Podcast edition

# OPTICS AND REFRACTION OUTLINE


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# PART 1: BASICS

## Relationships to Remember

### Relationships to remember: The most basic

| | |
|---|---|
| Prentice's Rule | $\Delta = h * D$ |
| Vergence formula | $U + D = V$ |
| Focal length | $f = \frac{1}{D}$ |
| Spherical equivalent | (sphere) + (1/2)(cylinder) |

### Relationships to remember: Power calculations

| | |
|---|---|
| *Refracting* power of a spherical surface | $D_s = \frac{n'-n}{r}$ |
| Power of a thin lens immersed in fluid | $\frac{D_{air}}{D_{aqueous}} = \frac{(n_{IOL}-n_{air})}{(n_{IOL}-n_{aqueous})}$ |
| *Reflecting* power of a spherical mirror | $D_{reflecting} = \frac{2}{r}$ |
| IOL power (SRK) | A - 2.5(Axl) - 0.9(K) |

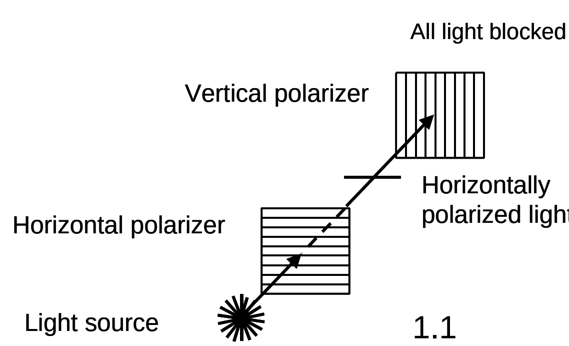
### Relationships to remember: Magnification

| | |
|---|---|
| Transverse magnification | $Mag = \frac{\text{Image distance}}{\text{Object distance}}$ |
| Axial magnification | $M_{axial} = (M_{tranverse})^2$ |
| Simple magnifier | $Mag = \frac{D}{4}$ |
| Telescope magnification | $Mag = \frac{D_{eyepiece}}{D_{objective}}$ |
| Spectacle lens | Mag = 2% per diopter of power |

# I. Physical Optics

A. Theories of light
1. Wave theory: light behaves like a wave
   a) frequency, speed, and wavelength
2. Particle theory: light behaves like a particle
   a) Discrete "packet" of energy is a photon.
3. Neither is perfect; both are used depending on the subject
4. Geometric optics:
   a) Most of what we cover in these notes
   b) Light is a "ray" - an artificial construct

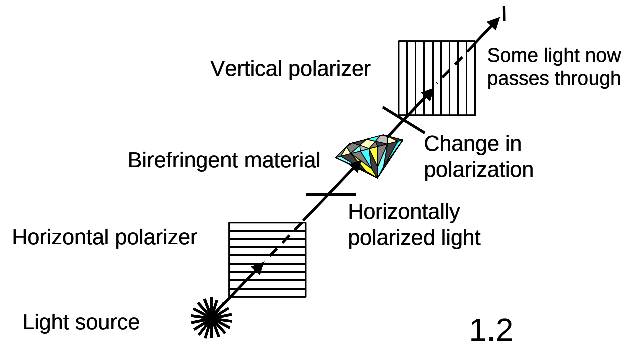
B. Polarization
1. Each light wave has an electrical field with a particular orientation.
2. A light beam is a collection of light waves.
   a) Non-polarized light - electrical field of each wave has random orientation.
   b) Polarized light - all electrical fields have same orientation.
3. Polarizing filter
   a) Only passes light polarized in one orientation
   b) **(Figure 1.1)** Crossed polarizers
      (1) One filter oriented at 90 degrees to another
      (2) All light is blocked



1.1

4. Clinical uses of polarized light
   a) "Haidinger's brushes"
      (1) entoptic phenomenon
      (2) seen when a polarizing filter is rotated in front of a blue background.
      (3) brush looks like a propeller,
   b) Titmus stereo testing
      (1) Polarized lenses allow different images to pass to each eye
      (2) Disparity between eyes converted to depth by brain

c) Polarized microscopy **(Figure 1.2)**
   (1) Crossed polarizers in path of light - field looks black to observer
   (2) Object of interest placed between polarizers
   (3) If object changes axis of polarization (birefringence), some light will get through and be visible to observer




1.2

d) Polarized sunglasses
   (1) Scattered and reflected sunlight is partially horizontally polarized
   (2) Polarized sunglasses use vertical polarizing filters to block horizontal component.

C. Interference
1. Occurs when two light waves overlap
   a) Constructive interference
      (1) Peak of one wave overlaps with peak of another, resulting in maximum intensity at that wavelength
   b) Destructive interference
      (1) Peak of one wave overlaps with valley of another, obliterating both waves
2. Applications
   a) Antireflection coatings
   b) Interference filters (fluorescein angiography)
   c) Interference fringe potential acuity device

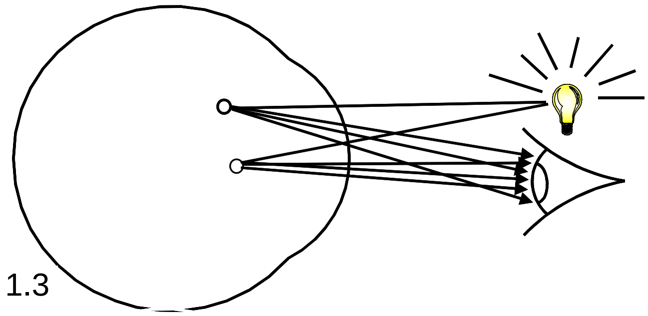
D. Coherence
1. Ability of two waves to interfere with each other
2. OCT (Optical coherence tomography)
   a) Uses *interference* to detect change in *coherence* of light passing through the layers of the eye

E. Diffraction
1. Light waves bend (spread) slightly when they encounter an aperture
2. The smaller the aperture, the greater the diffraction
3. Example: The pupil
   a) A pupil aperture of less than 2.5 mm begins to limit acuity.

F. Scattering
1. Light particles bounce off of gas molecules in the atmosphere
2. Blue light scatters more
   a) Responsible for blue appearance of sky

G. Reflection
1. **(Figure 1.3)** Asteroid hyalosis - reflected light from particles makes it difficult to observe patient's retina

2. **(Figure 1.4)** No light source inside of patient's eye - no problem with reflection (or with visual acuity)
3. Severe asteroid hyalosis: consider fluorescein angiography (effective light source inside of eye)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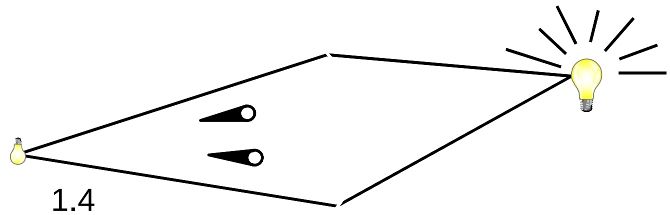
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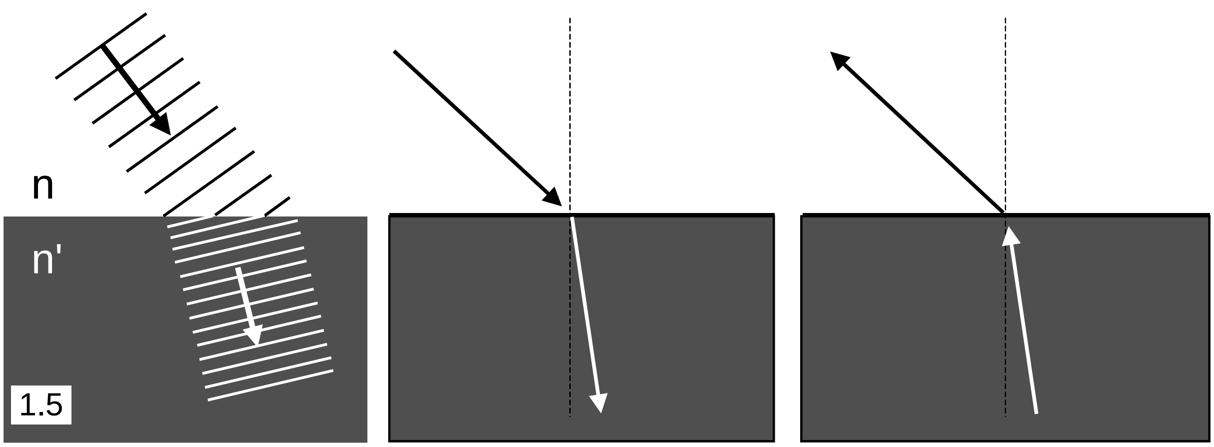
H. Power measurements
1. Radiometry
    a) Total light power
    b) Measured in watts
2. Photometry
    a) Responsiveness of eye to light power
    b) Measured in candelas, lumens, lux, foot candles, or apostlibs

I. Refractive index
1. The ratio of the speed of light in a vacuum to the speed of light in that material.
2. Table 1.1. Refractive index for different parts of the eye and for common lens materials.

| Material | n |
|---|---|
| Air | 1.00 |
| Water | 1.33 |
| Aqueous | 1.33 |
| Vitreous | 1.33 |
| Cornea | 1.37 |
| Crystalline lens | 1.42 |
| PMMA | 1.49 |
| Crown glass | 1.52 |
| High index lenses | 1.6 - 1.8 |

Table 1.1

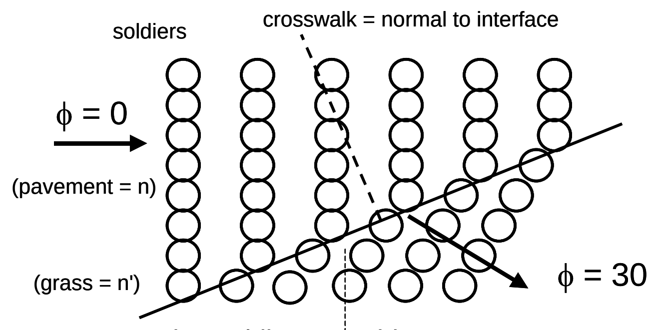
J. Snell's law: $n \sin ø = n' \sin ø'$
1. n is the index of refraction of a material and ø is the angle of a light ray within that material relative to the normal.
    **a)** Defines how strongly light is refracted (bent) when passing from one material to another **(Figure 1.5).**



1.5

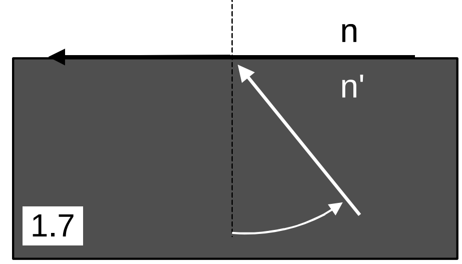
2. Direction of deflection:
    a) Towards normal when passing from a medium with a lower index of refraction to a higher one.
    b) Bent away from the normal when passing from high to low refractive index

c) Ways to remember this:
   (1) Think about higher index materials being harder for the light to get through, so the light rays take a shorter path.
   (2) Think of a line of soldiers marching on the pavement next to tall grass. The soldiers on the grass are slowed down, and the line of soldiers is bent toward the normal **(Figure 1.6)**



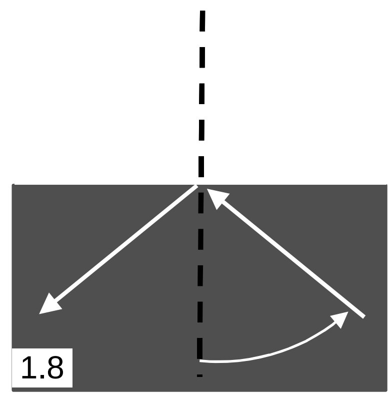

1.6 Imagine soldiers marching onto grass...

K. Critical angle
   1. Angle at which light is bent exactly 90° away from the normal **(Figure 1.7)**.
   2. Calculated using Snell's law.
   3. Example: Glass/air interface has critical angle of 41°.

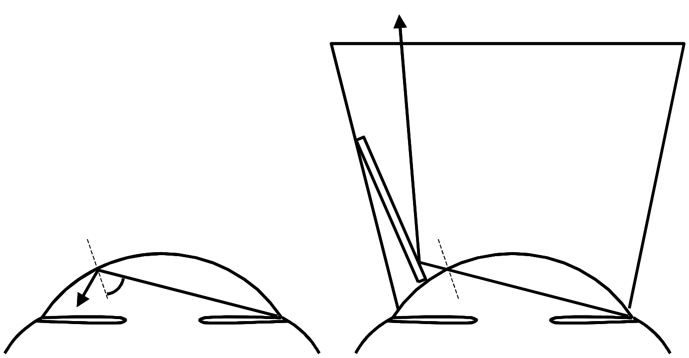



Critical angle

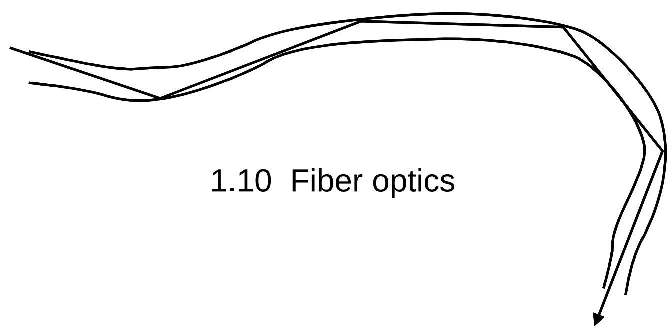
L. Total internal reflection
   1. Angle of incidence *exceeds* the critical angle **(Figure 1.8)**
      a) Light is not refracted
      b) It is reflected back into the material with the higher index of refraction
   2. Examples:
      a) Gonioscopy **(Figure 1.9)**
      b) Fiber optics **(Figure 1.10)**
      c) Indirect ophthalmoscope eye pieces




Greater than critical angle



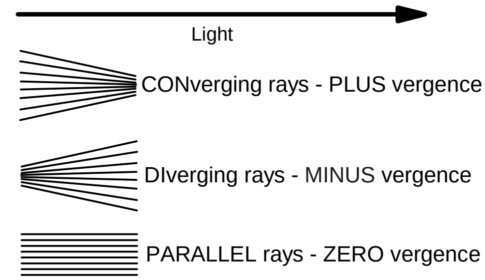
1.9 Gonioscopy



1.10 Fiber optics

# II. VERGENCE

A. The amount of spreading of a bundle of light rays coming from a single point **(Figure 2.1)**

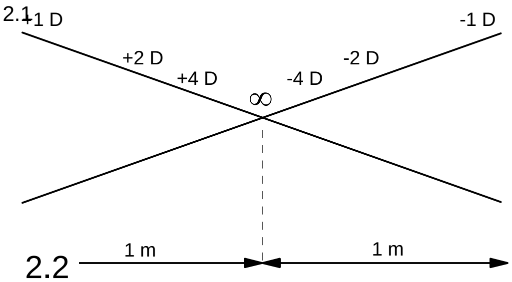



2.1

B. Direction of light travel must be specified
   1. Usually left to right unless otherwise indicated

C. Sign of vergence
   1. Plus vergence - converging light rays
      a) Rare in nature
      b) Must be produced by another optical system
   2. Minus (negative) vergence - diverging light rays
   3. Zero vergence - parallel light rays

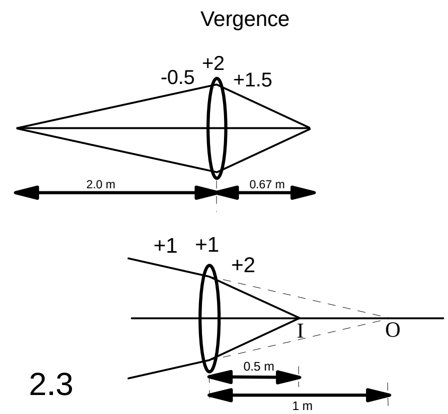
D. Diopter
   1. The reciprocal of the distance (in meters) to the point where light rays would intersect if extended in either direction **(Figure 2.2)** .




2.2

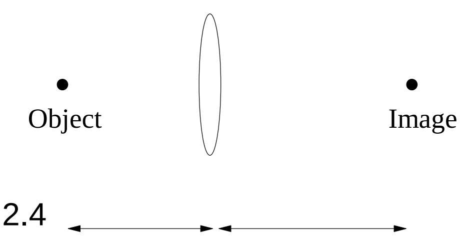
E. Lens function
   1. Adds vergence to light
   2. Amount of vergence = power of lens (in diopters)
   3. Sign
      a) Plus lens adds vergence
      b) Minus lens subtracts vergence

F. Basic lens formula
   1. U + D = V
      a) U = vergence of light entering lens
      b) D = power of lens (amount of vergence added by the lens)
      c) V = vergence of light leaving lens
   2. Examples from lecture in **Figure 2.3**




2.3

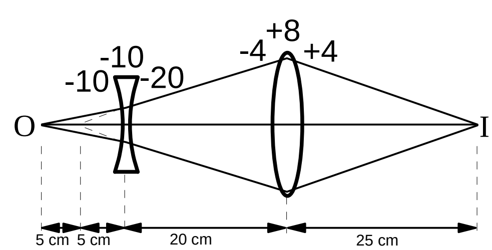
   3. Extra example: Object is 0.5 m from +5 D lens **(Figure 2.4)**




2.4

      a) U = 1/0.5 = -2 (negative because light leaving natural object is divergent)
      b) U + D = -2 + 5 = +3 = V
      c) Image is located 1/3 = 0.3 m to right of lens

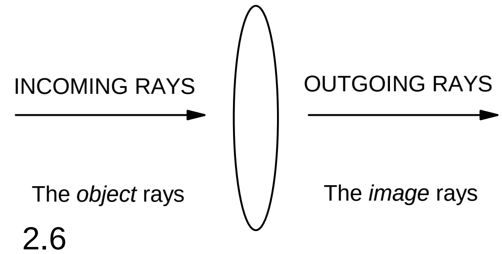
G. Multiple lens systems
   1. Apply U + D = V sequentially **(Figure 2.5)**
   2. Image of first lens becomes object of second lens



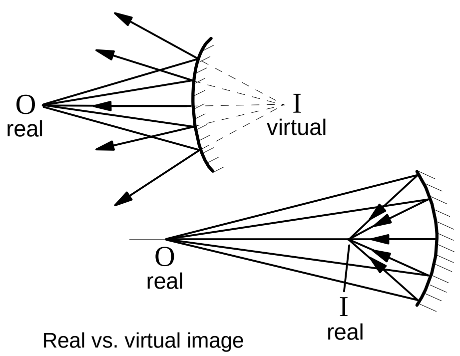

2.5 Two lens system

H. Object or image?

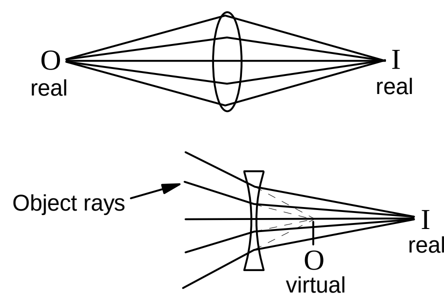
1. Again, assume light travels from left to right. **(Figure 2.6)**
2. Object rays
    a) Rays that define the object
    b) Always on incoming (left) side of lens
3. Image rays
    a) Rays that define the image
    b) Always on outgoing (right) side of lens




2.6



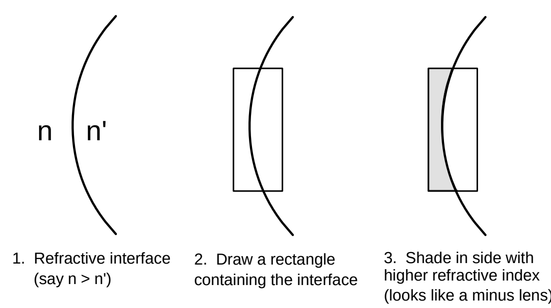

2.7 Real vs. virtual image




2.8 Real vs. virtual object

I. Real or virtual image?
1. Image itself can be on *either* side of lens **(Figure 2.7)**
2. Real image
    a) Image on same side of lens as actual rays of light that define the image (image rays)
3. Virtual image
    a) Image on opposite side of lens from image rays
    b) Image must be located by *imaginary extensions* of the light rays.
4. Real vs. virtual object - same definitions as above **(Figure 2.8)**
    a) Object can be on either side of lens
    b) Real if object on same side as object rays (left side of lens)
    c) Virtual if on opposite side of object rays (right side of lens).

