Refractive Techniques

To write a complete spectacle prescription, a refractionist must determine eight quantities: the vertex distance; interpupillary distance; and the prescription parameters--sphere, cylinder and cylinder axis--for each eye. Finding the first two is relatively straightforward. But there is considerable subtlety in obtaining the prescription parameters. The problem is twofold; first the three parameters are not independent so that they can be measured one at a time; second, there is a good deal of unreliability in any given measurement due to erratic patient response, shifting examiner criteria, and actual fluctuations in the parameters themselves. These problems are overcome by what mathematicians or engineers would call an <u>iterative</u> process which continually refines an estimate of ocular refraction through the accummulation of more and more data obtained with a variety of techniques.

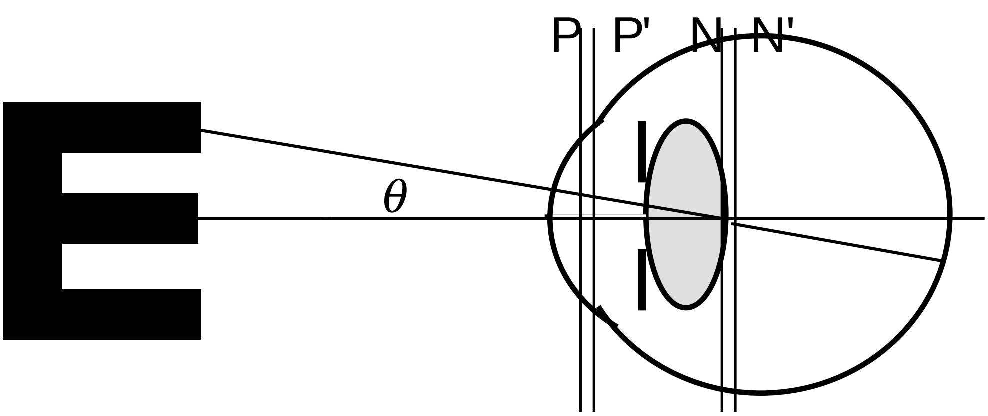
Refraction techniques can be classed as <u>subjective techniques</u> which require patient responses and <u>objective techniques</u> which require no patient responses. In fact most so-called "objective" techniques like retinoscopy are, in fact, examiner subjective. The only truly objective techniques are those like autorefraction completely performed by a machine.

In what follows we'll go through the steps in a refraction in pretty much the order in which they're done.

Visual Acuity

The first thing done in an optometric examination is to measure the patient's "vision", actually visual acuity. A variety of charts have been evolved for the purpose. A portion of a typical chart might be as follows:

The patient's job is to read as far down the chart as possible. The farther down he reads, the better his vision. What visual acuity tests do is to measure the eye's ability to separate two images, to tell whether there are one or two.



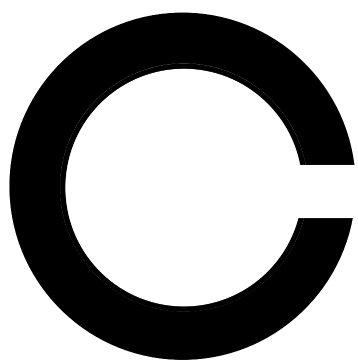
The most common system for indicating the resolving power of the eye is the Snellen system. So-called Snellen optotype letters are constructed so that the component parts such as the legs of the **E** in the diagram above are separated by a given spacing. The letter was rated by the distance at which the spacing 1 minute of arc. A 20 ft target, for example, had component separations of 1 minute at 20 ft, a 50ft target had component separations of 1 minute at 50 ft from the subject. One then exposes the subject to a series of these targets at some standard testing distance, typically 20 ft (6 m).

The acuity of the patient is given by the following fraction:

Snellen acuity=(testing distance)÷(rating of smallest detected letter)

An acuity of 20/15, for example, indicates that the patient saw the "15 foot" letter at a testing distance of 20 feet. The smaller the bottom number, the better the acuity. A person with 20/20 acuity can just resolve a grating in which the lines are separated by one minute of arc at 20 feet.

For those who can't read English letters, other targets are used. Tumbling E charts use the Snellen **E** in various orientations. Landolt C charts use a letter **C** with a gap.The patient's job is to indicate the orientation of a given letter, usually by pointing.



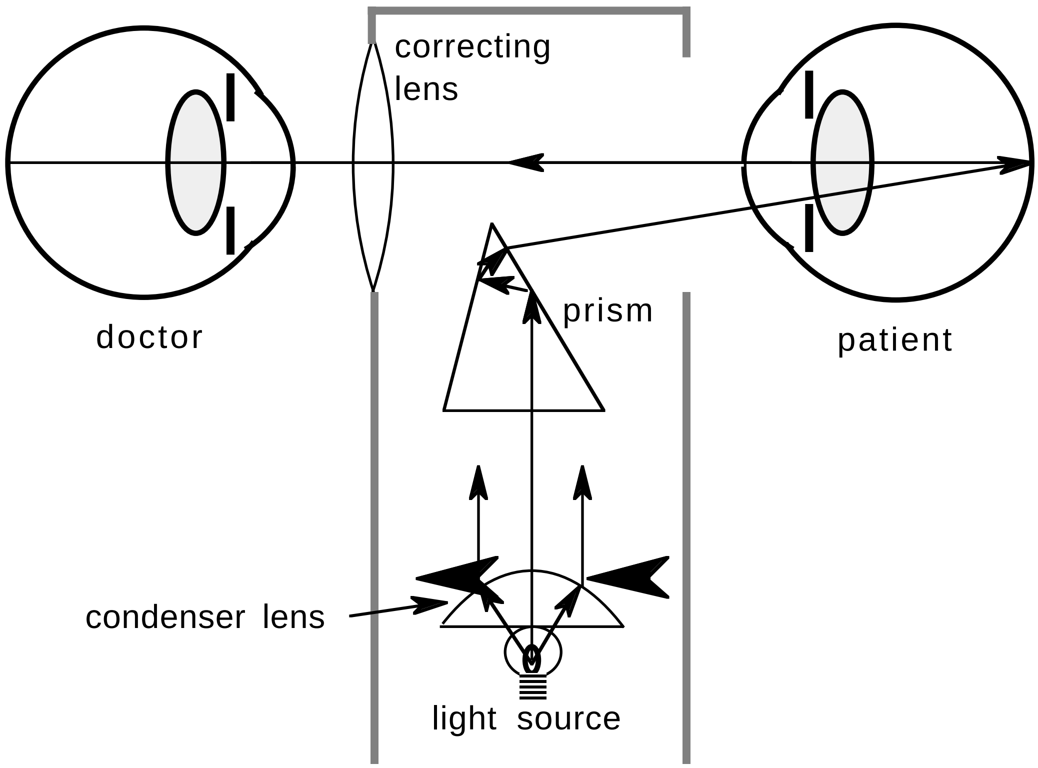
Landolt **C**

Symbols from other alphabets or even non-alphabetical symbols may be used on charts if the visibility of the symbol can be equated to that of a Snellen letter. If, for example, a given size of the symbol  could be correctly identified as a telephone by a subject with 20/20 best corrected acuity when the symbol is ten feet from the subject, that symbol is can be taken as equivalent to a 40 foot letter.

