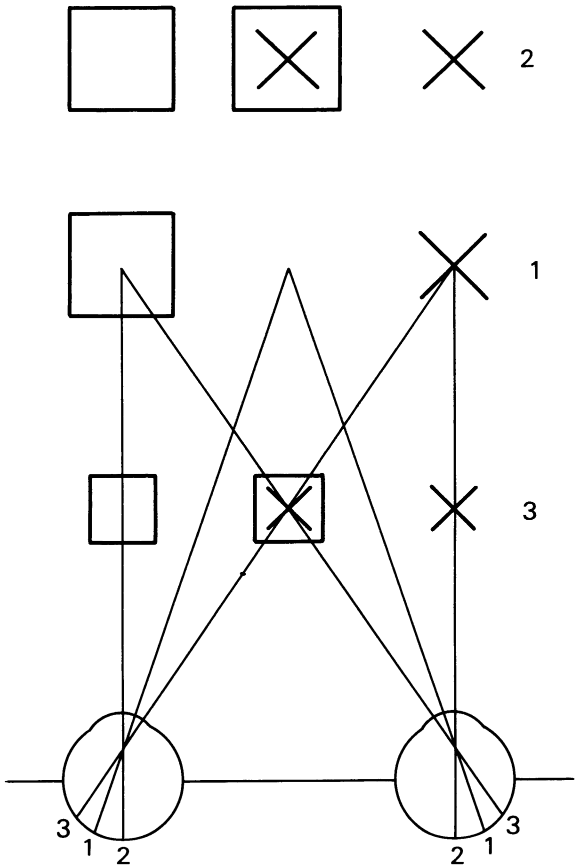


FL	= Fixation light
RIL	= Red image seen by left eye
RF	= Red filter
RE	= Right eye
LE	= Left eye
f_L and f_R	= Foveas
IL	= Abnormal stimulus and projection
IR	= Normal foveal location
AP	= Abnormal projection

In strabismus with normal correspondence, with a convergent strabismus the iamge seen by the left eye is to the left of that seen by the right eye and the subject will experience crossed diplopia (A). If the subject has a divergent strabismus the image seen by the left eye is to the right of that seen by the right eye and the subject will experience uncrossed diplopia (B).

The image of the non-fixating eye is always projected in space in the opposite direction to which the eye is turned.

CHANGE OF APPARENT SIZE OF OBJECTS WITH CONVERGENCE AND DIVERGENCE

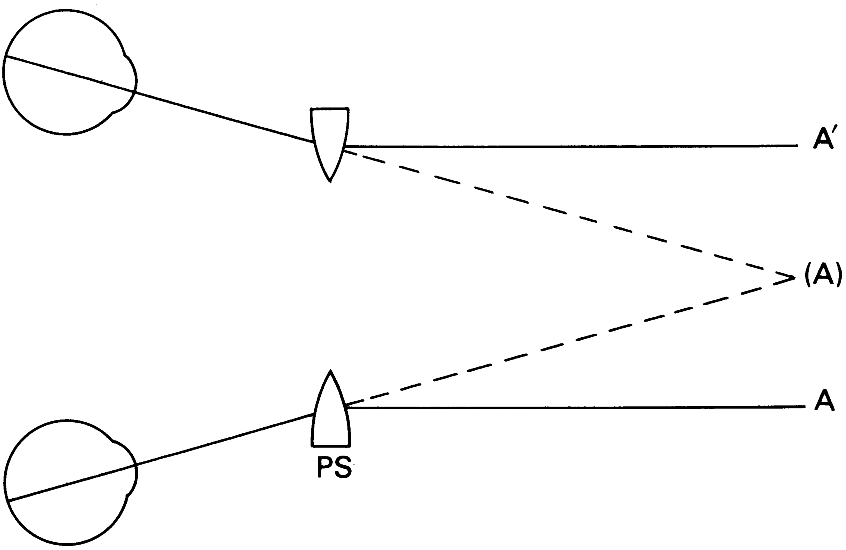


If a subject views a cross and a square at a normal reading distance (1), he can make the cross appear to move into the square in two ways. Firstly, by over-converging and producing crossed diplopia as in 3, or secondly by diverging slightly and producing uncrossed diplopia as in 2.