J. Refracting power of a spherical surface
1. $D_s=(n'-n)/r$
    a) n' - n = difference in refractive index
    b) r = radius of curvature of surface (in meters)
2. Determine plus vs. minus power **(Figure 2.9)**
    a) Draw rectangle containing curved surface
    b) Shade in side with higher refractive index
        (1) If shaded side is convex, surface has plus power
        (2) If concave, surface has minus power
3. Example: Power (in air) of plano/convex PMMA




2.9 Refractive power of spherical surface lens with radius of curvature of 8 mm

a) n' = 1.49 (from section 1); n = 1.00; r = 0.008

b) D = +61.25 D

K. Power of thin lens immersed in fluid

1. Refracting power of a thin lens is proportional to the *difference in refractive index* between the lens and the medium.

   a) The radius of curvature does not change, so it does not need to be included in the equation.

$$\frac{D_{air}}{D_{fluid}} = \frac{n_{lens} - n_{air}}{n_{lens} - n_{fluid}}.$$

2. Example: Power of lens above when dunked into aqueous fluid

   a) $D_{air}$ = 61.25, $D_{fluid}$ = ?

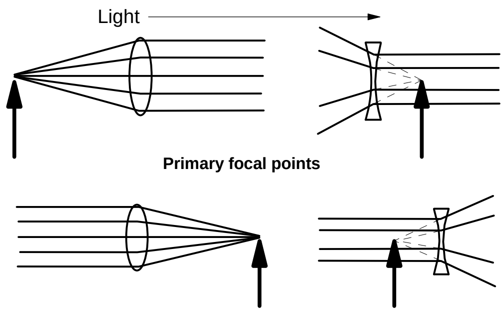
   b) $n_{lens}$ = 1.49, $n_{air}$ = 1.00, $n_{fluid}$ = 1.33

   c) Fill in blanks above. (61.25 / $D_{fluid}$) = 3.06.

   d) Solve for $D_{fluid}$ = 61.25/3.06 = 20.00 D in aqueous

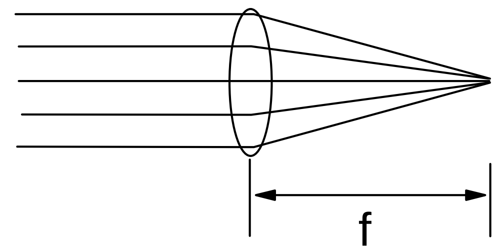
# III. LENSES AND RAY TRACING

A. Focal points




3.1 Secondary focal points

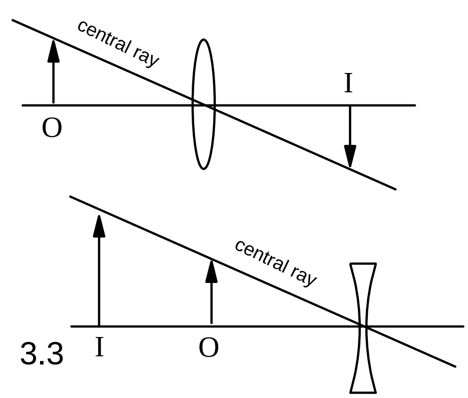
1. Focal point - point on one side of lens corresponding to parallel rays of light on the other side of the lens **(Figure 3.1)**
   a) Anterior (primary) focal point
      (1) Point along optical axis at which an object must be placed for parallel rays to emerge
      (2) Image is formed at infinity
   b) Posterior (secondary) focal point
      (1) Point along optical axis at where parallel rays are brought to focus




3.2 Focal length

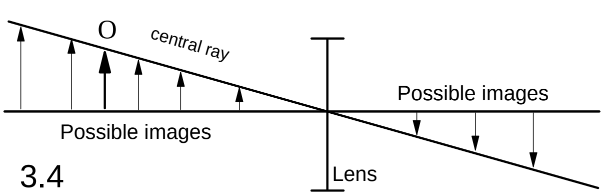
2. Focal length
   a) Distance from ideal lens to each of its focal points **(Figure 3.2)**
   b) If specified in meters, it is the reciprocal of lens power
   c) Example: Focal length of +10 D lens is 0.1 m.

B. Ray tracing

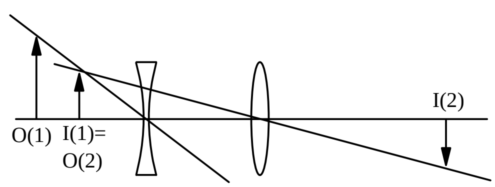



3.3

1. Central ray gives additional information **(Figure 3.3)**
   a) Image size
   b) Image orientation (upright vs. inverted)
2. Central ray is drawn from tip of object through center of ideal thin lens **(Figure 3.4, 3.5)**
   a) Object must be *extra-axial* - that is, it must extend away from the optical axis
   b) To use central ray:
      (1) Draw object with extra-axial extension to indicate height
      (2) Locate distance of image from lens (and side of lens) using U + D = V
      (3) Draw central ray
      (4) Draw image from location of optical axis up (or down) to central ray.
      (5) Tip of image corresponds with tip of object.




3.4



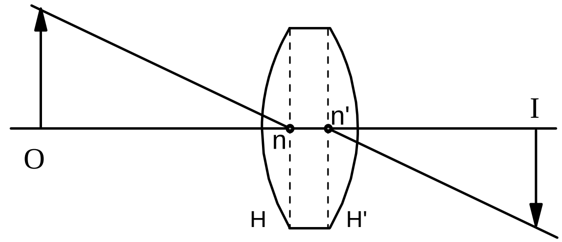

3.5 Central ray - multiple lens systems

C. Image size and orientation
1. Images may be located along the optical axis in two ways:
   a) Vergence formula (U+D=V)
   b) Ray tracing
2. Vergence formula easier to apply

3. Ray tracing gives image size and orientation
    a) Only the central ray is required

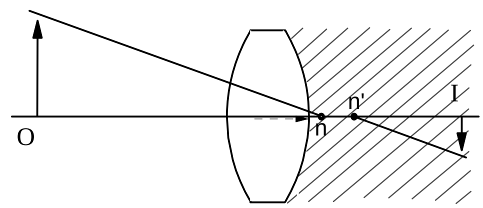
D. Thick lenses

1. Ideal thin lens fully described by optical center and two focal points **(Figure 3.6)**



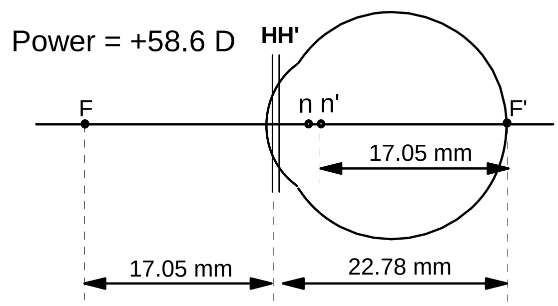
3.6 Thick lens

2. Not so simple in real life
3. Ordinary lens has six cardinal points
    a) Two principal points (or principal planes, H and H')
    b) Two nodal points (n and n')
    c) Two focal points (F and F')
4. Refraction occurs at principal planes
    a) U is measured from H; V is measured from H'
    b) Focal lengths are also measured from principal planes
5. Central ray passes through both nodal points
    a) Heads into the n
    b) "Jumps" across to n'
    c) Continues out of n' parallel to original direction
6. Nodal points coincide with principal planes
    a) Important exception: Different refractive medium on opposite sides of lens **(Figure 3.7)**
        (1) Example: Human eye has air on one side, aqueous on another
        (2) Nodal points are both "pulled" into medium with higher refractive index. Example: The human eye.



3.7 Nodal point shift

E. Gullstrand's schematic eye **(Figure 3.8)**

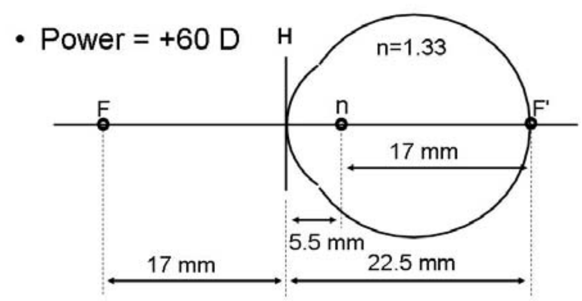


3.8 Gullstrand's schematic eye

1. Has two focal planes and two nodal points.
    a) Anterior focal point
        (1) Measured from the principal plane
    b) Posterior focal point
        (1) Measured from the nodal point.
        (2) Coincides with the retina

F. Reduced schematic eye **(Figure 3.9)**

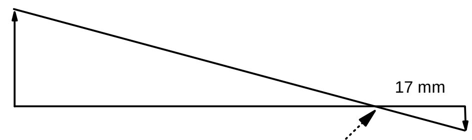
1. Easier to use than more complicated models
2. One surface, one nodal point and one equivalent plane
3. Accurate enough for most calculations



3.9 Reduced schematic eye

G. Can use schematic eye to generate formula to determine retinal image height for any object viewed by the eye **(Figure 3.10)** : $\frac{\text{Object height}}{\text{Retinal image height}} = \frac{\text{Distance from nodal point}}{17 \text{ mm}}$.

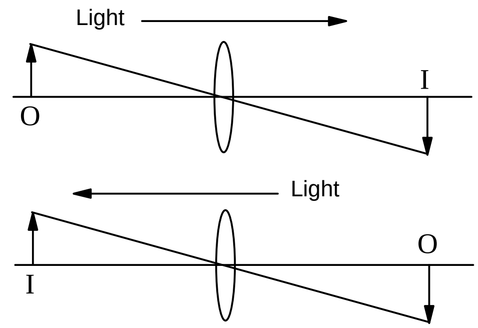
- a) Example
  - (1) Retinal image size of 10 cm object held 2 m from lens
    - (a) Obj height (100 mm)
    - (b) Distance from nodal point 2000 mm
      - (i) OK, 2005.5 mm, to be exact
    - (c) Cross multiply to solve for retinal image height = 0.85 mm




3.10 Retinal image size

H. Conjugate points and planes

1. A pair of corresponding object and image points is considered a pair of "conjugate" points **(Figure 3.11)**
2. If light is turned around, image and object switch places
3. Examples of conjugate planes
   - a) Projector screen and retina
     - (1) If light were turned around (for example, if fiber optic light source were placed inside of eye), image of retina would be visible on projector screen as long as eye is in focus on screen
     - (2) Even without fiber optic light source, image of retina is still present, just not visible
   - b) Direct ophthalmoscope
     - (1) Image of patient's retina is on examiner's retina
     - (2) Image of examiner's retina is on patient's retina
       - (a) Patient cannot see examiner's retina becau se most photons are traveling the wrong way
   - c) Indirect ophthalmoscope - 3 conjugate planes
     - (1) Patient's retina
     - (2) Aerial image plane
     - (3) Examiner's retina



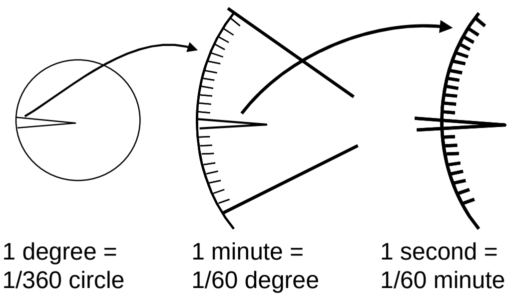

3.11 Conjugate planes

# PART 2: REFRACTION

## IV. VISUAL ACUITY TESTING

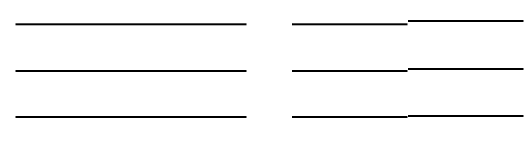
A. Pinhole acuity
   1. Pinhole reduces size of blur circle (increases depth of focus of eye)
   2. Can correct about 3 D of refractive error
   3. Optimal size is 1.2 mm
      a) Larger pinholes do not neutralize refractive error
      b) Smaller pinholes increase diffraction and decrease the amount of light entering the eye

Degrees, minutes, seconds of arc




4.1

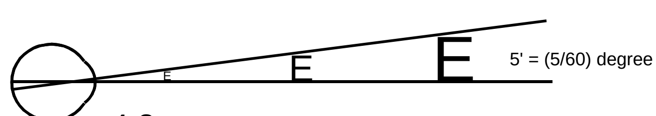
B. Types of visual acuity
   1. Minimum visible
      a) Detection of a black dot on a white background
      b) 1 to 10 arc seconds **(see Figure 4.1 for definition of arc second)**
   2. Minimum separable
      a) Also called minimum resolvable or minimum legible
      b) ordinary visual acuity
      c) 30 to 60 seconds of arc
   3. Vernier acuity **(Figure 4.2)**
      a) Also called hyperacuity or spatial minimum discriminable
      b) Detection of a break in a line
      c) 3 to 5 seconds of arc
      d) Less than the separation of photoreceptors!



4.2 Vernier acuity

C. Visual acuity charts
   1. 20 size optotype "E" from a chart that is meant to be viewed at 20 feet is 8.73 mm tall
      a) Each leg is 1.75 mm tall
      b) "E" subtends 5 minutes of visual angle
      c) Each leg and space subtends 1 minute of visual angle

D. Visual acuity testing in low vision patients **(Figure 4.3)**
   1. Low vision patients may not be able to see standard acuity chart
   2. Move patient and chart closer together
      a) Note size and distance of the optotype seen




4.3

      b) Example:
         (1) Patient reads 20/200 line from 20 feet
         (2) Move patient up to 5 feet away
         (3) If he reads 30 size optotype, at 5 feet, acuity is 5/30 or 20/120

        (4) Longer testing distance thus underestimated acuity
    c) If still unable to see chart at closer distance, may need less accurate measures:
        (1) Counting fingers at a certain number of feet
        (2) Hand motions
        (3) Light perception with or without projection

E. Near visual acuity
  1. Must be tested at a noted distance (usually 14")
    a) Reduced Snellen acuity (inches or cm)
    b) Jaeger
    c) Point type

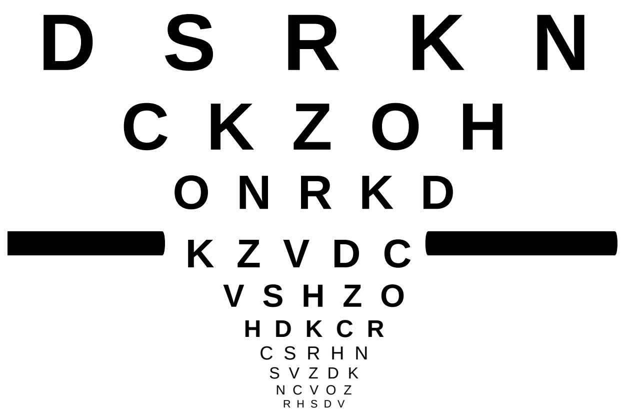
F. Visual acuity testing in preliterate children or illiterate adults
  1. Blink to light
  2. Optokinetic response
  3. Fixation behavior
    a) FFM (fixes, follows, maintains)
    b) CSM (central, steady, maintained)
    c) Preferential looking
        (1) Teller acuity cards
        (2) Vernier acuity cards
  4. Picture optotypes
    a) Allen figures
    b) Kindergarten chart
  5. Letter optotypes
    a) HOTV
    b) Illiterate (tumbling) E
  6. EEG-based
    a) VEP (visual evoked potential)
    b) Only method that does not require motor response from patient

G. Factors (other than disease) that reduce measured visual acuity.
  1. Uncorrected ametropia
  2. Eccentric viewing
  3. Decreased contrast
  4. Large (> 6 mm) or small (<2.5 mm) pupil size
  5. Young or old age

H. Legal blindness (US federal definition)
  1. Worse than 20/100 (ZERO letters on the 20/100 line), or
  2. Visual field in the better eye is 20° or less in diameter.
  3. Note: Visual requirements for driver's license vary by state

I. ETDRS (Early Treatment of Diabetic Retinopathy Study) eye chart.

1. Also known as the Ferris-Bailey distance visual acuity chart **(Figure 4.4)**
2. Used in large studies that use visual acuity as an outcome
3. Letters are of equal viewing difficulty
4. Five letters per line
    a) Space between letters is equal to letter size on that line
5. Geometric progression of optotype height
    a) Changes in 0.1 log unit increments.