The charts most commonly used in the United States consist of Snellen optotypes with a 20/10 line at the bottom and lines of successively larger letters increasing in 5 foot steps to 20/40 and thereafter in 10 foot steps, crowned with a 20/400 **E.** A digit at the beginning of the line indicates the letter size, as in the figure on page 1. The number of letters per line diminishes as the letters become larger. A number of arrangements have been proposed for the letters on an acuity chart. Perhaps the most appealing is the Bailey-Lovie LOGMAR chart in which each line down the chart is a factor of $(2)^{1/3}=1.26\ldots$ smaller than its predecessor and all lines have five Snellen optotype letters. In English units this gives lines of 20/10, 20/12, 20/16, 20/20, 20/25, 20/32, 20/40,... The LOGMAR chart is especially beloved of low vision practitioners since it gives more large letters than standard charts.

Experienced practitioners can estimate refraction from visual acuity. A good rule of thumb is to divide the bottom number of the English Snellen fraction by 10 to get approximate refraction. For example, a patient with 20/50 acuity would be expected to require a $\pm 0.50D$ correction.

Direct Ophthalmoscopy



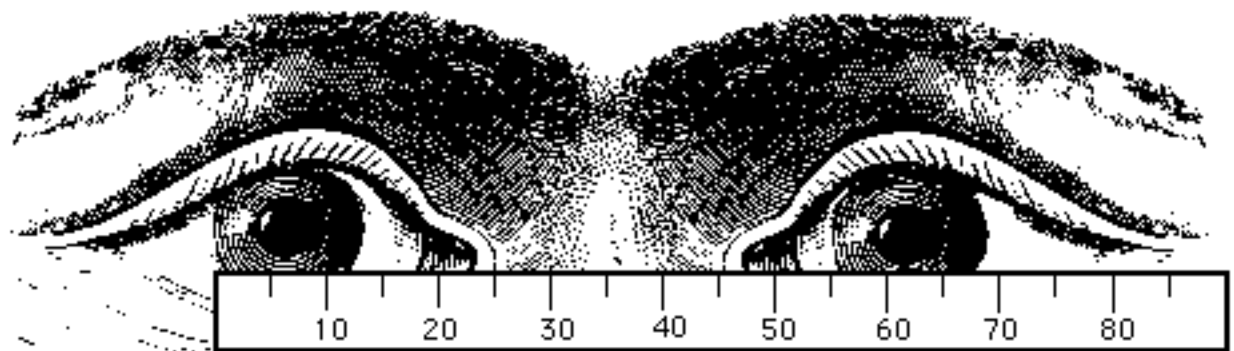
The ophthalmoscope is intended mainly to give the doctor a view of the retina, but it can also be used to give an approximation of the refraction. The diagram above shows how a direct ophthalmoscope works. For the doctor to see the patient's retina clearly, the power of the correcting lens must be the algebraic sum of the ametropias of the doctor's and patient's eyes minus the dioptric amount of their accommodation. For astigmatic patients and doctors, use the equivalent sphere. The technique is especially helpful with young children and other patients who can't respond to subjective tests or sit still for more lengthy objective procedures like retinoscopy or autorefraction.

Example: A doctor who is a two diopter myope accommodates one diopter while looking at the retina of a five diopter hyperope who is an absolute presbyope. What correcting lens will be needed in the doctor's direct ophthalmoscope?

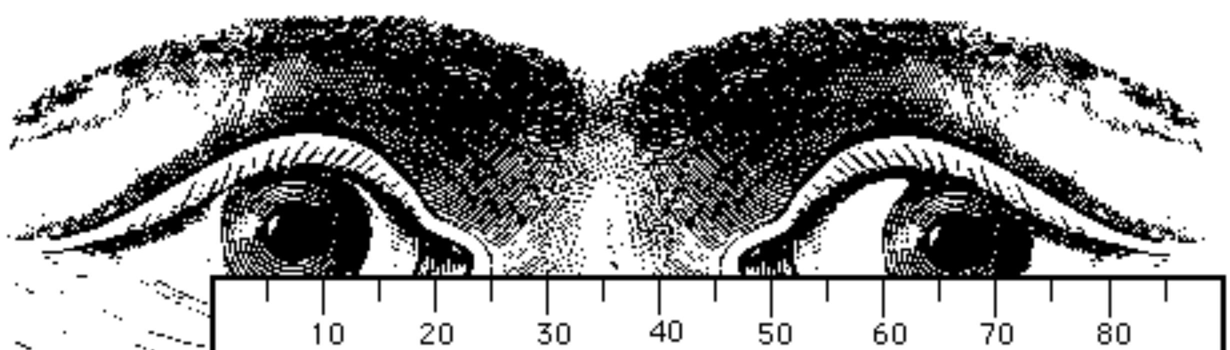
Solution: $F_{correcting\ lens}$=-2-1+5=+2 diopters.

Interpupillary Distance

The interpupillary distance or PD is simply the distance in millimeters between the center of the pupils of the two eyes. Two PD's are measured, the distance PD when the patient is looking at a remote object and the near PD when the patient is looking at an object 40cm away from his face. The near PD is about 5 mm less than the distance PD. This distance is needed to center spectacle lenses properly in an eyewire and to set the PD of the phoroptor or trial frame prior to refraction. Usually the interpupillary distance is measured with a narrow ruler called a PD rule.



With the doctor's face positioned about 40 cm from the patient, ask the patient to look at the doctor's left eye. Measure the distance from the lateral limbus of the right eye to the medial limbus of the left, 55mm in the picture above. That is the near PD.