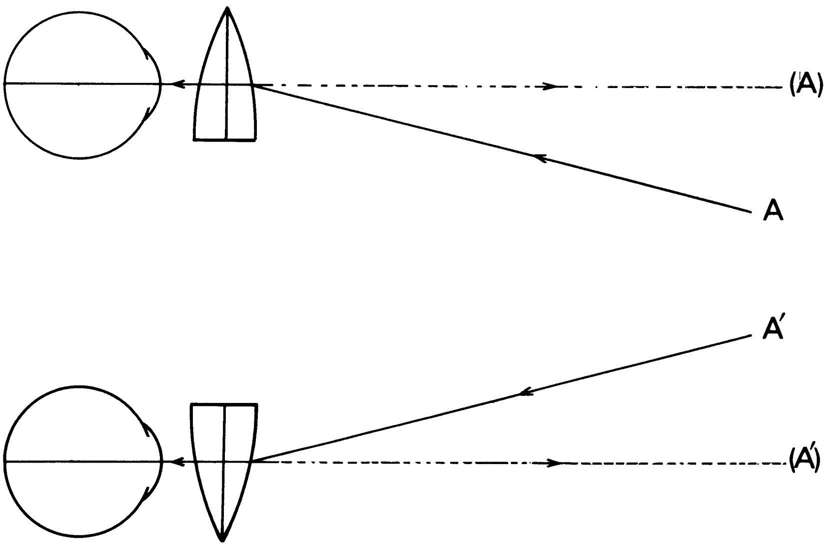
Although the sizes of the retinal images of the cross and square have not altered, they will appear much smaller in the converged position than in the diverged position.

The explanation of this phenomenon is the feedback mechanism which dictates what the size of the object will be. Under normal conditions objects coming close stimulate convergence, but even though the retinal images are larger, they are not perceived as being larger, but rather as a constant size. Thus when the eyes converge and the image on the retina does not become larger, the brain interprets this as a shrinking object.

STEREOSCOPES



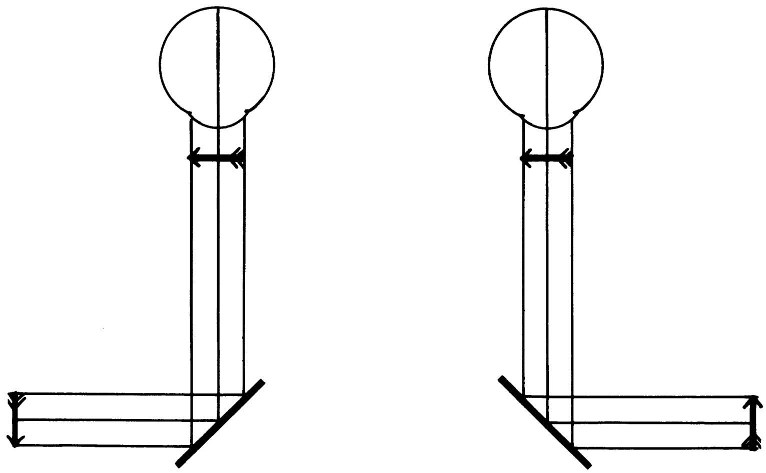
A simple diagram showing how targets A and A' will appear projected to a similar plane in spaced and fused (A). PS = prism spheres.



The use of prisms and positive lenses will permit stereoscopic vision with relaxed accommodation and convergence.

This is an example of a simple stereoscope; note that accommodation can be relaxed by the use of suitably powered sphero-prisms.

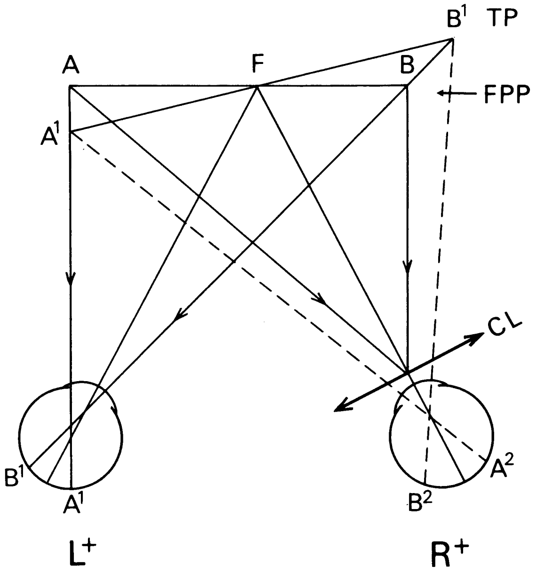
MIRROR STEREOSCOPE



Using mirrors, two separate targets can form images fusing in the same plane in space (used in X-ray diagnosis.