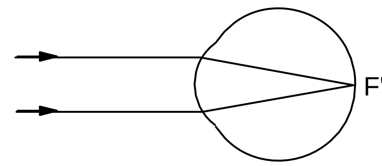



4.4. Ferris-Bailey distance visual acuity chart

# V. REFRACTIVE ERROR

A. Refractive error definition (in terms of focal point)

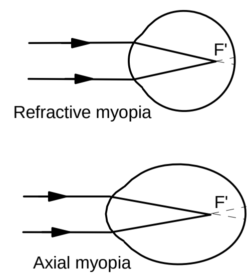
1. When secondary focal point (F') is not located on the retina
2. Accommodation completely relaxed
3. Emmetropia: Focal point is on the retina **(Figure 5.1)**
4. Myopia: Focal point in front of the retina
5. Hyperopia: Focal point behind the retina




5.1 Focal point in emmetropia

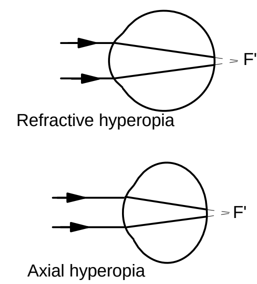
B. Axial vs. refractive myopia and hyperopia

1. Axial myopia **(Figure 5.2)**
   a) Refractive power of the eye is normal (about 60 D)
   b) Eye is too long
2. Refractive myopia
   a) Refractive power of the eye is too strong
   b) Eye length is normal
3. Axial hyperopia
   a) Refractive power of the eye is normal **(Figure 5.3)**
   b) Eye is too short
4. Refractive hyperopia
   a) Refractive power of the eye is too weak
   b) Eye length is normal
   c) Example: Apha kia




Focal point - types of myopia

5.2

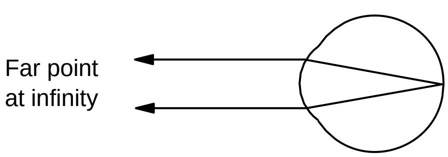



Focal point - types of hyperopia

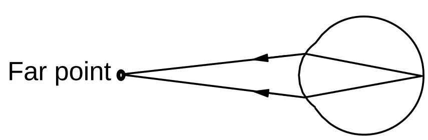
5.3

C. Refractive error definition (in terms of far point)

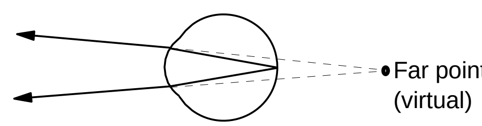
1. Far point: farthest away eye can see with accommodation completely relaxed.




5.4 Far point - emmetropia




5.5 Far point - myopia

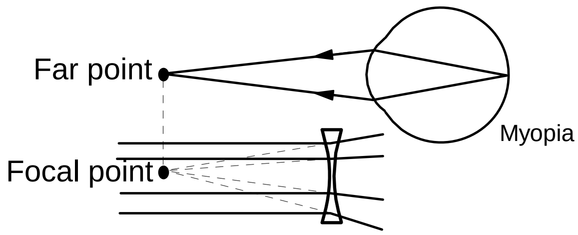



5.6 Far point - hyperopia

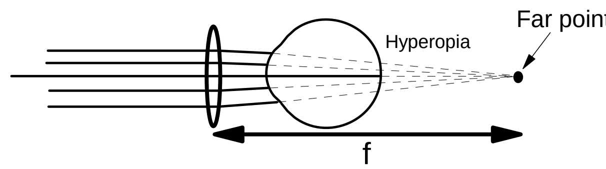
   a) Located by turning light around **(Figure 5.4)**
      (1) Start at a point on the retina
      (2) Trace rays of light backward through the optics of the eye
      (3) Point where rays intersect is far point of the eye
   b) Myopia - far point in front of eye **(Figure 5.5)**
   c) Hyperopia - virtual far point behind eye **(Figure 5.6)**
   d) Far point very different from focal point
      (1) Focal points never more than a few millimeters away from the retina
      (2) Far point can extend all the way to infinity

D. Correction of ametropia - steps

1. Locate far point of eye
    a) Myopic eye: Far point in front **(Figure 5.7)**
    b) Hyperpopic eye: Far point behind **(Figure 5.8)**




5.7 Correction of ametropia



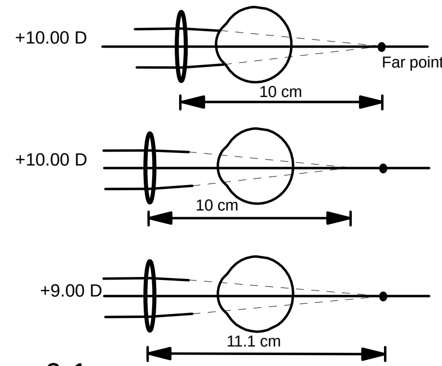

5.8 Correction of hyperopia

2. Select lens whose focal point coincides with far point
    a) Note: distance of lens from cornea makes a difference in lens power selected
3. That's all there is to it!

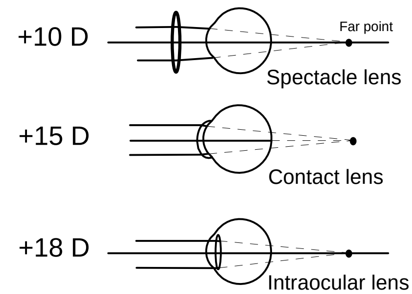
# VI. LENS EFFECTIVITY AND VERTEX DISTANCE

A. Lens effectivity - plus lenses

1. Moving lens away from the eye increases effective plus power **(Figure 6.1)**
    a) To correct refractive error with glasses, find lens with focal point that coincides with far point of the eye
    b) In a hyperope, far point is behind eye
    c) Moving lens forward moves its focal point forward
        (1) Lens is further away from far point of eye
    d) To match far point of eye, need longer focal length (lower power) plus lens
        (1) Current lens is effectively "too strong"
2. Moving lens toward eye decreases effective plus power
    a) The closer the lens is to the eye, the greater the power required to correct the same amount of hyperopia
    b) Aphakia is corrected by +10 to +12 D spectacles, or +15 D contact lens, or +18 to +20 D intraocular lens **(Figure 6.2)**




6.1 Lens effectivity - plus lens



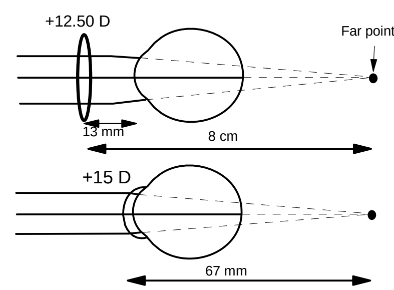

6.2 Lens effectivity - correction of aphakia

B. Vertex distance

1. Distance from the front of the cornea to the back of the optical correction
2. Most accurately measured with a Distometer®
    a) Measure from the back of the lens to the surface of the closed eyelid
    b) Distometer scale automatically adds 2 mm
3. Especially important with higher power spectacle corrections (≥ 5 diopters)
    a) Lens effectivity changes with distance from the eye.

C. Vertex distance conversion

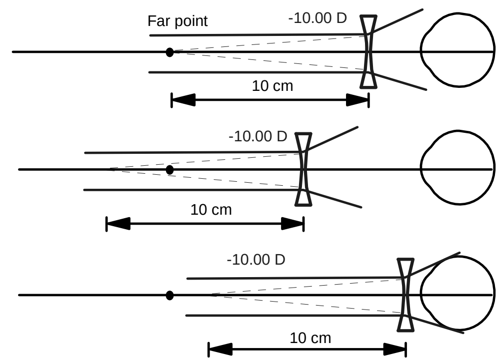
1. Locate focal point of present lens **(Figure 6.3)**
    a) This is the far point of the eye
2. Measure distance from new lens to far point
    a) Reciprocal of this distance = new lens power
3. Example: +12.50 D lens with 13 mm vertex distance
    a) Wish to change to contact lens
    b) Far point is 1/12.50 = 0.08 m behind spectacle lens
    c) New vertex distance is 80 mm - 13 mm = 67 mm
    d) 1 / 0.067 = 15; New contact lens power is +15.0 D
4. Note for myopes far point is in front of eye
    a) Example: -12.50 lens with 13 mm vertex distance has same effective power as a -10.75 D contact lens




6.3 Vertex distance correction

D. Lens effectivity - minus lenses

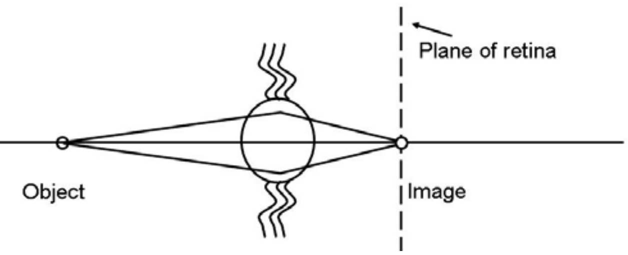
1. Myope's far point is in front of the eye **(Figure 6.4)**
2. Moving lens forward moves focal point further from far point of the eye
   a) Lens itself is now closer to far point
      (1) Shorter focal length (higher power) required to correct same refractive error
      (2) Thus current lens is "too weak" in its new position
3. In other words, moving lens forward increases its effective plus power (decreases effective minus power)
4. Both myopes and hyperopes may slide glasses down nose when reading to increase effective plus power (and decrease accommodative requirements)




6.4 Lens effectivity - minus lenses

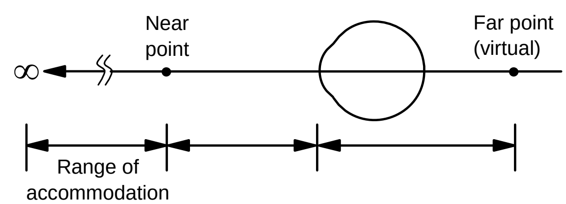
# VII. ACCOMMODATION AND PRESCRIBING BIFOCALS

A. Accommodation
  1. Increase in total dioptric power of eye
  2. Increased convexity of the lens
     a) Achieved through ciliary muscle contraction **(Figure 7.1)**



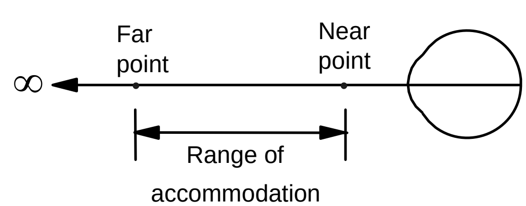

7.1

B. Accommodation - description
  1. Near point of accommodation
     a) A location
     b) Measured in centimeters or meters
     c) Closest the eye can see clearly with accommodation maximally active
        (1) More technically, the point on the visual axis conjugate to the retina when accommodation is maximally active
  2. Amplitude of accommodation
     a) A quantity
     b) Measured in diopters
     c) The maximum number of diopters that the eye can accommodate.
  3. Range of accommodation
     a) A range
     b) Measured in centimeters or meters
        (1) Expressed as two locations - a near point and a far point
     c) The linear distance over which a patient can accommodate and maintain clear vision




7.2 Range of accommodation - hyperopic eye

  4. Example (not same as example in projected slides): 3 D hyperope with 7 D amplitude of accommodation
     a) Without correction - far point at infinity (must use up 3 D of amplitude to see clearly at infinity); near point at 1/4 = 0.25 m (only 4 D of accommodation left for near work). Range = infinity to 25 cm **(Figure 7.2)**
     b) With correction - Far point still at infinity. Now can use all 7 D for near work - near point is 1/7 m. Range = infinity to 14 cm
  5. Example: 3 D myope with 7 D amplitude of accommodation
     a) Without correction - far point at 1/3 m. Has 3 D "head start" on accommodation. Near point therefore 1/(7+3) = 0.1 m. Range 33 cm to 10 cm **(Figure 7.3)**
     b) With correction - same range as hyperope.




7.3 Range of accommodation - myopic eye

C. Clinical measurement of accommodation
  1. Best distance correction in place
  2. Select near target
     a) Small near card with approximately 20/30 letters

3. Ask patient to maximally accommodate on the target
   a) Gradually move target closer to the eye while strongly encouraging the patient to keep it in focus
   b) Slide target along a rule scaled in both diopters and centimeters
      (1) Prince Rule
      (2) RAF (Royal Air Force) Rule
   c) Record point where the patient can no longer keep target in focus
4. Some patients have poor accommodation
   a) Cannot see near target at any distance
   b) Give a +3.00 add to bring the far point to 1/3 meter
   c) Now perform test as above
   d) Subtract 3.00 D from final result
   e) Example: A patient has 20/20 distance acuity with a refraction of +2.00 D OU. Can not see near card at any distance, even with correction. With +5.00 D in phoropter (+3.00 + +2.00), can see near target on Prince rule up to 25 cm away. Amplitude of accommodation would be (1/0.25) = 4 D, but you gave a +3.00 D head start, so true amplitude of accommodation is 4-3 = 1.00 D.

D. Typical amplitudes of accommodation based on age:

| Age | Average amplitude of accommodation |
|---|---|
| 40 | 6 D |
| 44 | 4 D |
| 60 | 1 D |

Table 7.1

E. Determination of bifocal add: 3 methods

1. Measure amplitude of accommodation
   a) Most rigorous method
      (1) Determine preferred working distance
      (2) Take reciprocal
      (3) Subtract half of accommodative amplitude
      (4) Remainder is recommended add
   b) Example: Preferred working distance 1/3 meter. Reciprocal = +3.00 D. Accommodative amplitude 1.00 D. Recommended add = 3.00 - (1.00/2) = +2.50 D.
   c) Good for unusual cases
      (1) Early presbyope on borderline for bifocals
      (2) Asymmetric accommodative ability
         (a) Trauma
         (b) Tonic pupil
      (3) Not happy with new reading add
2. Use tables
   a) Much less exact, but faster
      (1) Determine preferred working distance
      (2) Subtract half of accommodative amplitude taken from table
      (3) Remainder is recommended add

b) Accommodative amplitude varies widely among any age group

c) Probably acceptable for patients where need for reading add is clear and no reason to expect unusual accommodative ability

3. Trial and error in office

F. Types of hyperopia

1. Absolute hyperopia

a) Minimum plus correction required for clear vision at distance

b) Non-cyclopleged

2. Manifest hyperopia

a) Maximum plus correction the eye can accept without blurring of vision

b) Non-cyclopleged

3. Facultative hyperopia

a) Manifest hyperopia - absolute hyperopia

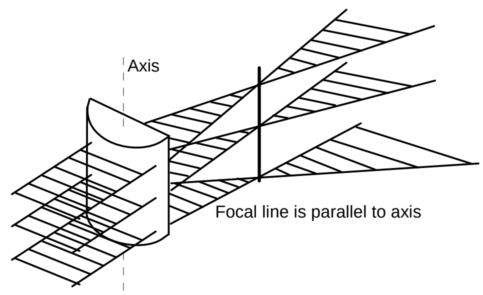
4. Latent hyperopia

a) Cycloplegic hyperopia - manifest hyperopia

5. Example: Absolute hyperopia 0.5 D, Manifest hyperopia 1.5 D, Cycloplegic (total) hyperopia 2.0 D. Therefore facultative hyperopia is 1.0 D, latent hyperopia is 0.5 D.

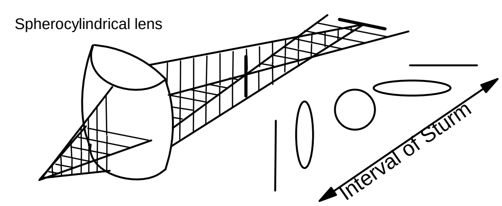
# VIII. ASTIGMATISM

A. Astigmatic lens (regular astigmatism)
   1. Different power in two meridians 90 degrees apart
   2. Produces two focal lines rather than a single focal point
   3. Pure cylindrical lens has power only in one meridian **(Figure 8.1)**
      a) Can be plus or minus power
      b) Power acts on planes of light perpendicular to axis of lens
      c) Produces focal line parallel to axis
         (1) Example: Illuminate a +3 D pure cylindrical lens with sunlight. When lens is held 1/3 m from ground, a focal line parallel to lens axis will be visible.
      d) Planes of light parallel to axis pass through without refraction



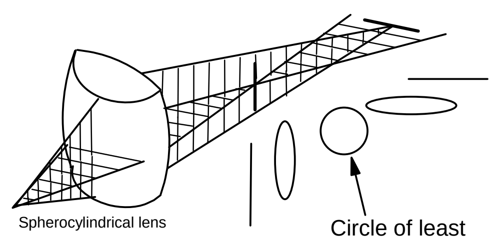

8.1 Pure cylindrical lens

   4. Spherocylindrical lens has power in two meridians **(Figure 8.2)**
      a) "Principal meridians"
      b) Can be described in three ways
         (1) Combination of two pure cylindrical lenses
         (2) Combination of spherical lens with minus cylindrical lens
         (3) Combination of spherical lens with plus cylindrical lens



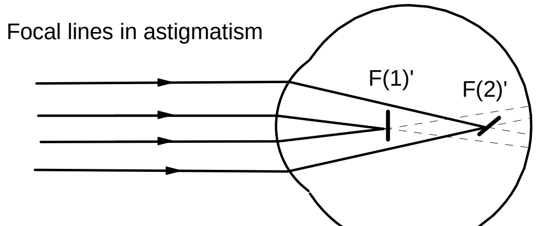

8.2 Astigmatic lens

B. Light rays produce characteristic pattern after passing through spherocylindrical lens
   1. Interval of Sturm
      a) Distance between the two focal lines
   2. Conoid of Sturm
      a) 3-dimensional envelope of light rays
      b) Geometrical figure formed by the rays of light
      c) Contains lens perimeter and focal lines
      d) Rays of light never focused to a point

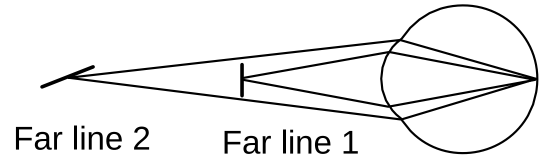



8.3

C. Circle of least confusion
   1. Located half way (in diopters) between focal lines **(Figure 8.3)**
      a) Take reciprocal of spherical equivalent of lens to locate circle of least confusion
      b) Light is equally blurred in all meridians
         (1) Conoid of Sturm has circular cross section at this point
         (2) Although letters are still blurred at this point, they are less distorted therefore easiest to recognize
      c) Shape determined by shape of lens aperture
         (1) Round pupil gives circular shape
         (2) Square aperture would give "square" of least confusion