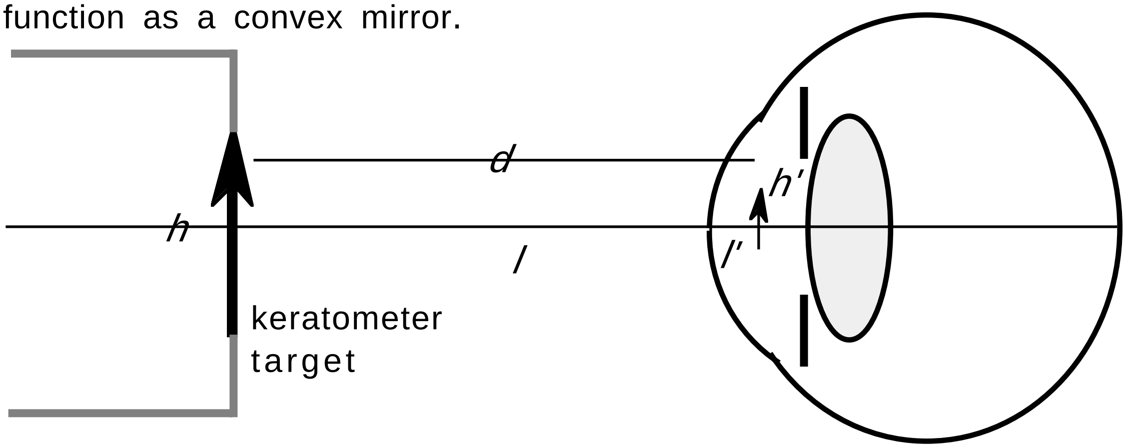


With the doctor's face still positioned about 40 cm from the patient, ask the patient to look at the doctor's right eye. Measure the distance from the lateral limbus of the right eye to the medial limbus of the left, 60mm in the picture above. That is the distance PD.

Essilor and some other companies make devices that can measure PD within one half millimeter, an accuracy necessary in dispensing progressive addition lenses. A movable lens in these devices places an image at 40cm, infinity, or any other distance from the patient. While the patient looks at that image the doctor adjusts the instrument until a vertical line blocks the Purkinje image of the target in each of the patient's cornea. The scale of the instrument converts the separation of the lines to a PD.

Keratometry

The keratometer is used to measure the curvature of the anterior corneal surface by measuring the size of an image reflected from the cornea function as a convex mirror.

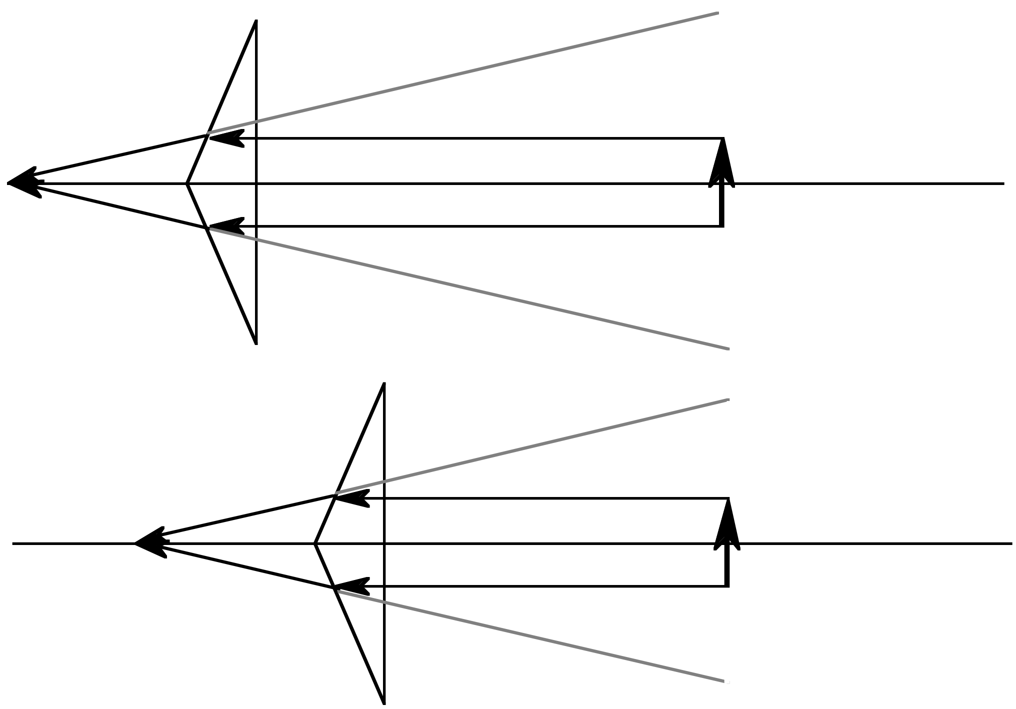


The keratometer is constructed with a target or keratometer mire at the front of the instrument. The image of the target is viewed through the microscope optics of the instrument and brought into focus by moving the instrument back and forth. Thus there is a fixed distance d between the target and the image formed in the cornea. If we know the magnification m of the image we can get for the radius of curvature of the cornea

$$r=2md=2dh'/h.$$

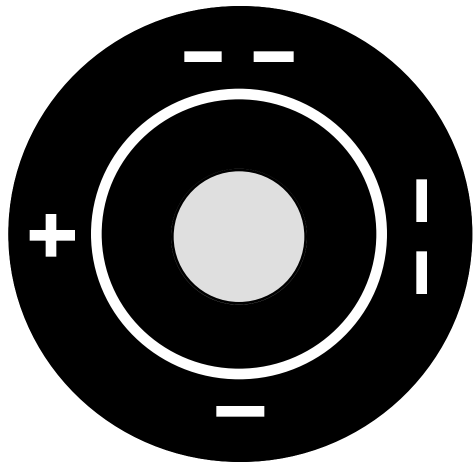
Thus knowing the distance d, a constant of the instrument, the size of the mire h, we can measure the radius of the cornea by measuring the size of the corneal image h'.

Because the image in the cornea is small, it is examined at high magnification. At such magnification, the normal oscillations of the eye make it impossible to compare the image height with any reticle scale. To measure the image size, then, clinical keratometers use a doubling system. The doubling system is inside the keratometer somewhere in the path of the light returning from the cornea to the doctor and it divides the light pencil from the image into two pencils. Thus the doctor sees two images. His job is to adjust the instrument until the images are separated a fixed distance. The mechanism that does this is calibrated to give a measure of h' which may be converted to a corneal curvature.