This method is applicable to large targets and the mirrors reduce the distortion. It is the principle used in the synoptophore. It can therefore be used to separate the eyes and also to obtain mobility by rotation either of mirrors or by object and mirror (p. 187).

ANISEIKONIA (IMAGE SIZE DIFFERENCE)



FPP = Front parallel plane (AFB)

A^1FB^1 = Plane in aniseikonia

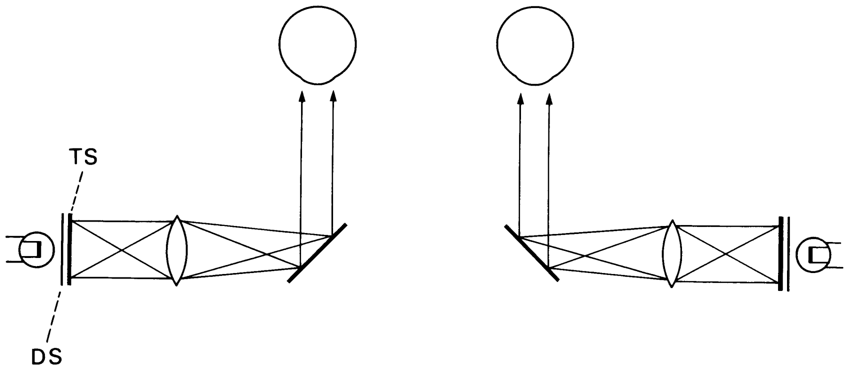
CL = Correcting spectacle lens for anisometropia

In anisometropia (in the diagram the right eye is hypermetropic) corrected by a spectacle lens, magnification is produced in the right eye. The projected rays give the spatial illusion of A being nearer than B. The aniseikonic (difference in image sizes) effect, can, if too great, cause diplopia and suppression.

A small degree of image size difference forms the basis of stereoscopic vision. The right and left eye can only rarely form the same-sized image of an object, unless the two eyes are always symmetrically placed about every point of fixation.

The degree of aniseikonia can be measured using either an Ogle-type aniseikonometer or special slides (Ruben) with aniseikonic lenses.

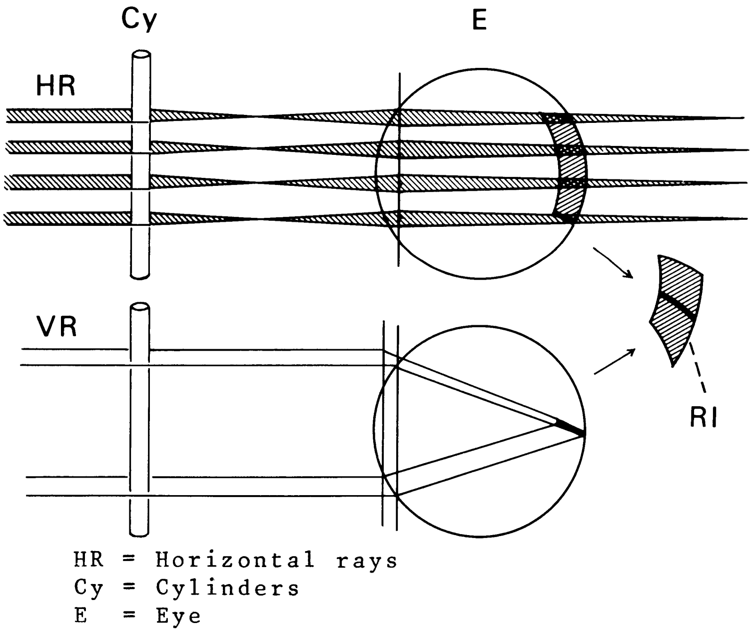
SYNOPTOPHORE (Haploscope)



TS = Slide
DS = Diffuser screen

A method for separating the eyes to estimate the degree of cerebral image fusion and stereoscopy.
It can also be used for measurement of aniseikonia.