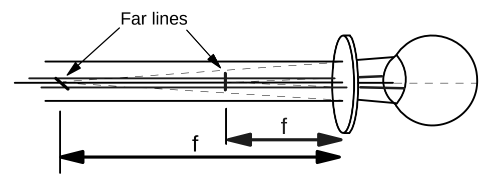



8.4 Compound myopic astigmatism



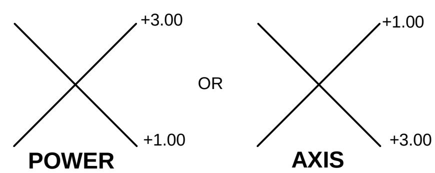

8.5 Far lines - astigmatism (compound myopic astigmatism)

D. Focal points (focal lines) in astigmatis
   1. Spherical lens has focal point; astigmatic lens has focal line
   2. Therefore astigmatic eye has not one focal point (off of retina) but rather two focal lines, either of which may or may not fall on the retina **(Figure 8.4)**
   3. Similarly, the astigmatic eye has not one far point but rather two far lines **(Figure 8.5)**
   4. Finally, to correct the refractive error of an astigmatic lens, you must choose a lens with two far lines that match the far lines of the astigmatic eye. **(Figure 8.6)**




8.6 Correction of astigmatism

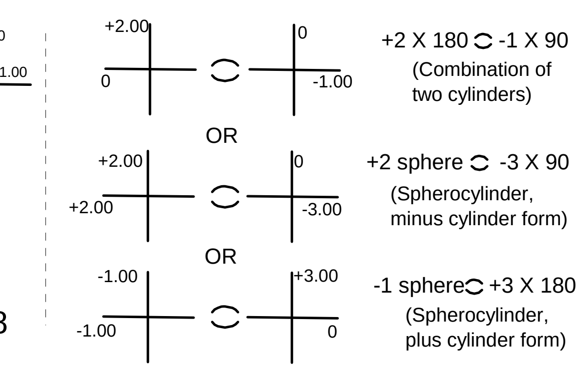
E. Cross diagram
   1. Diagram representing power on two principal meridians of astigmatic lens **(Figure 8.7)**
   2. Usually a power cross - label indicates power acting in that meridian
   3. Occasionally use axis cross - label indicates axis of power
      a) Used during retinoscopy with free lenses
      b) Important to indicate when axis cross is used to avoid confusion




8.7 +3.00 acting in the 45° meridian
+1.00 acting in the 135° meridian

F. Converting cross diagram of pure cylindrical lens to glasses Rx notation
   1. Spherical power is plano
      a) We just said it is a pure cylindrical lens
   2. Cylindrical power is on other arm of cross
   3. Axis is 90 degrees away from power
   4. Example: plano + 2.00 x 180
      a) Or +2.00 - 2.00 x 90 (see below)

G. Converting cross diagram of spherocylindrical lens to glasses Rx - Two methods **(Figure 8.8)**
   1. Two cross method
      a) Draw power cross as combination of two pure cylindrical lenses
      b) Add power to arm of first cross to convert it to spherical lens
         (1) Can use either of the two crosses
         (2) This is the spherical power of the glasses Rx



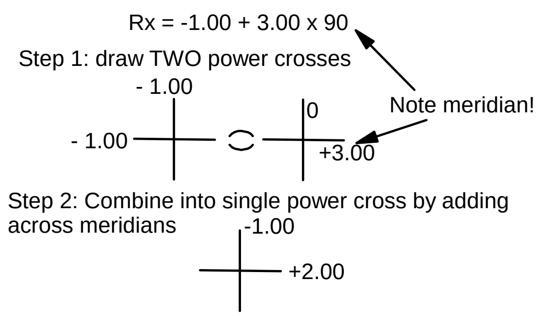

8.8

c) What you give to arm of first cross you must take away from arm of other cross to keep power of combination the same
   (1) This is the cylindrical power of the glasses Rx
d) Axis of glasses Rx is 90 degrees away from power
e) Example: -1.00 + 3.00 x 180 (or +2.00 - 3.00 x 90)

2. One cross method
   a) This method is faster because it requires less drawing but it is easier to get confused
   b) Select one arm of cross to be the sphere
      (1) Can use either arm
         (a) Choose more positive (less negative) arm to end up with minus cylinder
         (b) Choose more negative (less positive) arm to end up with plus cylinder
      (2) This will be spherical part of glasses Rx
   c) How much power must be added to first arm to get power on second arm?
      (1) This is cylindrical power of glasses Rx
   d) Axis of cylinder is 90 degrees away from meridian of second arm
   e) Try for example above
3. Use method that you are most comfortable with
4. Check your work
   a) Draw a power cross (see below) from the prescription you obtain
   b) Should bring you back to the original cross

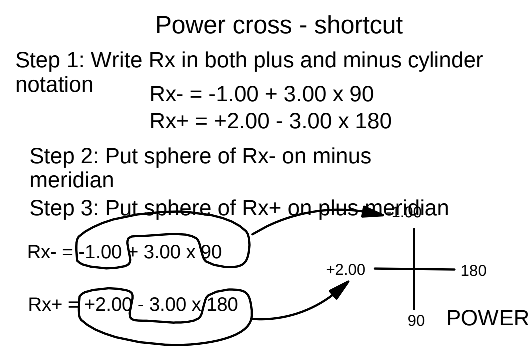
H. Converting glasses Rx to power cross: Two methods

1. Example 1 is in lecture – just the reverse of what we did above
2. Example 2: -1.00 + 3.00 x 90
3. Two power cross method **(Figure 8.9)**




8.9 Making a power cross

   a) Draw power cross for sphere and second power cross for cylinder
      (1) First power cross has -1.00 on both arms
      (2) Second power cross has plano in 90 meridian; +3.00 in 180 meridian
         (a) Remember, axis is 90 degrees away from power!
   b) Combine two power crosses into single power cross by adding across the meridians
      (1) Resultant power cross will have
         (a) -1.00 in 90 meridian (-1.00 @ 90)
         (b) +3 + -1 = +2 in 180 meridian (+2.00 @ 180)
         (c) Again, this is not the same as the example in the lecture slides
   c) Check your work by converting back to glasses Rx
4. Easy method **(Figure 8.10)**




8.10

   a) Write Rx in plus cylinder notation: -1.00 + 3.00 x 90
   b) Write Rx in minus cylinder notation:

+2.00 - 3.00 x 180

c) Drop cylinders and change "x" to "@"
 (1) -1.00 @ 90
 (2) +2.00 @ 180

d) That's your power cross!

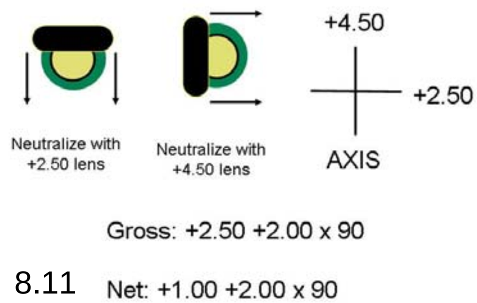
5. First method demonstrates better understanding of underlying principles. Second method must be memorized but requires no thinking.

I. Transposing plus to minus cylinder

1. New sphere = old sphere + old cylinder
2. New cylinder = same power as old cylinder with opposite sign
3. New axis = 90 degrees away from old axis

J. Retinoscopy with free lenses **(Figure 8.11)**

1. Orientation of streak = AXIS
2. Direction of movement = meridian of power
3. Sweep first principal meridian; record on *axis* cross
4. Sweep second principal meridian; record *axis* cross
5. Convert to spherocylindrical notation (note that you already have an axis cross)
6. Subtract working distance from sphere value



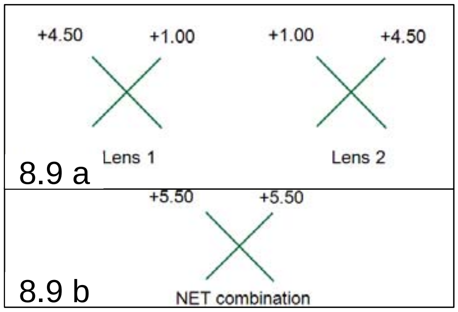

8.11

K. Combining cylinders at oblique axes

1. Refinement of high-powered Rx best done as over-refraction
 a) Going back to Phoropter adds too many variables
  (1) Vertex distance
  (2) Additivity error of multiple lenses
2. Usually old Rx already has cylindrical power
3. Sometimes over-refraction reveals new cylindrical power
 a) Example:
 b) Old Rx: +10.00 +1.00 x 180 gives 20/50.
 c) Over-refraction: -0.25 + 1.50 x 25 gives 20/20
4. New Rx can be determined two ways
 a) Carefully put old Rx AND trial lenses in lensmeter
  (1) Can read new Rx directly from lensmeter
 b) Otherwise requires complicated trigonometric calculation, though you can try to estimate without doing the calculations (next section)

L. Combining cylinders: Estmation method

1. Example: Rx +1.00 +3.50 x 45, combine with +1.00 +3.50 x 135, what is the approximate orientation and magnitude of the combined cylinder?
 a) Draw power cross for lens 1 and lens 2 **(Figure 8.9a)**
 **b)** Add across meridians **(Figure 8.9b)**




8.9 a

8.9 b

c) Review the result. As you can see, in this case both arms of the power cross have the same power, and the final lens power is actually +5.50 sph.

d) When the axes are not identical, you might want to approximate and assume that they are close to the same.

M. Types of astigmatism: Astigmatism classified two different ways

1. Depending on location of focal lines of eye **(Figure 8.10)**

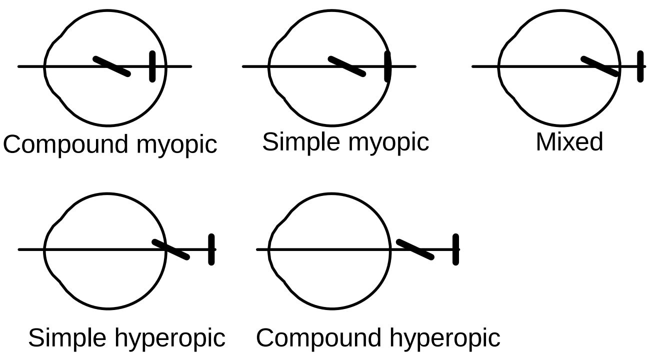
a) Compound myopic
(1) Both focal lines in front of retina

b) Simple myopic
(1) One focal line on retina
(2) One focal line in front of retina

c) Mixed
(1) One focal line in front of retina
(2) One focal line behind retina

d) Simple hyperopic
(1) One focal line on retina
(2) One focal line behind retina

e) Compound hyperopic
(1) Both focal lines behind retina

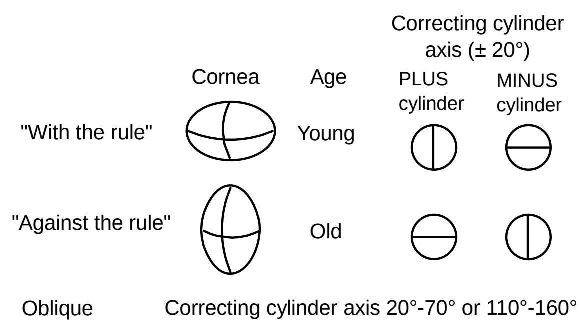



8.10 Types of astigmatism



2. Depending on orientation of astigmatism

a) With the rule **(Figure 8.11)**
(1) Cornea steepest in vertical meridian
(2) Typically seen in young patients
(a) Elastic lids press on top and bottom of cornea
(3) Axis of PLUS correcting cylinder within 20° degrees of vertical
(4) Axis of MINUS correcting cylinder within 20° degrees of horizontal

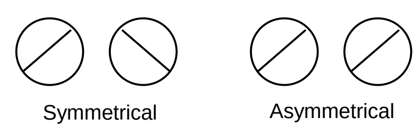



8.11 Types of astigmatism

b) Against the rule
(1) Cornea steepest in horizontal meridian
(2) Typically seen in older patients
(3) Axis of PLUS correcting cylinder within 20° of horizontal
(4) Axis of MINUS correcting cylinder within 20° of vertical

c) Oblique **(Figure 8.12)**
(1) Correcting cylinders not within 20° of horizontal or vertical
(2) Can be symmetric or asymmetric

d) This terminology allows plus cylinder people to talk to minus cylinder people




8.12 Oblique astigmatism

N. Determination of type of astigmatism based on glasses Rx

1. Determined by drawing power cross
2. Shortcut: Write Rx in BOTH plus and minus cylinder forms
3. Look at spherical power only and consult Table 8.1:

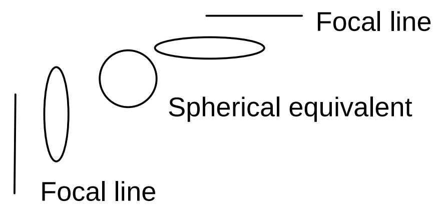
| Minus cyl format<br>Spherical power | Plus cyl format<br>Spherical power | Type of astigmatism |
|---|---|---|
| Positive | Positive | Compound hyperopic |
| Negative | Negative | Compound myopic |
| Plano | N/A | Simple myopic |
| N/A | Plano | Simple hyperopic |
| Negative | Positive | Mixed |
| Positive | Negative | Mixed |

Table 8.1

4. With-the-rule vs. against-the-rule vs. oblique determined by axis of correcting cylinder, as described above
5. Example
    a) +4.00 +2.00 x 105
    b) Minus cylinder format: +6.00 - 2.00 x 15
    c) Look at sphere - both are positive
    d) Must be compound hyperopic astigmatism
    e) Look at axis of correcting cylinder
        (1) Plus cylinder within 20 degrees of vertical. Must be with the rule. OR
        (2) Minus cylinder within 20 degrees of vertical. Must be with the rule

O. Spherical equivalent

1. Average spherical power of a spherocylindrical lens **(Figure 8.13)**
2. Sphere + (1/2) cylinder
3. Spherical equivalent of refractive correction places circle of least confusion on retina
4. During refraction, every 0.50 D change in astigmatic power should be balanced by a 0.25 D change in sphere power in the opposite direction



8.13

    a) Allows refinement of astigmatic power without changing spherical equivalent of lens
    b) Keeps circle of least confusion on retina

P. Jackson cross cylinder

1. Astigmatic lens with plano spherical equivalent
    a) Used to refine axis during subjective refinement of refraction
    b) Allows axis or power of cylinder to change without changing spherical equivalent of lens
2. Rx for ±1.00 D Jackson cross cylinder oriented with handle held in 90 degree meridian, white dot in 135 degree meridian
    a) Plus cylinder power at 135 degrees
        (1) Draw a power cross for better understanding
        (2) Power is +1.00 in one meridian, -1.00 in the other
    b) Plus cylinder notation: - 1.00 + 2.00 x 045
        (1) When flipped, Rx is -1.00 + 2.00 x 135
    c) Minus cylinder notation: +1.00 - 2.00 x 135

(1) When flipped, Rx is +1.00 - 2.00 x 45

d) Axis is determined by orientation of cross cylinder handle

3. Change in Rx when Jackson cross cylinder is flipped (refining power):

a) Example: Rx in trial frame is +4.00 +2.00 x 45

b) Rx with Jackson cross cylinder held over trial frame as above: +5.00 sphere

(1) Draw power cross for Rx

(2) Draw second power cross for Jackson cross cylinder

(3) Add meridians and write new Rx for combination

c) Rx with Jackson cross cylinder flipped: +3.00 +4.00 x 45

Q. Tight suture after cataract extraction: Example

1. Keratometry following cataract extraction

a) 40.00 @ 30

b) 43.00 @ 120

2. Look for tight suture in 120° meridian (11 o'clock)

3. If no tight suture and giving glasses Rx

a) Note 3 D difference between meridians

b) Will be corrected with 3 D cylindrical spectacle lens

c) 120° meridian is steepest

(1) It has the most plus power

d) Neutralized by -3.00 D of power in that meridian.

(1) Astigmatic refractive power exerted in the 120° meridian has its axis 90° away (at 30)

e) Glasses Rx will have cylinder power of -3.00 D x 30

f) Spherical power of glasses Rx depends on spherical refractive error of eye

(1) If required cylindrical correction has plano spherical equivalent, Rx is +1.50 - 3.00 x 30

(2) If spherical equivalent of eye's refractive correction is +1.00, Rx will be +2.50 -3.00 x 30.

4. Tight suture steepens cornea in that meridian **(Figure 8.14)**

a) Tight suture actually flattens cornea directly under suture

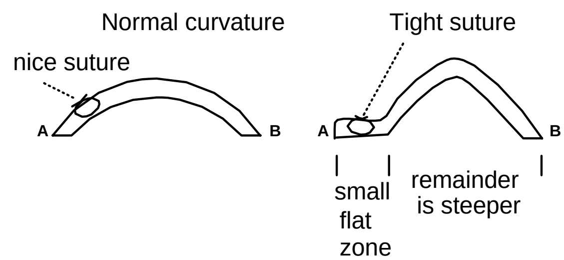
b) Circumference of globe must remain constant

c) Flattening under suture balanced by compensatory *steepening* of central cornea

5. K reading is higher in meridian of tight suture

a) Look for tight suture in meridian with steeper keratometry reading

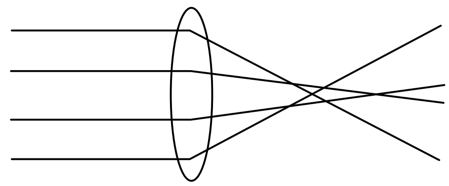
b) "Cut the higher K"




8.14 Distance A-B does not change!

# IX. ABERRATIONS, DISTORTIONS, AND IRREGULARITIES

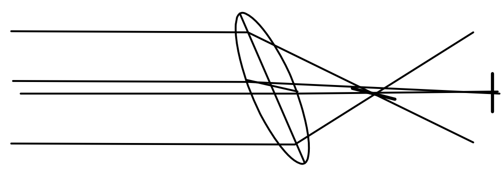
A. Spherical aberration
  1. Not all rays strike center of lens **(Figure 9.1)**
  2. Peripheral rays usually bent more strongly than central (paraxial) rays
    a) Peripheral rays come to focus closer to the lens
    b) This is positive spherical aberration
      (1) Negative spherical aberration is when central rays are bent more strongly than peripheral rays



9.1 Spherical aberration

  3. Can be decreased with proper lens design
    a) "Aspheric" lens
    b) "Bending" lens helps too
      (1) pure biconvex design > plano-convex > asymmetric biconvex > meniscus
  4. Clinical significance
    a) "Bulls eye" retinoscopic reflex
      (1) Seen during retinoscopy of some children
      (2) Center of pupil has "with" reflex, while periphery has "against" reflex.
      (3) Solution: neutralize the central part of the reflex
        (a) This is the part the patient will use when the pupil is normal size
    b) Increased myopia in low light levels
      (1) Pupil dilation exposes periphery of lens
    c) Increased myopia with lens dislocation
      (1) May be earliest sign of, for example, Marfan's syndrome

B. Astigmatism of oblique incidence
  1. Astigmatism induced by tilting a spherical lens **(Figure 9.2)**
    a) Tilting a plus lens
      (1) Induces plus cylinder (and some plus sphere)
      (2) Axis in axis of tilt
    b) Tilting a minus lens
      (1) Induces minus cylinder (and some minus sphere)
      (2) Axis in axis of tilt



9.2 Astigmatism of oblique incidence

  2. Clinical significance
    a) Off-axis retinoscopy
      (1) Common error of new retinoscopists, especially when examining children
      (2) Results in against-the-rule astigmatism
      (3) May obtain retinoscopy of +0.25 +1.00 x 180 in eye with no refractive error
    b) Undercorrected myopia
      (1) Undercorrected myopic patient will tilt glasses by raising temples
      (2) Increases minus sphere and cylinder
      (3) Undercorrected hyperopes don't bother tilting glasses
        (a) They can gain additional effective plus power by sliding glasses down nose

C. Coma
  1. The off-axis effect of spherical aberration
  2. Light rays are distributed in a pattern like that of a comet
  3. Increases as object moves from optical axis

# X. DIFFERENTIAL DIAGNOSIS OF ALTERATIONS IN REFRACTIVE ERROR

A. Acquired myopia - differential diagnosis

1. Increased refractive power
    a) Change in lens nucleus or shape
        (1) Cataract
        (2) Diabetes
        (3) ROP
    b) Lens repositioning
        (1) Ciliary muscle shift
            (a) Toxemia of pregnancy
            (b) Drugs (chlorthalidone, miotics, sulfonamides, tetracycline, carbonic anhydrase inhibitors)
        (2) Lens movement
            (a) Anterior lens dislocation
    c) Ciliary muscle tone
        (1) Antihistamines
        (2) Excessive accommodation (law and medical students)
        (3) Improper refraction technique (inadequate fogging)
    d) Corneal power increase
        (1) Keratoconus
        (2) Developmental glaucoma
2. Increased axial length
    a) Congenital or developmental glaucoma
    b) Posterior staphyloma.