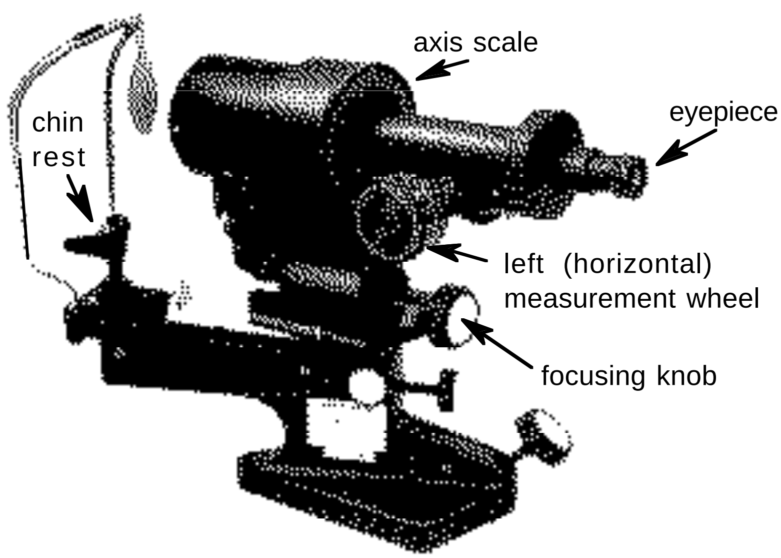


The most commonly used doubling system is a prism doubling system in which a pair of prisms is moved back and forth until the pair of images are tangent. The two diagrams above above show how varying the position of a biprism changes the position of the pair of images formed. This is called a variable doubling system. It is used in keratometers of the Bausch & Lomb type. Alternatively, fixed doubling leaves the prism configuration constant but allows the examiner to vary the target. This is used in the classic ophthalmometer.

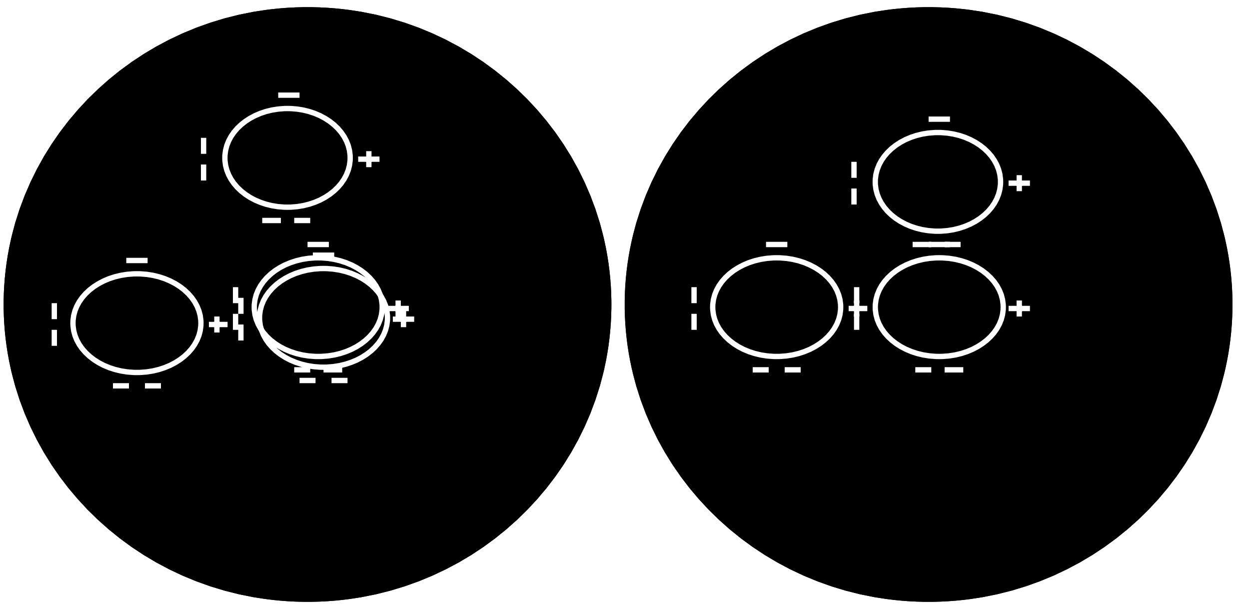
Keratometer mires are circular so that an astigmatic cornea makes them somewhat elliptical. The mires of many keratometers look like the figure below.



The picture below shows a typical keratometer. In use, the patient sits with his chin in the chin rest while the doctor adjusts the instrument and takes measurements.



The doctor's view through the eyepiece is initially like the left picture below. The image of the circular mire is somewhat elliptical (with the rule corneal astigmatism in this case). A Scheiner's disk arrangement causes the central mire to be doubled instead of blurred when the mire is out of focus. Doubled images of the mire appear above and to the left of the central mire.



Here are the steps in making a measurement.

☞ The doctor uses the focusing knob to get the central image single.

☞ The instrument is rotated until the doubled mire images line up with the central image.

☞ The horizontal and vertical measurement wheels are adjusted to get the doubled mires to overlab with the central mires.

☞ Power and meridian are read from the measurement wheels and axis scale. For example, if the horizontal measurement wheel reads 44.00 and the horizontal hashmark points to 175 on the axis wheel, the meridian at 175° has power 44.00D. This is written 44.00@175. **Do not confuse meridians and axes here.** The vertical meridian power and axis are determined in a similar way. The total reading is written in the form 44.00@175/45.25@085. Some doctors only write the angle of the horizontal meridian.

Keratometer readings have been estimated to be accurate to about ±0.37D in the horizontal meridian and somewhat less accurate in the vertical meridian.

There are three reasons for doing keratometry.

☞ To guide contact lens fitting.

☞ To monitor corneal changes in contact lens fitting, surgery, or other trauma.

☞ To help with refraction.

The keratometer reading helps in refraction by suggesting the origin of the refractive error, especially anisometropia (more on this later), and by giving an estimate of cylinder.