MADDOX ROD



HR = Horizontal rays
Cy = Cylinders
E = Eye
VR = Vertical rays
RI = Patch of light with line image 90^{o} to axis of cylinder

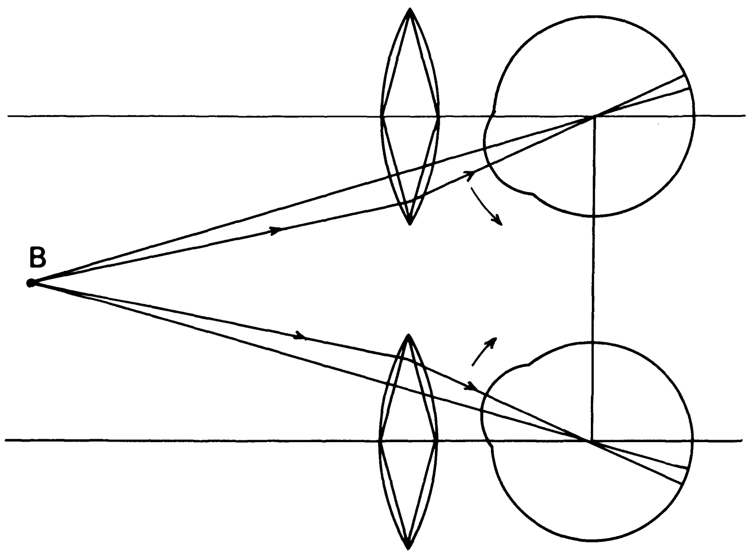
A method of separating the vision of the two eyes (see pages 186-187 for other methods).

Before studying the diagram, go back to the diagram on pages 62-63 and review refraction by a cylinder.

The Maddox rod or groove is a series of high-powered cylinders. Light from a distance source will, in the plane of the cylinder's axis, pass to the eye unrefracted. This light will be brought to a focus on the retina forming a line focus. This light in the plane of the cylindrical power will be brought to a focus in front of the eye. The line image cannot form a clear retinal image — only a blurred patch. The line focus is at 90° to the cylinder's axis.

The Maddox rod is used to dissociate the two eyes. Other methods are screens, (Maddox wing) mirrors and polarised light.

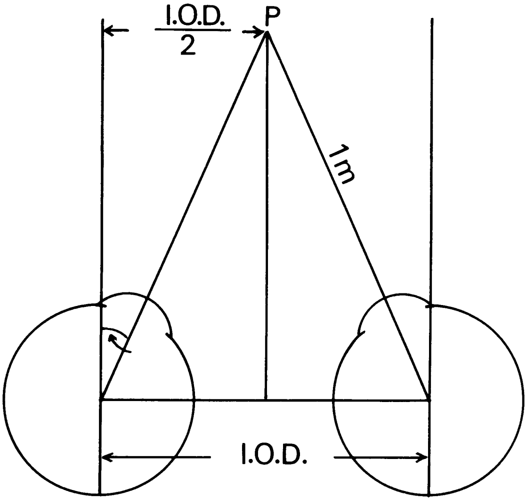
PRISM EFFECT OF SPECTACLES



A near point B will emit rays passing through the nasal areas of the positive lenses and producing a prism base-out effect. The eyes converge to maintain binocular single vision.

A prism base-in effect is produced in myopia, and when corrected with spectacles. Less convergence is therefore necessary to fixate B.

Consequently the wearing of an under-correction in high myopia of 2 dioptres will permit very good near fixation without convergence fatigue and some magnification effect as compared with the full correction.



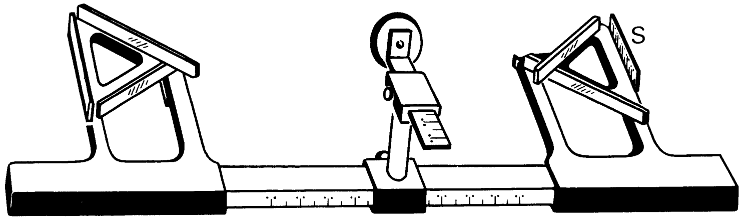
The inter-ocular distance varies in individuals. The convergence required to a near fixation point is directly related to the inter-ocular distance. In practice, accommodation and convergence are not fixed but allow some degree of play. Such factors as depth of focus and resolution will also allow some freedom of association between convergence and accommodation. In dioptres, convergence = M.A. x $\frac{1}{2}$(I.O.D.)(in cm). In dynamic retinoscopy (fixation of the retinoscope), accommodation lag is often found indicating that convergence is the more rapid component of B.S.V. near fixation.