B. Acquired hyperopia - differential diagnosis

1. Decreased effective axial length (retina pushed forward)
    a) Central serous retinopathy
    b) Tumor
        (1) Choroidal melanoma
        (2) Hemangioma
    c) Orbital mass with pressure on the posterior globe
2. Decreased refractive power of the eye:
    a) Absent or repositioned lens
        (1) Aphakia
        (2) Posterior lens dislocation
    b) Weak accommodation
        (1) Tonic pupil and Adie's syndrome
        (2) Trauma
        (3) Drugs (chloroquine, phenothiazines, antihistamines, benzodiazepines, marijuana).

C. Astigmatism - causes

1. Corneal causes
    a) Simple corneal astigmatism
    b) Keratoconus
    c) Masses

(1) Dermoid
(2) Lid tumors
(3) Chalazia
(4) Anterior orbital tumors

d) Ptosis

e) Corneal and scleral abnormalities
(1) Pellucid marginal degeneration
(2) Terrien's

2. Lenticular causes

a) Simple lenticular astigmatism

b) Lenticonus

c) Lens dislocation

d) Lens coloboma

D. Causes of inadequate accommodation

1. Lens

a) Normal presbyopia

2. Refraction

a) Latent hyperopia

3. Poor accommodation:

a) Systemic factors
(1) Oral medications (parasympatholytics, phenothiazines, tranquilizers, chloroquine)
(2) Concurrent systemic illnesses (hypothyroidism, severe anemia, diabetes)
(3) Prior encephalitis or meningitis

b) Remote factors
(1) Tumor
(2) Head trauma

c) Local factors
(1) Tonic pupil
(2) Cycloplegic use
(3) Ocular trauma

E. Accommodative spasm

1. Findings:

a) Esotropia

b) Miosis
(1) More pronounced when patient is esotropia

c) Acquired myopia

2. Treatment

a) Patient education

b) Relax accommodation
(1) Frequent breaks from reading
(2) Consider reading glasses
(3) Consider short course of cycloplegia

# XI. CONTACT LENSES

A. Approach to the patient

1. History
    a) Previous contact lens wear
    b) Dry eye
    c) Other conditions that might interfere with contact lens tolerance
2. Refraction
    a) See below for power calculation
3. External exam
    a) Lid abnormalities
    b) Note palpebral fissure
4. Slit lamp exam
    a) Lids
        (1) Flip lids to look for papillae
        (2) Note blepharitis
    b) Tear film
        (1) Note breakup time
        (2) Consider Schirmer testing
    c) Cornea
        (1) Vascularization
        (2) Unusual contour
        (3) Staining
        (4) Edema
    d) Pupil
        (1) Eccentricity
5. Keratometry
    a) Compare with refraction
        (1) Need to detect lenticular astigmatism
6. Discussion
    a) Rigid vs. soft lenses
    b) Appropriate and safe care of lenses
7. Fit lenses
    a) Rigid lens
        (1) Place fluorescein in fornix to stain tears
        (2) Evaluate pattern of tears under lens
            (a) Central touch - lens too flat
            (b) Pooling; low-riding lens - lens too steep
    b) Soft lens
        (1) Evaluate movement of lens with blink
            (a) Steep lens - no movement
            (b) Flat lens - excessive movement

B. Contact lens labeling

1. Usually three numbers separated by slashes
2. Base curve / Diameter / Power

3. Base curve usually specified as mm (radius of curvature of lens)
    a) Sometimes specified as Diopters
    b) Diopters are derived from standard formula
        (1) Example: 8.9 mm radius of curvature

$$D_{cornea} = \frac{0.3375}{r\ (\text{meters})} = \frac{337.5}{r\ (\text{mm})} = \frac{337.5}{8.9} = 37.9\ D.$$

        (2) Standardized conversion factor is 0.3375
            (a) With this factor, a 7.5 mm radius of curvature corresponds to exactly 45 D of power

C. Rigid lens - estimating fit
1. Choose base curve 0.5 D steeper than the lower keratometry reading
    a) Lower reading is flatter part of cornea
    b) If lens curvature matched flat part of cornea, tears could not fit between contact lens and cornea
        (1) "Tight lens" or "apical touch"
    c) Therefore add 0.5 D of power to this number
        (1) Tears fill the gap
        (2) Creates a "tear lens," which prevents apical touch
2. Must take this 0.5 D tear lens into account when calculating lens power

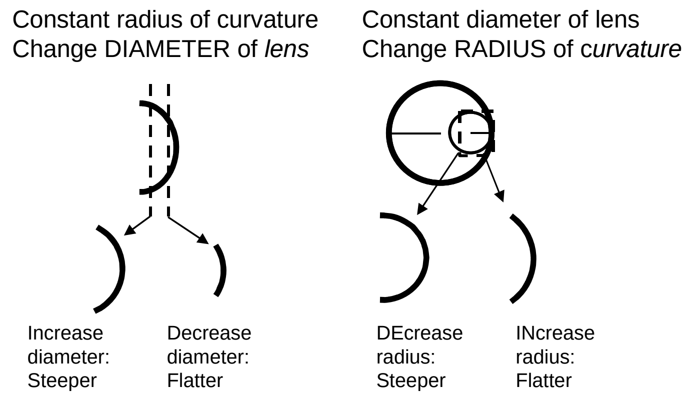
D. Contact lens power calculations
1. Soft lens - two methods
    a) Over-refraction
        (1) Estimate required lens power
        (2) Choose trial lens with proper fit
        (3) Refract over trial lens and add result to power of trial lens
            (a) Use spheres only unless you plan to prescribe toric soft lens
    b) Calculation
        (1) Obtain refraction
        (2) Convert to spherical equivalent (unless prescribing toric soft lens)
        (3) Convert to zero vertex distance
            (a) Not necessary if power less than 5 D
        (4) This is required lens power
2. Rigid lens - two methods
    a) Over-refraction (same as above)
    b) Calculation
        (1) Choose base curve as described above
        (2) Convert refraction to minus cylinder form
            (a) Minus cylinder is formed by tear lens
            (b) Can simply disregard minus cylinder
        (3) Convert refraction to zero vertex distance
        (4) Subtract 0.50 D tear lens power
        (5) This is the desired power
    c) Example
        (1) Keratometry: 44.50/45.50
        (2) Refraction (13 mm vertex distance): +11.50 +1.00 x 35
        (3) Choose base curve of 45.00 D (7.5 mm)
        (4) Convert refraction to minus cylinder (+12.50 - 1.00 x 125)
        (5) Disregard minus cylinder

(6) Convert to zero vertex distance (+15.00 D)
(7) Subtract value of tear lens (+15.00 - 0.50 = +14.50)
(8) Rx = 7.5 mm BC, +14.50 D

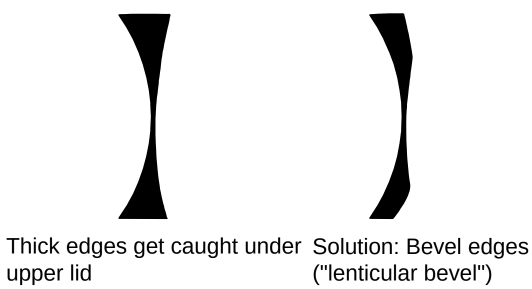
E. Changing contact lens fit

1. **(Figure 11.1)** Change base curve
   a) Smaller base curve (in mm) = shorter radius of curvature = steeper lens = tighter fit
   b) Larger base curve (in mm) = looser fit
2. Change diameter
   a) More effective with soft lenses
   b) For a given base curve:
      (1) Larger diameter = greater effective curvature = tighter fit
      (2) Smaller diameter = flatter lens = looser fit
         (a) Imagine that an nearly infinitely small diameter lens would consist of three points, which would form a plane

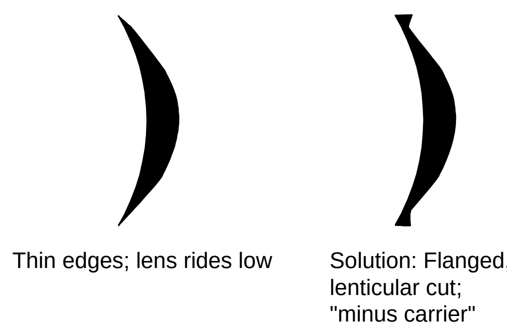
11.1 **Contact lens fitting: Changing fit**




11.2 **Contact lens: High minus problem**




11.3 **Contact lens: High plus problem**



# XII.REFRACTIVE SURGERY

A. Cornea: Anatomic considerations
    1. Has spherical aberration that may be complementary to the lens
        a) Ablation could interfere with that balance
    2. Front and back surface
        a) Results of front surface ablation may be altered by changes in back surface

B. Radial keratotomy
    1. Myopia: Eye too strong
        a) Cuts in the *peripheral* cornea weaken (and steepen) the periphery, causing the *center* to flatten (larger r)
    2. Astigmatic keratotomy
        a) Cut parallel to limbus in steep meridian

C. PRK and Lasik
    1. Sculpt cornea to desired shape
        a) Flatten center for myopia (increase r)
        b) Sculpt periphery for hyperopia (decrease r)
    2. Astigmatism
        a) Ablate in elliptical pattern

D. Conductive keratoplasty
    1. Produces band of tightening, which increases central curvature

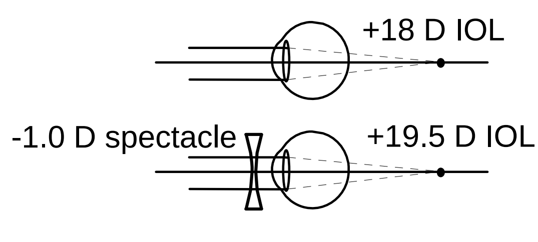
E. Refractive surgery aberrations
    1. Diffraction
        a) Most common in RK patients, who note starbursts at night
    2. Scatter
        a) Hazy flap surface
        b) Caused by irregular ablation
    3. Multifocality
        a) Different parts of the cornea have different powers
        b) Improved by larger optical zone
    4. Coma
        a) Off-center treatment
        b) Lights flare to one side - like a comet
    5. Spherical aberration
        a) Alteration in overall curvature of cornea (laser tends to undercorrect in periphery of treatment zone)
        b) Causes haloes

F. Customized ablations, based on wavefront optics, can minimize aberrations and improve accuracy

# XIII. INTRAOCULAR LENSES

A. Two types of formulas
  1. Theoretical formulas
    a) Derived from optical principles to determine “effective lens position”
      (1) Formerly called “anterior chamber depth”
      (2) Old formulas (Binkhorst) were not accurate enough
        (a) Used assumed dimensions for certain parts of the eye
  2. Empiric formulas
    a) Derived by regression analysis
      (1) Clinical results from thousands of operations are fed into computer
      (2) Pre-operative measurements such as axial length and keratometry are also fed in
      (3) Computer performs statistical processing to derive a mathematical relationship between pre-op measurements, IOL power, and post-op refraction
    b) Example: SRK (Saunders, Retzlaff, and Kraff) formula

B. SRK formula
  1. Most commonly used formula
  2. Appropriate for most normal eyes
  3. $P = A - 2.5\,L - 0.9\,K$
    a) P = power for emmetropia
    b) A = a "fudge factor," the "A constant"
      (1) A unique constant
      (2) Related to lens type and manufacturer
      (3) Can be personalized by analyzing your own results
    c) L = axial length (in mm)
      (1) Obtained using A-scan biometry
      (2) 1 mm error = 2.50 D error in IOL power
      (3) Measure in both eyes to reduce error
    d) K = average corneal curvature (in diopters)
      (1) Keratometry readings
      (2) 1 D error = 1.00 D error in IOL power
      (3) Remove hard contact lens at least two hours before measurement
        (a) Some say to remove two weeks ahead
  4. Post-op refraction
    a) Emmetropia not always goal
      (1) Consider refractive error of other eye
        (a) Beware anisometropia/aniseikonia
        (b) How long until surgery will be required in other eye?
        (c) Aphakia in other eye - in most cases put in IOL, plenty of ways to deal with aphakia later
      (2) Consider lifelong refractive history
        (a) Myopes may want to stay somewhat myopic
        (b) "The surgery was a failure, doctor. I can't read without my glasses anymore "
    b) Change calculated IOL power for emmetropia by 1.25-1.50 D for every diopter of desired ametropia **(Figure 13.1)**
    c) Example:
      (1) Calculated IOL power for emmetropia is +18.00 D




13.1 Planned post-operative myopia

(2) Desire myopia of -1.00 D
(3) Insert +19.50 D lens

C. IOL power calculations - short or long eyes

1. Axial length <23 or >24.5
2. Do not use standard formulas
    a) Older theoretical formulas tend to overestimate IOL power for short eyes
    b) SRK underestimates for shorter eyes, overestimates for longer eyes
3. Use newer-generation formulas
    a) More accurate with very long or very short eyes
    b) SRK II
        (1) Simple enough to calculate by hand
        (2) Same as standard SRK, but different A constant
        (3) Not as good as newer theoretical formulas for very long eyes

| Axial length | Modified A constant |
|---|---|
| Less than 20 | Add 3 |
| 20-21 | Add 2 |
| 21-22 | Add 1 |
| Greater than 24.5 | Subtract 0.5 |

Table 13.1

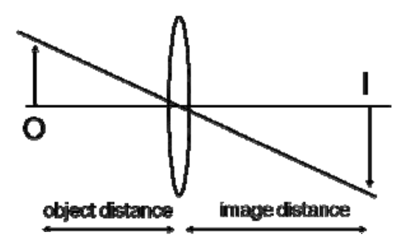
        (4) Example: Axial length of 19
            (a) SRK formula recommends IOL power of +32 D
            (b) SRK II formula recommends +32 + 3 = +35 D
    c) Newer theoretical formulas
        (1) Examples
            (a) SRK/T (“T" stands for "theoretical")
            (b) Holladay
        (2) Extremely complicated theoretical formulas refined by empiric observations
        (3) Cannot be calculated by hand
        (4) Included with software of many A scan units
4. SRK errors
    a) Keratometry: 1 D error = 1 D error
    b) Axial length: 1 mm error = 2.5 D error!
        (1) Measure axial length carefully
    c) Do not use SRK if eye <22 or >24.5 mm!
        (1) Use SRK II or other formulas

# PART 3 – OTHER OPTICS OF NOTE

## XIV.MAGNIFICATION AND TELESCOPES

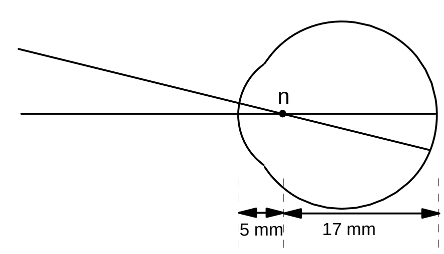
A. Three types of magnification
  1. Transverse
    a) Also called linear or lateral magnification
    b) Magnification of image size
    c) Must be able to measure object and image height
      (1) Either through ray tracing or in lab
  2. Axial
    a) Magnification of depth
    b) Magnification along the optical axis
  3. Angular
    a) Magnification of the angle subtended by an image vs. an object
    b) Used when you can not measure object or image size
    c) Example: moon-gazing with telescope
      (1) Moon *looks* bigger, but
      (2) Image of moon on retina must be smaller than moon
        (a) Unless you have a very large eye
      (3) Answer: Angle of visual field subtended by moon is greater when looking through a telescope than it is when viewing with naked eye

B. Transverse magnification
  1. Image size / object size **(Figure 14.1)**
  2. Proportional to image distance / object distance
    a) As long as you can calculate U + D = V, you can determine image and object distance and therefore you can calculate transverse magnification
  3. Example: Object is 1/3 m from +5 D lens.
    a) Object distance = 0.3 m
    b) U + D = V. -3 + 5 = +2
    c) Image distance = 1/2 = 0.5 m
    d) Transverse magnification = 0.5 / 0.3 = 1.7 X
      (1) The image is magnified
      (2) Inverted or upright? Draw central ray - it is inverted



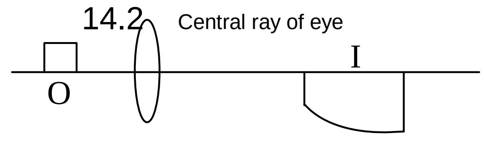
14.1

  4. Transverse magnification in eye
    a) Use model eye **(Figure 14.2)**
      (1) Since not every eye conforms to model eye, can only use this method as estimate of transverse magnification
      (2) Power = 60 D
      (3) Refraction occurs at surface of cornea
    b) Draw central ray through nodal point