Since the cornea accounts for about 2/3 of the eye's refractive power and most of its astigmatism, it is reasonable to use keratometric readings to estimate cylinder power in a spectacle prescription. If, for example, the vertical meridian has greater power than the horizontal meridian, the cornea is contributing with-the-rule astigmatism. If the vertical meridian has less power than the horizontal meridian, the cornea contributes against-the-rule astigmatism.

An an aphakic patient, one with no crystalline lens, all astigmatism is corneal and the keratometric cylinder should correspond to the spectacle cylinder.

In the phakic patient, estimating astigmatism is less straightforward. A number of rules have been suggested. The best known of these is Javal's rule which estimates the internal astigmatism to be -0.50x090 and combines that with the corneal astigmatism multiplied by a fudge factor of 1.25. In equation form,

$$\text{spectacle cylinder} = 1.25\text{x(corneal cylinder)} - 0.50\text{x}090.$$

This calls for an example:

Example: A patient's keratometer readings are 43.00@180/45.00@090. Estimate spectacle cylinder using Javal's rule.

Solution: From the keratometer readings, the corneal cylinder would produce specacle cylinder of -2.00x180. Javal's rule would then give

spectacle cylinder=1.25(-2.00x180)-0.50x090
=-2.50x180-0.50x090=-2.00x180.

Recently Grosvenor has proposed an alternate rule which is easier to use and, he claims, more accurate. Grosvenor's rule is identical to Javal's rule, except Grosvenor omits the fudge factor of 1.25. In the above example, for instance, Grosvenor's result would give

spectacle cylinder=-2.00x180-0.50x090
=-2.00x180-0.50x090=-1.50x180.

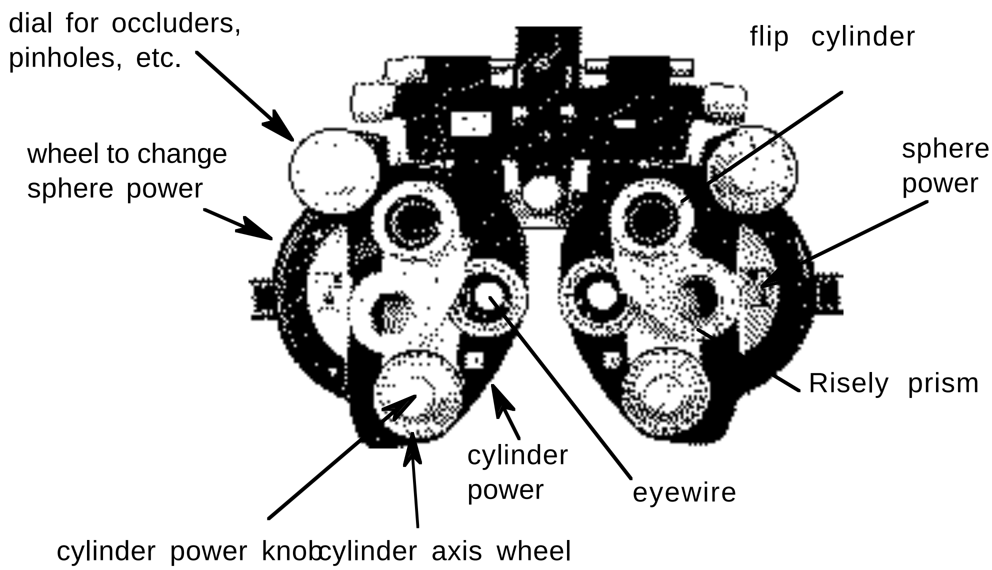
At this point in the refractive procedings, the doctor has an estimate of the patient's equivalent sphere from visual acuity and ophthalmoscopy and his cylinder from keratometry.

Refractors

Most of the remaining procedures require some sort of device to hold lenses in front of the patient. The simplest--and oldest--device is the trial frame. A trial frame looks like a pair of spectacles, but holds lenses from a trial set. Most North American optometrists find changing lenses in trial frames too slow and awkward for routine use.

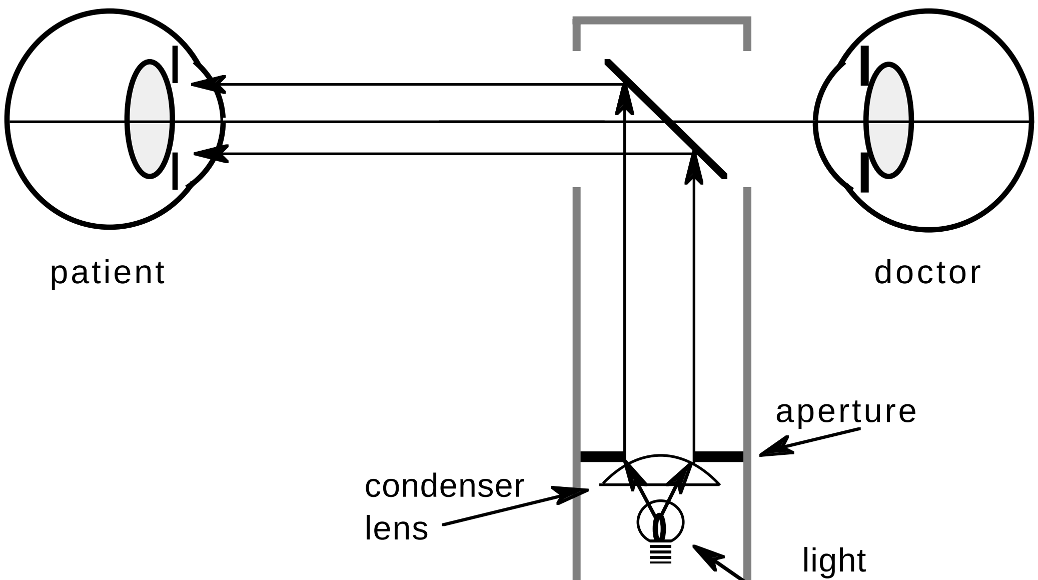
A variant of the trial frame is the trial clip. Trial clips clip on to the patient's habitual spectacles. Over-refractions are done on the patient by placing trial lenses in the trial clip which holds lenses just like the eyewires of a trial frame.

The <u>phoroptor</u> or <u>refractor</u> permits convenient and rapid manipulation of lenses during routine optometric use. The illustration below shows a typical modern phoroptor with many of its parts labelled.