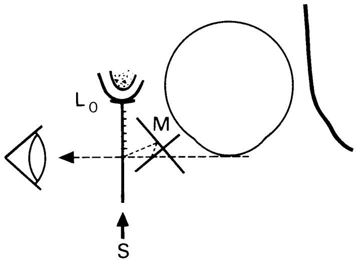
A metre angle is the angle of convergence necessary to fixate a point (P) 1m from the centre of the eyes' rotation, the eye accommodating 1 dioptre. The metre angle is therefore a measure of convergence.

SECTION VII

Miscellaneous

EXOPHTHALMOMETER (HERTEL)

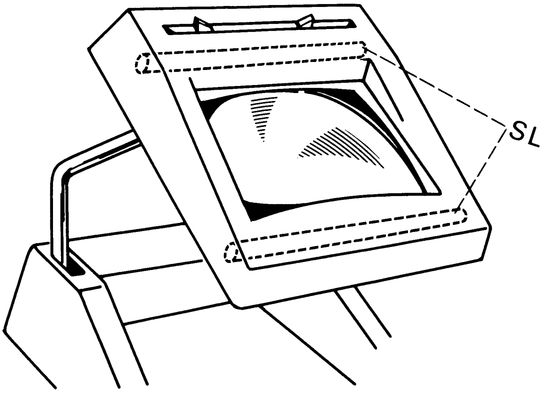




LO = Lateral orbital rim
M = Mirrors
S = Scale

The use of plane-mirror reflections should be obvious from the diagrams. It can also be used to check prosthesis projection.

MAGNIFYING AIDS (SEE MICROSCOPES AND THE POSITIVE LENS)

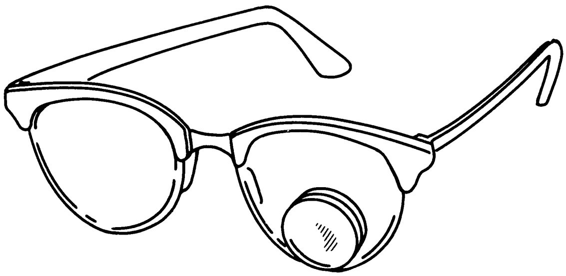


Simple desk magnifier with self-illumination
SL = Strip lights (x2)

Good illumination of the object is more important than magnification. Simple magnifiers produce powers of x2 to x8 (see diagram on p. 77).

$$M = \frac{F}{4}$$

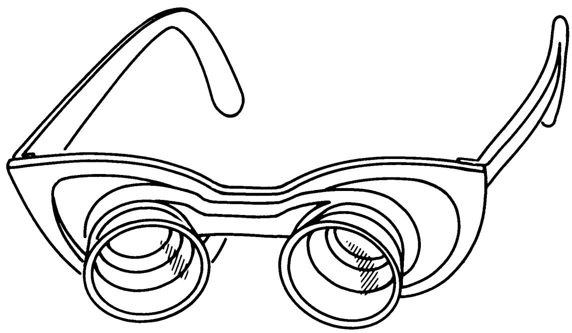
Thus if the image is projected to 250mm, this is the magnification to expect. Hence a +20.00 dioptre sphere gives a x5 magnification if the object is held between the anterior focal point (50mm) and the lens.



Spectacle lens fitted with micro-magnifier in near position (e.g. +20.00 dioptres)

$$M = x4$$

Therefore the trial set spectacle lenses can be used to stimulate a simple magnifier worn at the eye.



Binocular telescopic aids for
near work, e.g. x6

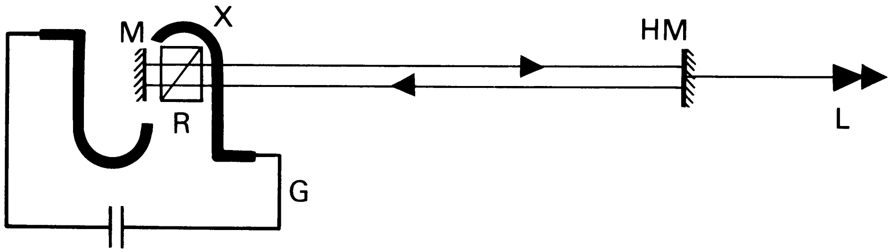
But trial sets of telescopic aids for distance and near work give magnifications of x2 to x10 and an increased working distance (see p. 160). Paraxial or coaxial illumination is often required with short working distances and high powers.