14.2 Central ray of eye

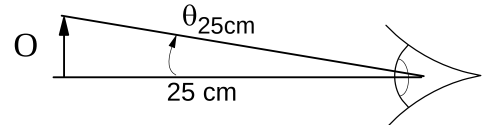
C. Axial magnification



14.3 Distorsion caused by axial magnification

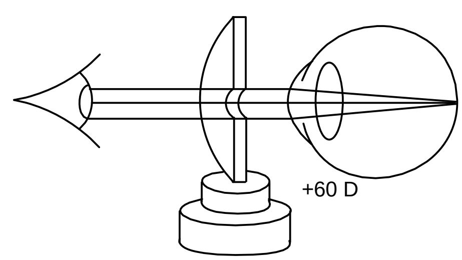
1. The square of the transverse magnification
2. Causes distortion of 3-D images **(Figure 14.3)**
   a) Occurs in indirect ophthalmoscopy
   b) See "Instruments" section for details
3. Example: Transverse magnification in example above = 1.7 x
   a) Axial magnification is $1.7^2 = 2.9$
   b) Image is 1.7 times taller and wider but 2.9 times deeper than object
      (1) Depth is exaggerated

D. Angular magnification
1. Two applications
   a) Objects and images at infinity
      (1) See moon-gazing example above
         (a) Note: since moon is at infinity, object distance does not change even if observer moves, say, to the top of a tall building
         (b) Therefore there is no need to specify a reference distance for the object
      (2) Although objects or images are infinitely large, they have finite angular size
   b) Viewing with an eye **(Figure 14.4)**
      (1) Eyes have different powers and lengths
      (2) Cannot determine size or distance of retinal image precisely
      (3) Example: Viewing an ant with a hand magnifier



14.4 Angular magnification

         (a) Ant viewed with naked eye at, say, 25 cm subtends 2 minutes of arc
         (b) Now view ant with 5 X magnifier
         (c) Image of ant now subtends 10 minutes of arc - covers five times more visual field
         (d) Problem: Can view with naked eye from any distance.
            (i) Unlike situation with moon-gazing, if you move closer to the ant, it will subtend a greater angle without using hand magnifier
            (ii) Therefore must specify reference distance when determining magnification power of hand magnifier
2. Hand magnifier
   a) Formula: Magnification = D/4
      (1) D = power of lens in diopters
      (2) Assumes 25 cm (1/4 m) reference distance
         (a) This is a generally agreed-upon standard reference distance
   b) Example: +12 D lens used as a simple hand magnifier
      (1) Magnification = D/4 = 12/4 = 3 X
   c) Example: Direct ophthalmoscopy **(Figure 14.5)**
      (1) Uses power of patient's eye as magnifier
         (a) D = 60
      (2) Magnification = D/4 = 60/4 = 15 X
      (3) Optic disc looks 15 times larger than it would if cut out of eye and viewed with naked eye at distance of 25 cm

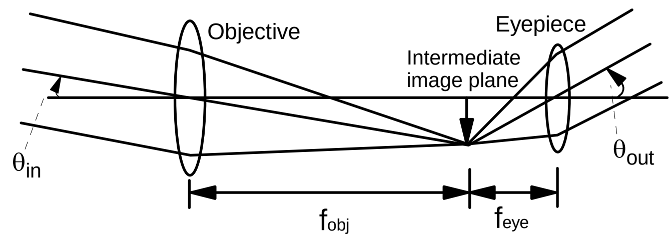


14.5 Magnification - direct ophthalmoscope

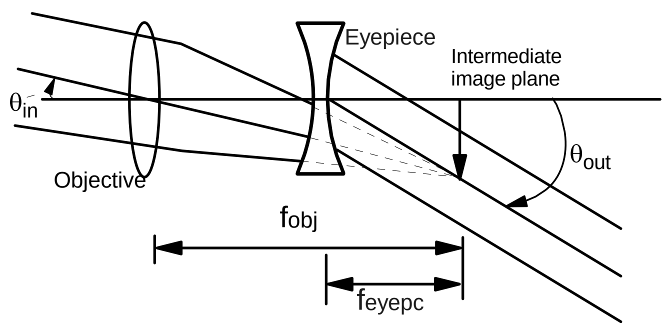
   d) Different reference distance
      (1) Formula: Magnification = D * (reference distance in m)
      (2) Example: Unscrupulous hand magnifier company uses 50 cm reference distance. Slogan: "More mag for less money"
         (a) Magnification of +12 D lens = D * (reference distance) = D * 0.50 = 6 X

(b) Objects look 6 times larger than they would if viewed with naked eye **at distance of 50 cm**
(c) But using standard reference distance, this would be a 3 X magnifier (see above)

3. Telescopes
   a) Two types
      (1) Astronomical **(Figure 14.6)**
         (a) Inverted image
         (b) Rarely used in ophthalmic optics
            (i) Lensmeter
         (c) Longer than Galilean telescope
            (i) Length = (focal length of eyepiece) + (focal length of objective)
      (2) Galilean **(Figure 14.7)**
         (a) Upright image
         (b) Frequently used in ophthalmic optics
            (i) Surgical loupe when used with add
            (ii) Magnification in slit lamp and operating microscope
         (c) Shorter than Astronomical telescope
            (i) Length = (focal length of eyepiece) - (focal length of objective)
   b) Angular magnification of both is the same
      (1) (Power of eyepiece) / (Power of objective)



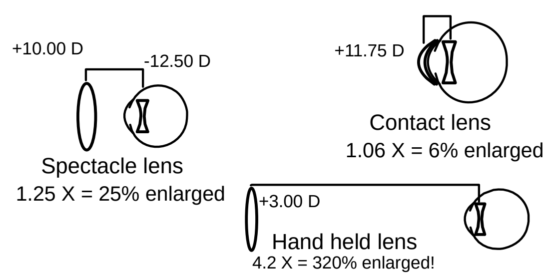

14.6 Astronomical telescope




14.7 Galilean telescope

4. Astronomical telescope

E. Error lens concept - used to explain spectacle lens magnification
   1. Non-axial refractive error: Eye has wrong amount of refractive power
   2. Can be modeled by adding to refractive power of eye
      a) Imagine placing an anterior chamber IOL in an otherwise normal eye (without removing natural lens)
      b) Add "plus" error lens to create a myopic eye
         (1) Requires minus spectacle lens to correct refractive error
      c) Add "minus" error lens to create a hyperopic eye
         (1) Requires plus spectacle lens to correct refractive error
   3. Error lens considered to act 5 mm behind cornea
   4. Magnification - Corrected aphake
      a) Use error lens of -12.50 D **(Figure 14.8)**
      b) Focal point of lens must coincide with far point of eye to correct refractive error
         (1) Note these coinciding far points create a Galilean telescope
            (a) Error lens = eyepiece
            (b) Corrective lens = objective
      c) Spectacle lens correction




14.8 Spectacle correction of aphakia

- (1) Far point of eye = 1/12.5 = 80 mm behind error lens
- (2) Find distance of spectacle lens from far point
  - (a) Assume vertex distance of spectacle lens = 15 mm in front of cornea
  - (b) Error lens = 5 mm behind cornea
  - (c) Spectacle lens is 80 + 5 + 15 = 100 mm away from for point
  - (d) Power of spectacle lens must be 1/0.1 = +10 D
- (3) Magnification = (Power of eyepiece) / (Power of objective) = (12.5 / 10) = 1.25 X
  - (a) Images are 25% enlarged when aphakia is corrected with a spectacle lens
- (4) Note 20/20 line subtends 1.25 X more retinal angle
  - (a) "20/20" acuity is really more like 20/25 or 20/30
  - (b) Opposite is true in myopes due to minification

d) Contact lens correction
- (1) Similar calculations
  - (a) Power of correcting contact lens is +11.75 D
- (2) Magnification = (12.50 / 11.75) = 1.06 X
  - (a) Images are 6% enlarged when aphakia is corrected with a contact lens

e) Correction of aphakia with +3.00 hand-held lens
- (1) Note focal length of +3.00 lens = 333 mm
- (2) Vertex distance must be (333 - (80+5)) = 248 mm!
- (3) Magnification = (12.50 / 3.00) = 4.2 X
  - (a) Images are 320% enlarged when aphakia is corrected with a hand-held, +3.00 D lens
    - (i) Note: 320% is correct - it is NOT 420%

5. Magnification - corrected myopia

a) Acts like reverse Galilean telescope
- (1) Plus error lens
- (2) Minus spectacle lens

b) Image is minified

F. Aniseikonia

1. Difference in perceived image size between eyes

a) More than 3-8% image size difference not tolerated by most

b) Common causes
- (1) Unequal refractive error (anisometropia)
  - (a) Monocular aphakia
  - (b) Pseudophakic surprises
- (2) Retinal problems
- (3) Occipital lobe lesions

c) Several factors influence how much is tolerated
- (1) Age (children can tolerate more)
- (2) Type of anisometropia
- (3) Duration
- (4) Binocularity and fusion potential

2. Magnification caused by spectacle correction of refractive error

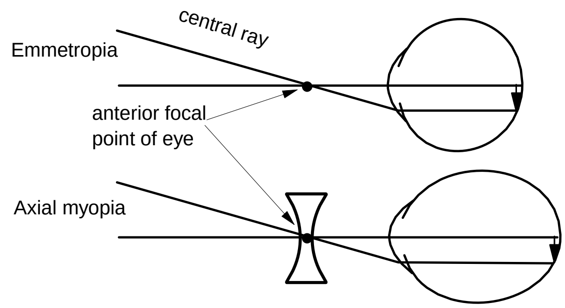
a) For standard vertex distance, change in retinal size 2% per diopter of power
- (1) Plus lenses magnify
- (2) Minus lenses minify

b) Example: Spectacle correction OD +1.00, OS -3.00
- (1) Magnification OD = 2 x 1 = 2% magnified
- (2) Magnification OS = 2 x -3 = 6% minified
- (3) Total difference between eyes = 8%
  - (a) May not be tolerated

3. If not tolerated, consider contact lens
    a) Simple contact lens correction may be sufficient
    b) If not, can overcorrect one eye for added change in magnification
        (1) Over-plus eye with larger image size to make more myopic
        (2) Now correct iatrogenic myopia in that eye with minus spectacle lens
        (3) This will shrink the image more than simple contact lens correction (see below)

G. Knapp's Rule

1. Place proper corrective lens at anterior focal point of eye **(Figure 14.9)**
2. Retinal image will be the same size in each eye no matter what the refractive error
    a) Key restriction: ametropia must be axial
    b) Best understood using ray tracing
3. Practical problems
    a) Ametropia almost never purely axial
    b) Vertex distance of 15-16 mm may be impractical for spectacle correction
    c) Retina stretched in high myopia
        (1) increased separation of photoreceptors can change effective magnification




14.9 Knapp's rule

# XV. LOW VISION

A. Patient evaluation

1. History
    a) Duration and course of visual loss
    b) Habits prior to visual deterioration
    c) Current needs
        (1) Occupational
        (2) Avocational
    d) Expectations
    e) Other physical limitations
        (1) Tremor
        (2) Deafness
    f) Previous low vision aid use
        (1) Most patients don't think of hand magnifiers as low vision aids
2. Examination
    a) Visual acuity
        (1) Measure with low vision chart
        (2) Distance and near
    b) Exacting refraction
    c) Accommodative amplitude
    d) Other findings that may influence the type of aid selected
        (1) nystagmus
        (2) photophobia
        (3) aniridia
        (4) visual field defects.
3. Trial
    a) Demonstrate variety of low vision aids
    b) Many patients will need more than one

B. Kestenbaum's Rule

1. Provides *starting point* for selection of near add
2. Take reciprocal of best distance acuity
    a) This is the add the patient will probably require for reading newsprint
3. Take reciprocal again
    a) This is the working distance (in meters) required using selected add
4. A handy coincidence
5. Example: Best corrected distance acuity = 20/80
    a) Patient wishes to read newspaper
    b) Start with add of (80/20) = +4.00 D
        (1) Working distance will be 1/4 = 0.25 m
        (2) Subjectively refine this add

C. Near aids

1. High-add spectacle lenses
    a) High-add bifocal

(1) Harder to make than single vision lens

b) High-add single vision lens
(1) Can incorporate base in prism if necessary
(a) Short working distance requires excessive convergence
(b) Only necessary if patient has binocular vision

c) Available powers: +4-+20 D

d) Advantages:
(1) Wide field of view
(2) Leave hands free
(3) Easy to carry
(4) Lower powers relatively discreet

e) Disadvantages
(1) Very close reading distance for higher adds
(a) Reciprocal of power
(b) 5 cm reading distance for 20 D lens

2. Magnifiers

a) Comparison with high-add spectacle lenses
(1) Less expensive
(2) Smaller field of view
(3) Variable eye-to-lens distance

b) Hand-held magnifier
(1) Powers up to +20 D (5 X)
(2) Most popular low vision accessory
(a) Advantages
(i) Easy to carry
(ii) Easy to obtain
(iii) Least expensive
(iv) Unobtrusive
(b) Disadvantages
(i) Hard to handle if patient had stroke, tremor, arthritis
(ii) Requires free hand

c) Stand magnifier
(1) Powers up to +50 D (12.5 X)
(2) Two types
(a) Fixed-focus type designed for use with reading add
(b) Adjustable height can adjust for refractive error or presbyopia
(3) Preferred by many older patients
(a) Advantages
(i) No handling required
(b) Disadvantage
(i) Bulky - do not fit in pocket

d) Lighted magnifier

3. Loupes

a) Telescopes with near add
(1) Reading distance may be fixed or adjustable

b) Advantages
(1) Greater working distance
(2) Leave hands free

c) Disadvantages
(1) Expensive

(2) Small field of view
(3) Heavy
(4) May be difficult to adjust
(5) Narrow depth of focus
(a) Requires precise head positioning

4. Electronic devices

a) Advantages
(1) Very high magnification
(2) Contrast reversal
(a) White letters on black background easier to read for some patients

b) Disadvantages
(1) Very expensive
(2) Not portable (but see "LVES" below)

c) Two types
(1) Closed circuit TV
(a) Video camera attached to monitor
(b) Difficult to follow page of text if it does not fit
(c) Requires manual dexterity to move page around in field of camera
(d) Portable example: Magnicam (http://www.magnicam.com/)
(2) Computer scanners
(a) Entire page is scanned in at once
(b) Words are displayed as continuous line
(i) Requires less dexterity to operate
(c) Can theoretically be attached to character recognition software and voice generation hardware
(i) Computer can read to patient
(d) Example: Kurzweil 1000 reading machine (http://www.kurzweiledu.com/kurz1000.aspx)

D. Non-optical aids

1. Large print items
a) Books
b) Playing cards
c) Telephones
d) Watches

2. Reading templates

3. Dark marking pens

4. Signature guides

5. Reading lamp for improved contrast

6. Absorptive lenses
a) Decrease glare
(1) albinism, aniridia
b) Keep eyes in dark-adapted state
(1) Red lenses for congenital achromatopsia

E. Distance aids

1. Telescopes
a) Power up to 8 X
(1) Higher powers restrict field of view too much
b) Advantages

(1) Portable

c) Disadvantages

(1) Conspicuous

(2) Expensive

(3) Limited field of view - disorienting

(a) Typical use - read bus sign or other signs

d) Binocular, spectacle mounted "bioptic" telescope

(1) Relatively small telescope

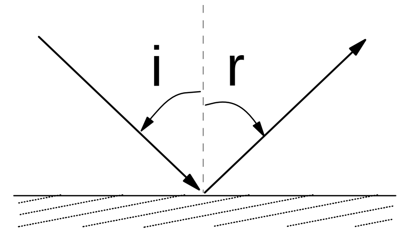
(2) Leaves peripheral vision intact

(3) Can get driver's license with bioptic telescope in some states

# XVI.MIRRORS

A. Laws of reflection

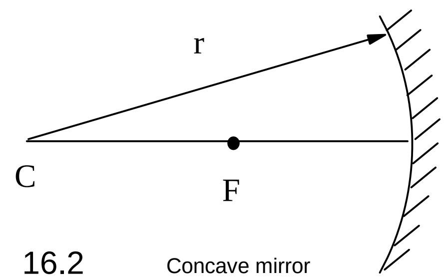
1. Angle of reflection = angle of incidence **(Figure 16.1)**
2. All of following are in same plane
   a) Incident ray
   b) Normal to surface
   c) Reflected ray




16.1 Laws of reflection

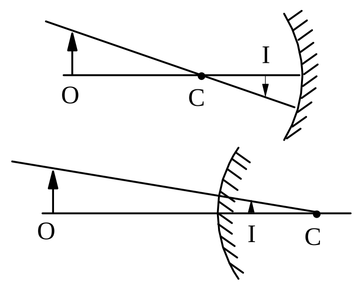
B. Mirror action

1. "Lens" that flips over image space by reversing the direction of light
2. Some mirrors also change vergence of light
   a) Convex mirrors
      (1) Add minus vergence
   b) Concave mirrors
      (1) Add plus vergence
   c) Plane mirrors
      (1) Change direction only
      (2) Add zero vergence




16.2 Concave mirror

3. Use U + D = V to determine how much vergence is added by mirror
   a) Power (D) determined by curvature of surface
   b) D(reflecting) = 2/r **(Figure 16.2)**
      (1) f = focal length of mirror
      (2) r = radius of curvature of mirror
      (3) Since light bounces off of mirror, no refractive index to worry about
         (a) Compare with formula for *refracting* power D(refracting) = (n'-n) / r
      (4) Example: Concave mirror with 50 cm radius of curvature
         (a) D = 2/0.5 = 4 D
         (b) +4 D since it is a concave mirror
            (i) A convex mirror with same radius of curvature is -4 D

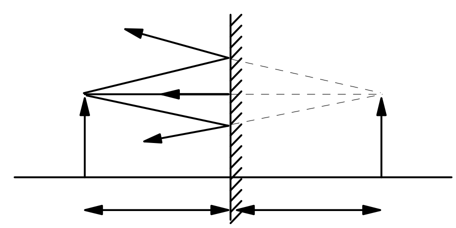



16.3 Mirrors - central ray

4. Use center of curvature of mirror to draw central ray **(Figure 16.3)**
   a) Do NOT draw central ray through center of mirror

C. Plane mirror

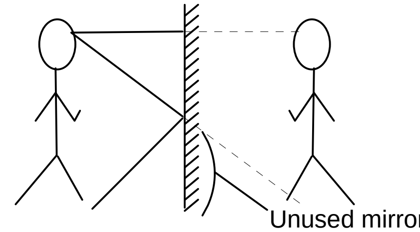
1. Image always:
   a) Virtual
   b) Erect
   c) Same size as object **(Figure 16.4)**



16.4 Plane mirror

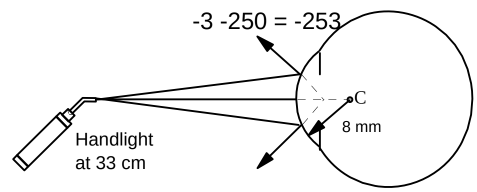
2. Field of view determined by mirror diameter
   a) Changing distance from object to image does not change field of view
3. Example
   a) Full length dressing mirror
      (1) Note: Only half-length mirror required to view entire self **(Figure 16.5)**
      (2) Example: Standing 1 m from plano mirror.