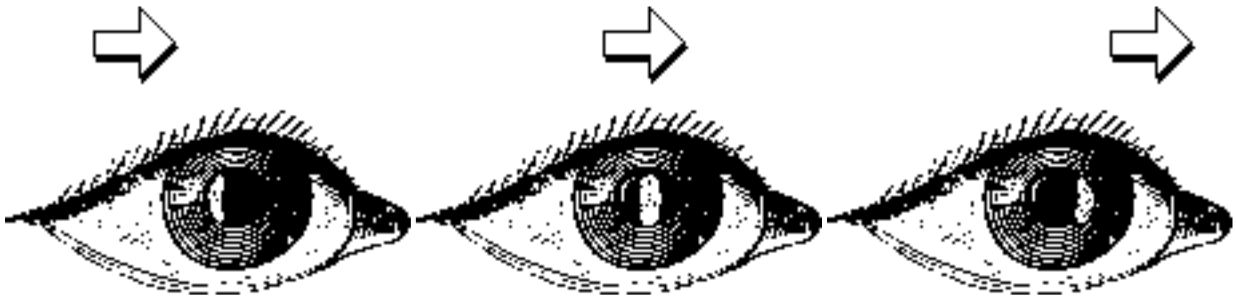
Retinoscopy

The retinoscope permits an "objective" estimate of a patient's refraction in which no subjective responses are required of the patient. The doctor shines the retinoscope's light into the patient's eye and then wiggles the light beam while watching the red reflex from the patient's retina in the patient's pupil. The optics of the retinoscope is shown schematically below.

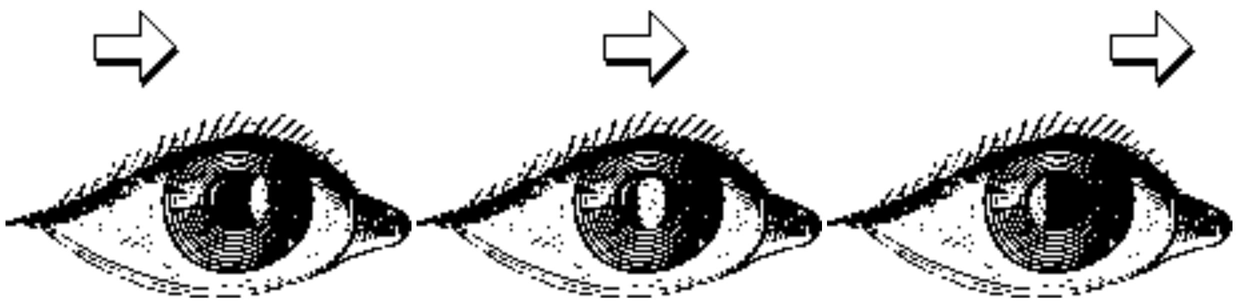


The illumination of the retina is achieved very much as it is with an ophthalmoscope. In the illustration, light leaving the retinoscope is collimated. Many instruments allow an adjustment of the position of the light source so that light leaving the retinoscope is convergent. For historical reasons, the position producing collimated light is the plane mirror position and the position producing convergent light is the concave mirror position. The aperture in the instrument can be round so that the retinoscope projects a spot of light making it a spot retinoscope. Nowadays the aperture is usually a slit so the retinoscope projects a stripe of light making it a streak retinoscope. A knob on the instrument permits the doctor to rotate the aperture.

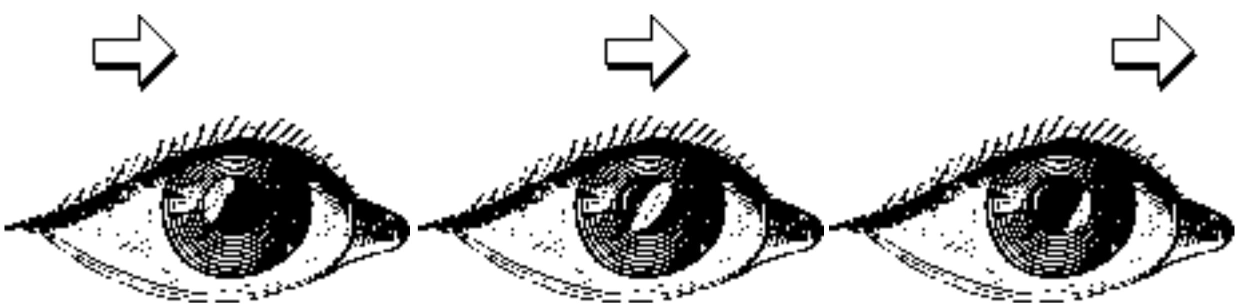
When the doctor moves the retinoscope beam across the patient's eye, the reflex can move in the same direction--with motion, in the opposite direction--against motion, or off at an angle--oblique motion. These motions are illustrated below for a streak retinoscope. The arrows show the direction of motion of the beam and the reflex is shown in the pupil.



with motion--add plus lenses to neutralize



against motion--add minus lenses to neutralize



oblique motion--rotate slit to get with or against motion

The nearer the patient's and doctor's retinas are to conjugacy, the faster the motion of the reflex. The doctor's task is to first rotate the beam to eliminate oblique motion, thus placing his streak in a principal meridian, and then to neutralize each of the principal meridians by changing lenses in front of the patient to achieve very rapid movement and/or reversal.

The origin of the reflex motion is vignetting between the patient's pupil and the doctor's pupil. Interestingly, what the doctor actually sees when he watches the light leaving the patient's pupil is the shadow of his **own** iris.

There are many techniques for doing retinoscopy with a minus cylinder phoroptor streak retinoscope. Here are the steps in one common method.

1. Instruct the patient to look at a remote object like the big **E** on the acuity chart so as to relax his accommodation.

2. Sweep the beam across the patient's pupil adjusting the phoropter spherical lens until there is against motion in all meridians.

3. Rotate the slit to until oblique motion is eliminated. The principal meridians are along and perpendicular to the slit orientation.

4. Neutralize the meridian with fastest against motion using spherical lenses.

5. Rotate the slit 90° and neutralize the other meridian using cylinder lenses oriented with the cylinder axis along the slit.

6. Subtract the working distance compensation (the reciprocal of the distance from the patient's eye to the doctor's eye, usually 1.50D) from result in the phoroptor to obtain the patient's prescription.

The technique above neutralizes against motion. But with motion is easier to see. Here is a retinoscopic technique using with motion and a minus cylinder phoroptor.

1. Instruct the patient to look at a remote object like the big **E** on the acuity chart so as to relax his accommodation.