Television screens and scanning cameras can be used to help sub-normal-vision patients, but are expensive, and high magnification is more suited to task performance than reading. Colour contrast must also be considered.

COHERENT LIGHT AND LASER

The emission of photons in a pulsed frequency, instead of the normal incoherent transmission, can be used in ophthalmology. The coherent light can be concentrated into small beams of very high intensity, in contrast to incoherent light. The energy dispersion when such a coherent beam meets an opaque media is sufficient to cause a high temperature which itself is sufficient to 'burn' tissues within the eye with exposures of only a fraction of a second and with beams of only a small diameter (e.g. 0.3mm). Coherent light can be produced by bringing the atoms in a transparent medium to an excited state so that emission of photons occurs. Initially this was done by xenon-coil exitement of a ruby. The photons were reflected backwards and forwards into the ruby to bring the emission to a sufficiently high level to allow a controlled beam to be emitted. Such light emission is called LASER (light amplification by stimulated emission of radiation). The argon laser is used more often in ophthalmology since the monochromatic laser is effective in treating the retina in front of a red chorio-retinal ground.

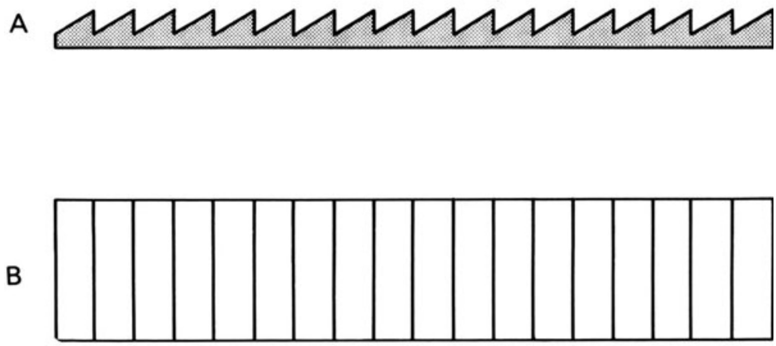
The laser is now mounted on a slit-lamp microscope stand for treatment of retinal lesions, producing iridectomies (glaucoma therapy), corneal lesions and neovascularisation.



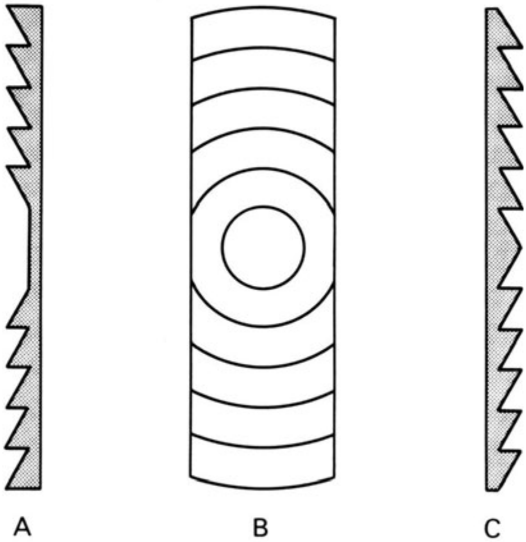
M = Mirror
R = Ruby crystal
X = Xenon exciter coil
G = Exciting electrical circuit
HM = Half-silvered mirror
L = Laser beam

N.B. The use of the laser must be controlled to safeguard the practitioner and other personnel from hazards, e.g. macular burns.

FRESNEL'S PRINCIPLE (see pages 55 and 75)



Principle of Fresnel's prism strip
in plastic (2mm thick section)



A = Principle of negative lens with Fresnel's principle
B = Front
C = Principle of positive lens with Fresnel's principle

By using strips of reflectors or refracting surfaces light can be converged or deviated as in lenses, if arranged in concentric circles. When the strips are in parallel a prism effect can be obtained. Thus thin concentric prisms cut into 2mm thick plastic can produce high powers of either prism or lenses over very large areas. This method of reflecting light to form emerging and parallel light beams has been used in searchlights and in lighthouses, and for operating lights (cf. radar, etc.).

The stick-on thin lenses are chiefly used as temporary prisms for orthoptic treatment. The control of aberrations is not easy by this method and the total effect produces an indistinct image.