(a) U = 1/1 = -1
(b) U + D = V: -1 + 0 = -1
(c) Image distance = 1/V = 1 m (to right of mirror)
(i) Image is 1 + 1 = 2 m away from object
(ii) Image is virtual and erect



16.5 Plane mirror

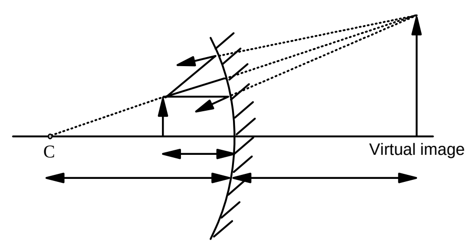
D. Convex mirror
1. Image always:
a) Virtual
b) Erect
c) Smaller than object
2. Examples
a) Rear view mirror
b) Cornea **(Figure 16.6)**
(1) Keratometer measures reflecting power of cornea (convex mirror) to determine corneal radius of curvature



16.6 Convex mirror - cornea

(2) Radius of curvature of typical cornea = 8 mm
(a) Reflecting power = 2/r = 2/0.008 = -250 D
(3) Example: 10 cm illuminated target held 1/3 m from cornea.
(a) Locate image:
(i) U = 1/0.1 = -3
(ii) U + D = V: -3 + (-250) = -253
(iii) 1/253 = .004 = 4 mm (behind cornea)
(b) Determine magnification:
(i) Magnification = image distance / object distance = 4/333 = 0.012 X
(ii) Object size = 10 cm
(iii) Image size = 10 cm * 0.012 = 0.12 cm = 1.2 mm
(c) Summary: If cornea with 8 mm radius of curvature is illuminated with 10 cm object at distance of 1/3 m, the reflection will be 1.2 mm high and 4 mm behind the surface of the cornea
(i) Image is virtual and erect

E. Concave mirror
1. Image can be:
a) Virtual or real
b) Erect or inverted
c) Smaller or larger
d) Depends on where object and image are with respect to center of curvature of mirror



16.7 Concave mirror

(1) Experiment with ordinary shaving mirror to see how image changes from upright to inverted depending on object distance
2. Example: +4 D shaving mirror
a) Note: radius of curvature is 0.5 m
b) Object held 1/6 m from +4 D shaving mirror **(Figure 16.7)**
(1) Locate image
(a) U + D = V: -6 + 4 = -2
(b) Image distance = 1/2 = 50 cm to *right* of mirror (virtual image)
(2) Determine magnification
(a) Image distance / object distance = 0.5/0.167 = 3 X

(b) Draw central ray to determine that image is upright

c) Object held 1/3 m from +4 D shaving mirror **(Figure 16.8)**

(1) Locate image

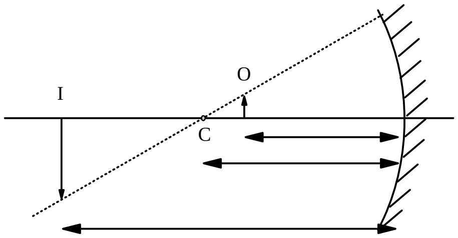
(a) U + D = V: -3 + 4 = +1

(b) Image distance = 1/1 = 1 m to *left* of mirror (real image)

(2) Determine magnification

(a) Image distance / object distance = 1/0.33 = 3 X

(b) Draw central ray to determine that image is inverted




16.8 Concave mirror

d) Object held 1 m from +4 D shaving mirror

(1) Locate image

(a) -1 + 4 = +3

(b) Image distance = 1/3 = 33 cm to left of mirror (real image)

(2) Determine magnification

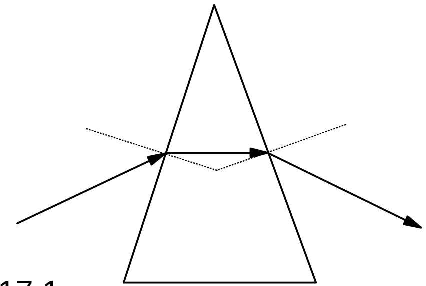
(a) Image distance / object distance = 0.33/1 = 0.33 X

(b) Draw central ray: image is inverted

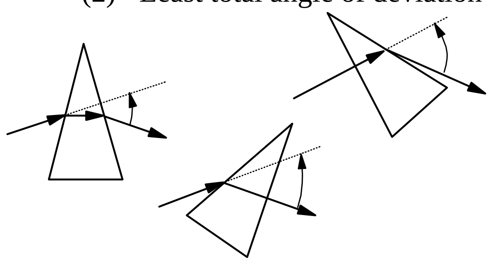
# XVII. PRISMS

A. Calibration of prisms

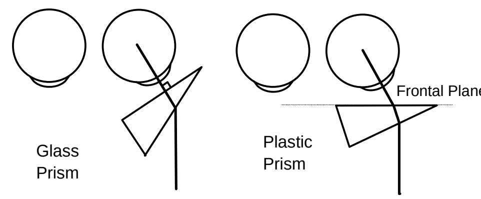
1. Bend rays of light **(Figure 17.1)**
   a) Light bends toward base of prism
   b) Amount of bending depends on angle of incidence
2. Prisms held in different positions **(Figure 17.2)**
   a) Prentice position
      (1) One face of prism perpendicular to light rays
   b) Position of minimum deviation
      (1) Equal bending at face of each prism
         (a) Angle in = angle out
      (2) Least total angle of deviation of light



17.1 Position of minimum deviation

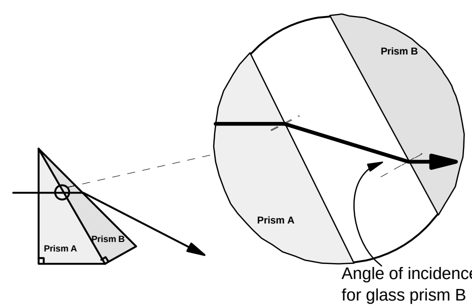


17.2 Prisms - angle of incidence




17.3 Proper positioning of prisms

3. Different types of prisms calibrated for use in different positions **(Figure 17.3)**
   a) Prism labeled as, say, 20 prism diopters may or may not actually cause 20 prism diopters of deviation
      (1) Depends on angle of incidence
      (2) Example: Look at distant object through $40^{\Delta}$ prism (base in)
         (a) Rotate prism about vertical axis
         (b) Watch how effective prism power changes
         (c) Note position of minimum deviation
   b) Plastic orthoptic prisms (and prism bars) calibrated for minimum deviation position
      (1) Close approximation: Hold rear surface of prism in frontal plane
   c) Spectacle lenses calibrated for Prentice position (automatic when using lensmeter)
   d) Glass orthoptic prisms calibrated for Prentice position
      (1) Visual axis must be perpendicular to back surface of prism
      (2) Glass prisms rarely used anymore
         (a) Can be recognized two ways
            (i) Heavier than plastic prisms
            (ii) Inevitable chips in edges
      (3) Don't stack prisms (wrong angle of incidence for second prism) **(Figure 17.4)**

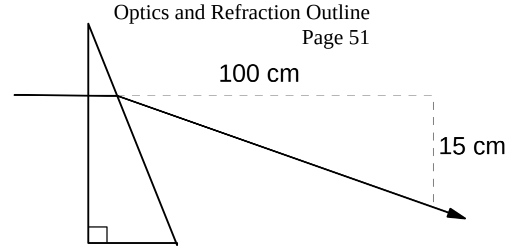



17.4 Don't stack prisms

B. Prism diopter

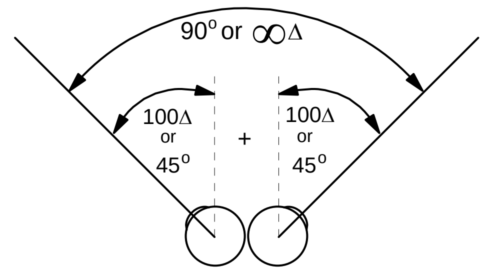
1. Displacement (in centimeters) of light ray passing through prism, measured 100 cm from the prism **(Figure 17.5)**

a) Example: 15$^{\Delta}$ prism held base down in front of a laser
   (1) Beam will be displaced down 15 cm at a distance of 100 cm from prism
   (2) Displaced down 30 cm at distance of 200 cm



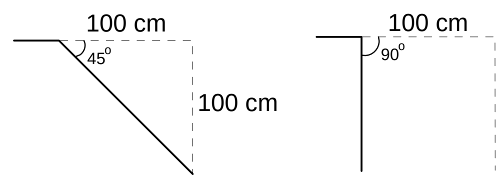
17.5 Prism diopter

2. Naming conventions
   a) Abbreviations: ("P.D." or "$^{\Delta}$")
   b) "Prism diopters" sometimes shortened to "prisms"
   c) Should ***not*** be shortened to "diopters"
      (1) Confuses lens power with prism power
3. Relationship to angle of deviation is not linear
   a) 45 degree deflection of light = 100$^{\Delta}$ **(Figure 17.6)**
   b) 90 degree deflection of light **(Figure 17.7)**
      (1) Infinite prism diopters!
      (2) Light *never* intersects a screen held 100 cm away



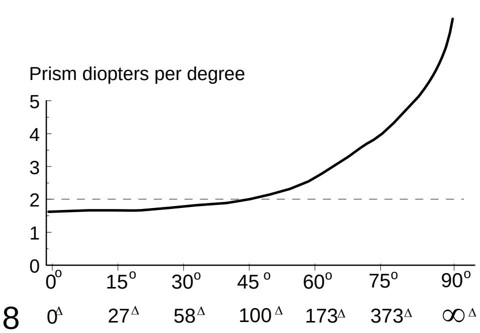
17.6 Prism diopters are non-linear

   c) Conversion between prism diopters and degrees **(Figure 17.8)**:
      (1) Angles less than 45 degrees
         (a) Each degree is approximately equal to 2$^{\Delta}$
         (b) Handy when describing magnitude of deviation to patients
      (2) Angles greater than 45 degrees
         (a) Must use trigonometric formula
            (i) P.D. = 100 tan (degrees) or
            (ii) degrees = tan$^{-1}$ (P.D. / 100)



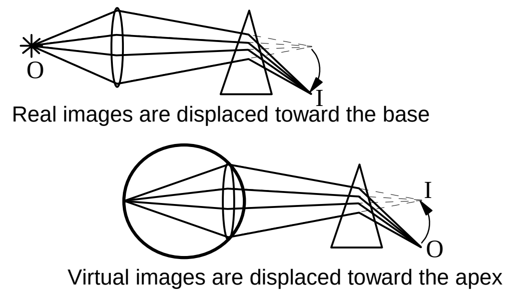
17.7 100 prism diopters Infinite prism diopters

C. Displacement of images by prisms
1. Depends on whether considering real or virtual image
2. Real image
   a) Example: base down prism placed in path of slide projector beam
      (1) Prism bends light rays toward base
      (2) Base down prism will displays image of slide down on screen
   b) Example: Power of prism is 4$^{\Delta}$, distance from screen is 10 m
      (1) 4$^{\Delta}$= 4 cm per 100 cm = 4 cm per 1 m
      (2) Same as 40 cm for 10 m
      (3) Image moves down 40 cm



17.8

3. Virtual image
   a) Example: Viewing object through base down prism using eye
      (1) Light rays are displaced toward base
      (2) Must create imaginary extension of rays of light heading toward eye
         (a) Eye doesn't "know" that light rays were deflected by prism
         (b) Thinks they traveled in straight line
      (3) Image (perceived by eye) is virtual, and higher than object
   b) Example: Prism held base up over right eye of orthophoric patient
      (1) Induces right hypertropia (left hypotropia)



17.9 Displacement of images by prisms

- (a) or hyperphoria if patient can fuse images
- (2) Two ways to determine induced deviation
  - (a) Trace rays from fovea, through prism
    - (i) Rays deflected upward through base up prism
    - (ii) Eye therefore looking higher than it should be
    - (iii) Must be hypertropia in that eye
  - (b) Deviation can be corrected with base down prism over right eye
    - (i) From clinical experience you know that base down prism corrects a hypertropia

c) Summary
- (1) Light rays always displaced toward base **(Figure 17.9)**, but
  - (a) Real images displaced toward base
  - (b) Virtual images displaced toward apex

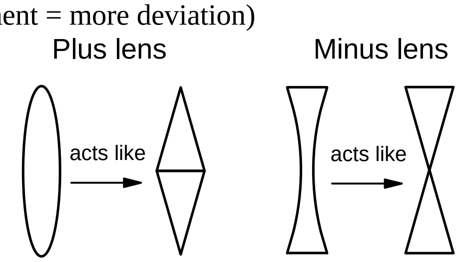
4. Prentice's rule

a) Lenses have no prismatic power if light travels through optical center
- (1) A ray passing through the optical center of a lens passes through undeviated

b) As distance from optical center increases, prismatic power increases

c) Prism diopters of induced deviation proportional to
- (1) Power of lens (greater power = more deviation)
- (2) Distance of ray from optical center (more displacement = more deviation)

d) Formula: $\Delta = h\,D$
- (1) h = distance from optical center in ***centimeters***
- (2) D = power of lens in Diopters



17.10

e) Direction of displacement **(Figure 17.10)**
- (1) Minus lenses act like prisms held apex to apex
  - (a) Optical center is between the two prisms
    - (i) Ray traveling above optical center sees base up prism
    - (ii) Ray traveling below optical center sees base down prism
    - (iii) Use similar reasoning for horizontal displacement
- (2) Plus lenses act like prisms held base to base
  - (a) Optical center is between the two prisms
    - (i) Ray traveling above optical center sees base down prism
    - (ii) Ray traveling below optical center sees base up prism

f) Example: Laser beam passed 1.5 cm below optical center of +5 D lens
- (1) $\Delta = h\,D = (1.5)*(5) = 7.5^{\Delta}$
- (2) Laser sees base up prism
- (3) Displaced up $7.5^{\Delta}$

5. Measurement of strabismus through prismatic effect of spectacle lenses **(Figure 17.11)**

a) Deviating eye does not look through optical center

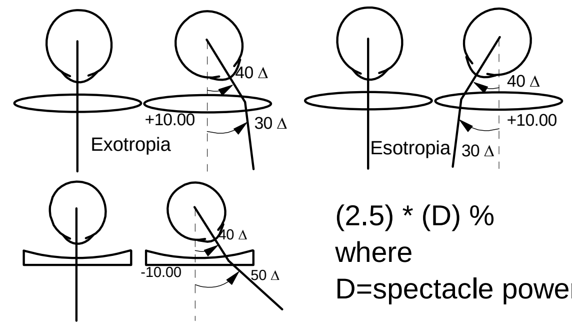
b) During prism and cover testing, prismatic power of lens may change measured deviation
- (1) Significant changes if lens power greater than 5 D

c) Plus lenses decrease measured deviation
- (1) Exotropia: exotropic eye looks through base in prism effect
- (2) Esotropia: esotropic eye looks through base out prism effect

(3) Less prism required to neutralize deviation
(4) Measured deviation less than true deviation

d) Minus lenses increase measured deviation
(1) Exotropia: exotropic eye looks through base out prism
(2) Esotropia: esotropic eye looks through base in prism
(3) More prism required to neutralize deviation
(4) Measured deviation greater than true deviation
(5) "Minus measures more"

e) Amount of change in deviation
(1) (2.5)*(D) %
(2) Example: +10.00 D glasses with $40^{\Delta}$ exotropia
(a) Change in measured deviation = (2.5) * (10) % = 25%
(b) Measured deviation is less (since plus lenses)
(c) Measured deviation is (40) - (40*0.25) = $30^{\Delta}$
(d) Technically perfect but optically novice surgeon operates for $30^{\Delta}$, finds $10^{\Delta}$ residual exotropia post-operatively



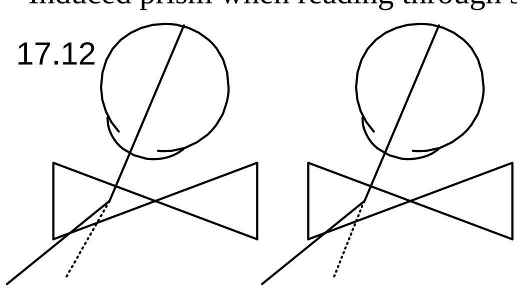

17.11 Spectacle correction and strabismus measurements

(3) Example: +10.00 D glasses with $40^{\Delta}$ exotropia
(a) Change in measured deviation = (2.5) * (10) % = 25%
(b) Measured deviation is more
(c) 40 + (40 * 0.25) = $50^{\Delta}$
(d) Novice surgeon operates for $50^{\Delta}$, finds $10^{\Delta}$ esotropia post-operatively

f) Cosmetic effects of high-powered glasses on strabismus
(1) The opposite of cover testing
(2) Plus lenses magnify
(a) Eyes look bigger
(b) Exotropia and esotropia both more noticeable
(c) Cosmetic deviation is larger
(3) Minus lenses minify
(a) Eyes look smaller
(b) Exotropia and esotropia less noticeable
(c) Cosmetic deviation is smaller

D. Induced prism when reading through spectacle lenses

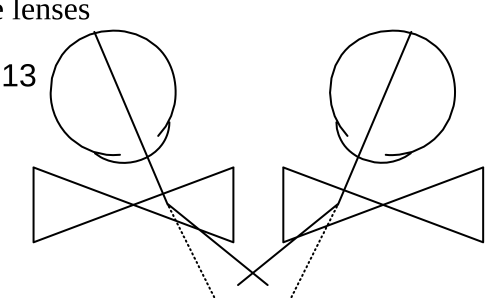
17.12



Prismatic effect - gaze right through minus lenses



17.13



Prismatic effect - converging through minus lenses



1. If both lenses have same power

a) **(Figure 17.12)** Prismatic effect is the same for each eye for pure horizontal or vertical displacements
(1) No induced phoria or tropia