2. Sweep the beam across the patient's pupil adjusting the phoropter spherical lens until there is with motion in all meridians.

3. Rotate the slit to until oblique motion is eliminated. The principal meridians are along and perpendicular to the slit orientation.

4. Neutralize the meridian with fastest with motion using spherical lenses.

5. Rotate the slit 90° and neutralize the other meridian using spherical lenses. Count the number of additional "clicks" of plus lens necessary to achieve neutrality. Rotate the cylinder axis until it is perpendicular to the retinoscopis streak and dial that many clicks of minus cylinder into the cylinder cell.

6. Subtract the working distance compensation (the reciprocal of the distance from the patient's eye to the doctor's eye, usually 1.50D) from result in the phoroptor to obtain the patient's prescription.

Here is an example of a working distance compensation.

Example: A doctor's working distance (the distance from his eye to the patient's eye) in retinoscopy is 67cm. He gets neutral motion when a +2.75D lens is in the phoropter. What is the patient's spectacle prescription?

Solution: The dioptric equivalent of the working distance is 1/67cm=1.50D so the Rx is +2.75D-1.50D=+1.25D.

There are many other techniques and tricks for retinoscopy. For example, some doctors use the concave mirror position of the retinoscope to brighten the reflex, although that is scarcely necessary with the halogen bulbs now universally employed. By placing the focus of the retinoscopic beam in front of the patient, concave mirror position also reverses the direction of motion, i.e. with motion is neutralized with minus lenses and against motion neutralized with plus lenses. A few doctors also claim they can achieve great accuracy in cylinder axis by focusing the beam somewhat and rotating the streak until the streak lines up with the retinoscopic reflex.

The retinoscopy described above is actually static retinoscopy. Dynamic retinoscopy is performed in much the same manner but with the patient looking at a near target instead of the wall chart. Since the patient's accommodation and hence refractive state changes as lenses are added to obtain neutrality, interpretation of dynamic retinoscopy results is somewhat obscure. Dynamic retinoscopy occupied an important place in the analysis scheme of the Optometric Extension Program (OEP).

Monocular Subjective Examination

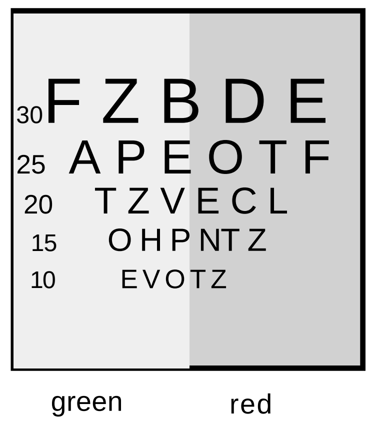
With the retinoscopic result, the doctor should be close to the proper prescription for the patient. That prescription is now typically refined with subjective techniques which require the patient's responses. The monocular subjective refracts one eye at a time, the refraction being completed in the binocular balance.

Equivalent Sphere

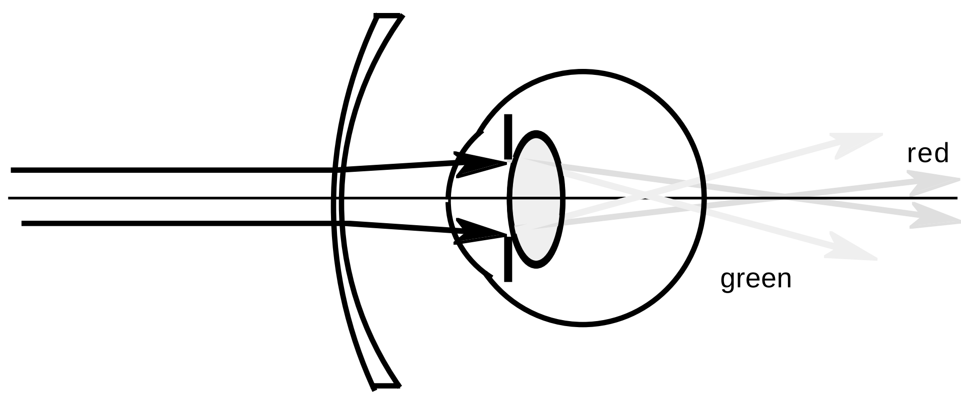
Assuming the patient doesn't suffer from ocular disease or amblyopia, his acuity through the retinoscopic result won't be too bad, hopefully 20/40 or better. The next step is to adjust the power of the spherical lens until the prescription in the phoroptor approximates the patient's equivalent sphere.

One way of doing this is to unfox to best visual acuity. Add plus spheres to the retinoscopic finding until the patient is blurred (fogged) then unfog by removing plus until acuity ceases to improve. A good rule to remember is that a -0.25D removal of fog improves acuity about one line on most acuity charts.

Another approach is to use the red-green test. This test takes advantage of the chromatic aberration of the eye. Due to that chromatic aberration, red light from a white object focuses behind green light.



In performing the test, a red-green mask is slid over the acuity chart in the projector so the chart looks like the illustration above.

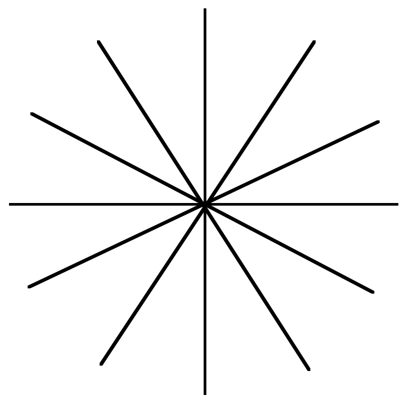


If the appropriate equivalent sphere sits before the patient, the letter in the red and green will correspond to equal blur circles and hence be equally clear, as in the diagram.

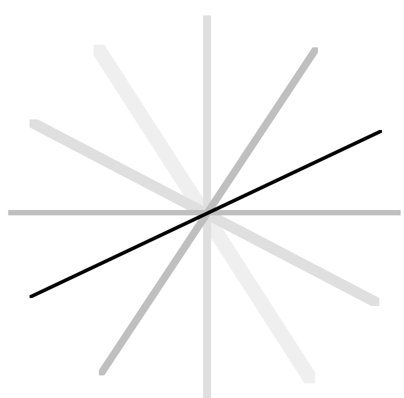
Cylinder Determination

There are many, many ways of determining the patient's refractive cylinder, but only a few in common use. Here are four, three common and one esoteric.

The fan dial determines cylinder by asking asking a patient to look at a chart like that shown below with twelve lines radiating from its center and identify the line which is sharpest and clearest. The patient should be slightly fogged with no cylinder lens in the phoroptor.

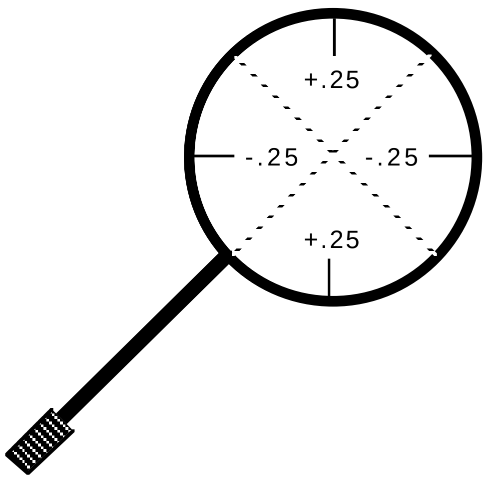


To the patient the chart may look like the illustration below. He identifies the clearest line by giving its clock position, two o'clock in the example. The cylinder axis is thirty times the clock position, 30x2=60° in this example. The phoroptor cylinder is set at that axis and cylinder power is increased until all lines are equally clear. That is the patient's cylinder correction. As cylinder power is added, sphere power should be adjusted to keep equivalent sphere constant, +0.25DS for every -0.50DC.



The most common technique in practice uses the Jackson cross cylinder variously known as the Stokes lens, flip cylinder, or simply cross cylinder.

The cross cylinder is a lens with the same power but opposite signs in the two principal meridians, e.g. +0.25DCx045/-0.25DCx135. The equivalent sphere is, of course, zero. The cylinder powers vary, ±0.25DC and ±0.375DC being most popular. The lens is mounted so that by turning a knob it can be flipped around its principal meridians or around the meridian halfway between the principal meridians. On a phoroptor the flip cylinder is moved in front of the lens cell. The figure shows a hand held cross cylinder used in trial frame refractions. The hash marks are along the principal meridians. Usually the axis negative powered meridian is marked with red letters and the axis of the positive power meridian with white.



To refine an estimate of axis, place the cross cylinder with the principal meridians bracketing the approximate cylinder axis and flip the cylinder around the line between the principals meridians (one of the dotted lines in the figure above) while the patient compares the view of the chart. The patient should be directed to look at the smaller letters on the chart so as to recognize more easily small differences in sharpness. While flipping the chart ask the patient, "which way are the letters more clear, sharp, and easy to read; with lens 1 or [*flip*] with lens 2?" With a minus cylinder phoroptor move the cylinder toward the red hash mark while the cross cylinder is in the position giving greatest clarity, reallign the cross cylinder and try again. When the principal meridians of the cross cylinder bracket the patient's correct cylinder axis he will say, "both lenses look about equally clear." Then move on to power determination.

For power determination, align the principal meridians of the flip cylinder with the principal meridians of the patient's prescription. Flip the cylinder as before. If the patient finds the view clearest with the red hash mark superimposed on the cylinder axis, increase cylinder power. If he finds the view clearest with the white hash mark superimposed on the cylinder axis, decrease cylinder power. When both views are equally clear, quit.

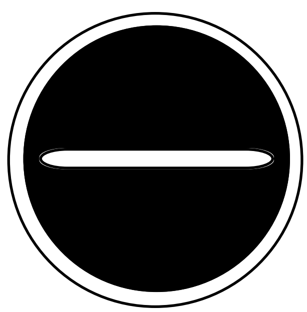
In practice, doctors often alternate between axis and power determination, continually refining estimates. Learning to make the process converge efficiently to an end point is part of the optometric craft.

Rotation to Best Acuity

An elegantly simple way of determining cylinder axis is to simply have the patient rotate the tentative cylinder until his acuity is best. This works best for high astigmatism where cross cylinder and fan dial often work poorly.

Stenopaic Slit

Stenopaic slits are found in most trial lens sets and consist simply of a piece of cardboard from which a slit shaped aperture has been cut out (see below).



Phoroptors don't usually have stenopaic slits but one can be made by masking off a slit on the -0.125D auxilliary cylinder and mounting in the cylinder cell.

While the patient is fogged as for a fan dial test, the patient or doctor rotates the slit before the eye to the position of clearest vision. The slit is now alligned along the minus cylinder axis. The doctor can now procede with a conventional subjective refraction or refract the two principal meridians separately with the stenopaic slit.

Trouble Shooting

So what do you do if at the end of the refraction the patient still has poor acuity, worse than, say, 20/20? Some possible causes are:

- ☞ a botched refraction
- ☞ amblyopia
- ☞ corneal distortion
- ☞ ocular disease such as cataract or macular degeneration
- ☞ malingering

Some tests useful in diagnosis are:

- ☞ pinhole acuity. A pinhole placed before the eye shrinks the diameter of the retinal blur circle, effectively shunting the optics of the eye-spectacle system. If the pinhole improves the acuity, the patient has a refractive anomaly, either a botched refraction or a distorted corneal. Since diffraction limits pinhole acuity to 20/25 or worse, this test only helps if the refraction produces acuity in the 20/40 range or worse.
- ☞ direct ophthalmoscopy. This rules out most cataracts, macular disease, and many corneal conditions. The canny doctor does direct ophthalmoscopy **before** refraction for this reason.
- ☞ keratometer mire quality. If the image of the keratometer mires is distorted, the cornea is likely distorted too. This occurs most frequently as a sequel to rigid lens wear.
- ☞ acuity through a trial rigid lens. If acuity improves with a rigid lens (with or without over-refraction lenses), there is something wrong with the patient's cornea since the rigid lens behaves optically like an artificial cornea.

☞ The patient's demeanor and responses during refraction usually tip off the experienced doctor to the malingerer. There are a variety of tests to confirm malingering. One that's often helpful is to retake the patient's visual acuity with the patient 10 ft instead of 20 ft from the chart. This has negligible effect on the vergence from the chart. From geometry, then, the patient should read a line half the size of his previous acuity, e.g. a patient who claims to only read the 20/80 with the doctor's best refraction at 20 ft should read the 20/40 line at 10 ft. Most malingerers do not understand that geometric relationship and will continue to read only the 20/80 line.