(2) May get some image displacement

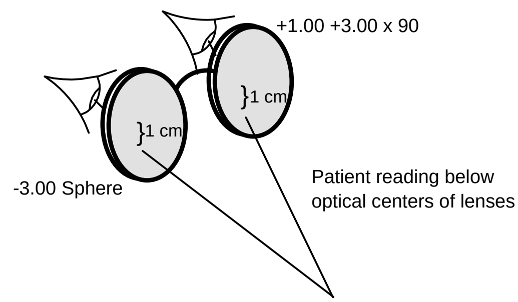
b) Not much of a problem
   (1) Takes a few minutes for brain to adapt when switching from glasses to contact lenses and back

c) **(Figure 17.13)** Equal and opposite prismatic effect when converging
   (1) Minus lenses act like base-in prism - aids convergence
   (2) This is another reason why it is harder for a myope to read when switching from glasses to contact lenses (see accommodation for first reason)

2. If lenses have different powers (anisometropia)

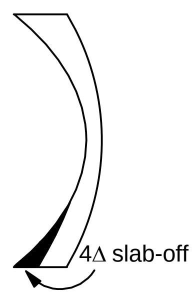
a) Horizontal or vertical displacement of eyes induces net prismatic effect
   (1) Most patients use fusional abilities to adapt to horizontal effect without difficulty
   (2) Vertical effect much more likely to cause diplopia or asthenopia

b) Example: Reading 1 cm below optical center through OD -3.00 sphere, OS +1.00 +3.00 x 90 **(Figure 17.14)**
   (1) Right eye lens power in vertical meridian = -3.00 D
   (2) Prism power = h D = (1 cm) * (3 D) = $3^{\Delta}$ (base DOWN over right eye)
   (3) Left eye power in vertical meridian = +1.00 D (draw power cross)
   (4) Prism power = h D = (1 cm) * (1 D) = $1^{\Delta}$ (base UP over left eye)
   (5) Net prismatic power = $4^{\Delta}$
   (6) Can consider power as acting either base down over right eye or base up over left eye
   (7) Cover testing will reveal left hypertropia

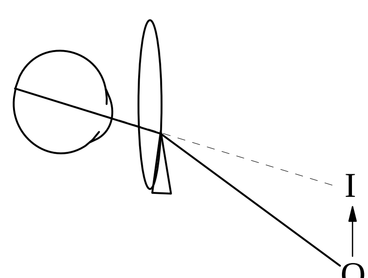



17.14 Prismatic effect - reading position

c) Treatment of vertical prismatic effect of anisometropia
   (1) Prescribe contact lenses
      (a) Optical centers move with eyes
   (2) Lower optical centers of spectacle lenses
      (a) In example above, lower optical centers 0.5 cm
      (b) Patient will have $2^{\Delta}$ left hypertropia in reading position (easier to fuse)
      (c) Will now have $2^{\Delta}$ right hypertropia in primary position (should also be easy to fuse)
   (3) Prescribe slab-off prism **(Figure 17.15)**
      (a) Also called "bicentric grinding"
      (b) No prismatic effect in primary position
      (c) Prescribe less than the full deviation
         (i) Measure deviation by prism and cover test rather than by calculation
         (ii) Most patients can fuse part of the deviation without difficulty
      (d) Slab off prism is taken off the more minus (or less plus) lens
   (4) Prescribe separate single vision glasses for distance and near
   (5) Prescribe dissimilar segments
   (6) Apply Fresnel prism over bifocal segment only
      (a) Good when you aren't sure if this is why patient is anisometropic




17.15 Slab-off prism

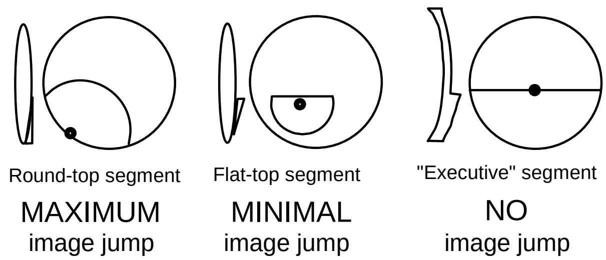



17.16 Bifocals - image jump

E. Prismatic effects - bifocal segments

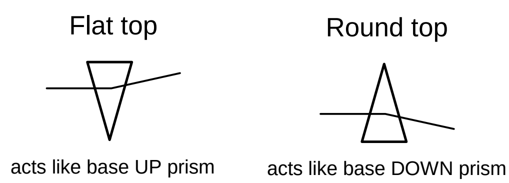
1. Image jump

a) Produced by bifocal segment only **(Figure 17.16)**
   (1) Not influenced by type of underlying lens
b) Sudden introduction of prismatic power at top of bifocal segment
c) Object suddenly jumps up as line of sight crosses from lens to bifocal segment
d) Depends only on type of bifocal segment **(Figure 17.17)**
   (1) Round-top segment: maximum image jump
   (2) Flat-top segment: minimal image jump
   (3) Executive segment: no image jump
   (4) Progressive "segment": no image jump
e) Determined by distance of top of segment from optical center of segment



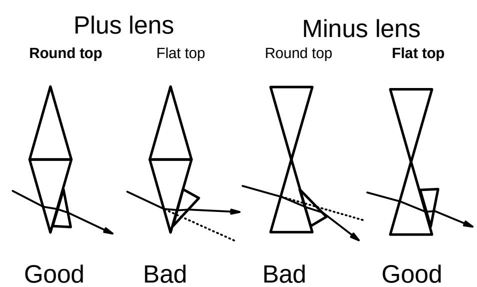

17.17 Bifocals - image jump

2. Image displacement
   a) Produced by combination of lens and bifocal segment
   b) Measured in reading position (not at junction between lens and segment)
   c) Contribution of segment in reading position **(Figure 17.18)**:
      (1) Round-top segment acts like base down prism
      (2) Flat top segment acts like base up prism




17.18 Bifocals - prismatic effect

   d) Contribution of lens in reading position
      (1) Plus lens acts like base up prism
      (2) Minus lens acts like base down prism
   e) Combination of lens and segment **(Figure 17.19)**
      (1) Plus lens
         (a) Round top segment balances base-up effect
            (i) Minimum image displacement
         (b) Flat top gives additional base-up effect
      (2) Minus lens
         (a) Round top segment adds to base down effect
         (b) Flat top segment balances base down effect
            (i) Minimum image displacement

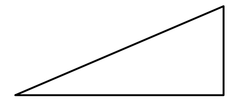



17.19

3. Summary
   a) Minus lens
      (1) Flat top segment preferred
         (a) Less image jump
         (b) Less image displacement
   b) Plus lens
      (1) Round top gives less image displacement
      (2) Flat top gives less image jump
      (3) Image displacement probably more bothersome than image jump
         (a) Most people make a vertical saccade (and converge) when shifting from distance to near, making image jump less noticeable
      (4) Therefore round-top probably preferred
         (a) But opticians tend to dispense flat top segments
            (i) Easier to make
            (ii) Less expensive for patient
         (b) Don't need to interfere unless patient is complaining

F. Fresnel prisms

1. Very narrow adjacent prism strips on a thin sheet of plastic **(Figure 17.20)**
2. Commercially available as Press-On™ prisms
    a) Available powers: 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 25, and $30^{\Delta}$
3. Advantages
    a) Light weight
    b) Convenient
        (1) Easy to apply in office
        (2) Can be applied to half of lens (upper or lower)



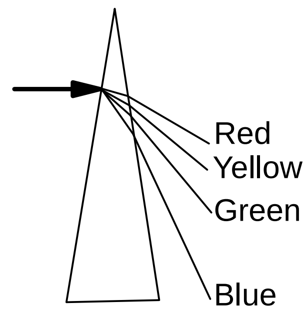
Conventional Prism

17.20 Fresnel Prism

4. Disadvantages
    a) Compromise acuity
        (1) Especially with higher power prisms
        (2) Glare and chromatic aberration
    b) Difficult to clean
    c) Lines are cosmetically apparent

G. Oblique prism

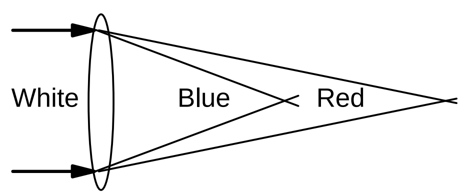
1. Use vector addition to combine horizontal and vertical prism
    a) Helpful when trying to prescribe single Fresnel prism for combined deviation
        (1) Two prisms for the price of one
    b) Example: $5^{\Delta}$ base up combined with $5^{\Delta}$ base out
        (1) Forms right triangle with two legs of $5^{\Delta}$ each
            (a) Pythagorean theorem $5^2 + 5^2 = c^2$
            (b) $c^2 = 25 + 25 = 50$
            (c) c = square root of 50 = 7.1
        (2) In this case, give $7^{\Delta}$ base up and out in 45° meridian



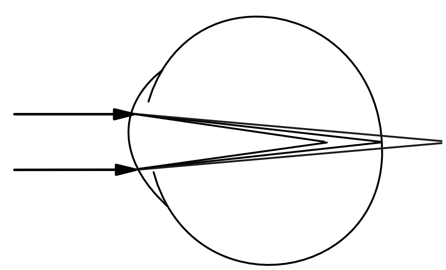

Prisms - chromatic effects
17.21

H. Chromatic effects

1. Prisms
    a) Refractive index varies with wavelength **(Figure 17.21)**
    b) **B**lue rays are **B**ent more than red rays
        (1) Prisms disperse white light into its component colors
2. Lenses
    a) Plus lenses bend blue rays more than red rays **(Figure 17.22)**
    b) Causes chromatic aberration
        (1) Blue lenses come to focus closer to the lens than red rays
3. Chromatic aberration
    a) Human eye has significant chromatic aberration **(Figure 17.23)**
        (1) 3 diopters difference in focusing power between deep blue and near-infrared
        (2) Causes emmetrope to be myopic when viewing world in blue light




17.22 Lens - chromatic aberration



17.23 Human eye - chromatic aberration

b) Duochrome test
   (1) Red and green filters create 0.5 D difference
   (2) Red background clearer
      (a) Focal point of all colors in front of retina
      (b) Eye is "fogged" or myopic
   (3) Green background clearer
      (a) Focal point of all colors behind retina
      (b) Eye is overminused or hyperopic
   (4) Both sides equally clear
      (a) Red as far in behind retina as green is in front
      (b) Yellow light in perfect focus on retina
      (c) This is optimal for viewing with white light
   (5) To perform test
      (a) Start with red side clearer
         (i) Relaxes accommodation
      (b) Add minus sphere until letters in equal focus
   (6) Works fine with color blind individuals
      (a) Based on chromatic aberration, not on color recognition

# PART 4 – PRACTICAL MATTERS

Review of formulas

**Relationships to remember:**
**The most basic**

| | |
|---|---|
| Prentice's Rule | $\Delta = h * D$ |
| Vergence formula | $U + D = V$ |
| Focal length | $f = \frac{1}{D}$ |
| Spherical equivalent | (sphere) + (1/2)(cylinder) |

**Relationships to remember:**
**Power calculations**

| | |
|---|---|
| *Refracting* power of a spherical surface | $D_s = \frac{n'-n}{r}$ |
| Power of a thin lens immersed in fluid | $\frac{D_{air}}{D_{aqueous}} = \frac{(n_{IOL}-n_{air})}{(n_{IOL}-n_{aqueous})}$ |
| *Reflecting* power of a spherical mirror | $D_{reflecting} = \frac{2}{r}$ |
| IOL power (SRK) | A - 2.5(Axl) - 0.9(K) |

**Relationships to remember:**
**Magnification**

| | |
|---|---|
| Transverse magnification | $Mag = \frac{\text{Image distance}}{\text{Object distance}}$ |
| Axial magnification | $M_{axial} = (M_{tranverse})^2$ |
| Simple magnifier | $Mag = \frac{D}{4}$ |
| Telescope magnification | $Mag = \frac{D_{eyepiece}}{D_{objective}}$ |
| Spectacle lens | Mag = 2% per diopter of power |

## XVIII. Prescribing glasses

A. Retinoscopy - importance of working distance
   1. At neutralization, far point of eye is at peephole of retinoscope
   2. Must move far point of eye to infinity
   3. Subtract reciprocal of working distance
      a) Average working distance is 67 cm
      b) 1 / 0.67 m = 1.50 D
      c) Thus, subtract 1.50 D from value obtained at neutralization

B. Refraction in patient with poor retinoscopic reflex
   1. Pay careful attention to center of retinoscopic reflex
   2. Use bright (halogen) retinoscope
   3. Move closer (adjust working distance accordingly)
   4. Contact lens over-refraction
      a) Eliminates irregular astigmatism caused by cornea
   5. Consider a stenopeic slit refraction.

C. High-index lenses
   1. Plastic lenses: n = 1.66 and up
      a) Thinner lenses, lighter weight
      b) May have smaller "sweet spot" of clear vision
      c) Some have lower light transmission
      d) Different curvatures require adjustment
   2. Glass lenses: n = 1.80
      a) Excellent clarity, scratch resistant, BUT

b) Do not meet US safety standards

c) Available only from overseas

3. Problems with high-index lenses

a) Chromatic aberration

(1) A white spot will have a blue or yellow shadow or "ghost"

b) Smaller area of clearest vision

D. High minus lenses – how to improve appearance

1. Cycloplegic refraction - make sure patient is not overminused
2. Smaller frames
3. Bevel and polish lens edges
4. Use high-index material
5. Use plastic (versus glass) to decrease the weight
6. Flatter base curve
7. Thick frames to hide the thick edges
8. Finally, consider contact lenses.

E. Causes of night myopia

1. Pupil dilation in low light levels

a) Positive spherical aberration

(1) Rays refracted more strongly by periphery of lens

b) Irregular astigmatism revealed by larger pupil

2. Length of refraction lane

a) At best, lane is 6 meters (20 feet) long

(1) Patient is 1/6 diopter (0.167 D) undercorrected

(2) Add minus power ( - 0.25 D ) to final refraction

3. Purkinje shift

a) Spectral sensitivity shifts to shorter wavelengths in lower light levels

b) Chromatic aberration moves the focal point anteriorly, producing myopia.

4. No accommodative targets in dark

a) Nothing to "anchor" accommodation

b) Patient may "fog" self

F. Aphakic spectacles - disadvantages

1. Ring scotoma

a) Object seems to disappear as patient looks laterally

b) Ring scotoma moves centrally as eyes gaze to the side

c) A consequence of the prismatic effect of lenses.

2. Pincushion distortion

a) Periphery of image is magnified more than center

3. Magnification (15%)
4. Weight
5. Cost

G. Causes of glasses intolerance in children
  1. Poor parental motivation
    a) Be sure Mom and Dad understand reason for glasses
  2. Improper fit
    a) Frames too big
    b) Flat nasal bridge
    c) Optician not comfortable with children
    d) Child mishandles glasses, necessitating frequent readjustment
  3. Failure to relax accommodation
    a) Consider a short course of cycloplegia to relax accommodative efforts.

H. How to judge a glasses prescription by simple inspection
  1. Move glasses back and for to look for "with" (minus lens) or "against" (plus lens) movement
  2. Look for image magnification (plus lens) or minification (minus lens) to estimate the severity of refractive error
  3. Inspect a round object through the glasses
    a) If oval, lens has cylindrical power
    b) Axis of elongation = axis of minus cylinder
  4. Look for magnification and peripheral distortion in lower half of the glasses
    a) Indicates presence of progressive bifocals

I. Accommodative requirements with contact lenses
  1. Myope must accommodate more through contact lenses than through glasses despite proper distance correction in both cases
    a) Difficult to understand intuitively
      (1) Distance viewing - light rays entering eye are parallel
        (a) No accommodation required
      (2) Near viewing - light rays entering eye have negative vergence
        (a) Accommodation is required
        (b) Vergence when light strikes spectacles is different than vergence when light strikes contact lens
        (c) In myope, light is more divergent after passing through proper contact lens than it is after passing through proper spectacle correction
    b) Note that prismatic effects also favor near work in the myope wearing glasses
      (1) Eyes converge and therefore experience base-in effect through minus lenses

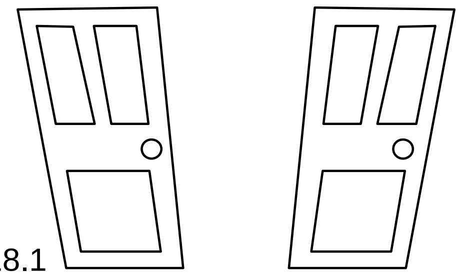
J. Progressive addition lenses
  1. Channel of progressively higher (plus) power
    a) Ground into front of lens
  2. Advantages
    a) No line to bother the cosmetically conscious
    b) Variable add for different activities
  3. Problems
    a) Marked irregular peripheral astigmatism.
      (1) Most annoying with higher power adds

(2) Most bothersome to patients who have already worn traditional bifocals

b) Segment height difficult to adjust

K. Correction of astigmatism in adults

1. Causes subtle distortion under monocular viewing conditions
   a) If with- or against- the rule, correction will cause objects to be taller or wider
   b) If oblique, correction will cause rectangles to appear tilted
2. Significant distortion of depth if oblique correction given to both eyes
   a) One eye sees rectangles tilted one way
   b) Other eye sees rectangle tilted other way
   c) Binocular vision system interprets image disparity as depth **(Figure 18.1)**
   d) Patient may complain bitterly
      (1) Especially if astigmatism has never been corrected before, or axis has changed



18.1
Left eye sees this Right eye sees this
End result is a stereogram

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3. Several ways to make correction more tolerable
   a) Methods that do not compromise acuity
      (1) Reassure patient
         (a) Most eventually adapt
         (b) Younger patients adapt faster
         (c) Children rarely complain at all no matter how much you give them
      (2) Minimize vertex distance
      (3) Consider contact lenses
         (a) Another way of minimizing vertex distance
      (4) Lenses should be minus cylinder type
         (a) Cylinder on the back surface
         (b) Most lenses made this way, but you never know unless you check
   b) Methods that compromise acuity
      (1) Rotate cylinder toward 90 or 180 degree meridian
      (2) Decrease power of cylinder

L. Why do Jackson Cross cylinders come in different powers?

1. Patients with poor acuity need to be shown a bigger difference for comparison
2. Use higher powers for lower visual acuities (Table 18.1)

| Acuity (while cross is in use) | Jackson cross cylinder power |
|---|---|
| 20/15 to 20/20 | ±0.12 D |
| 20/25 to 20/30 | ±0.25 D |
| 20/40 to 20/60 | ±0.50 D |
| 20/70 to 20/200 | ±1.00 D |

Table 18.1

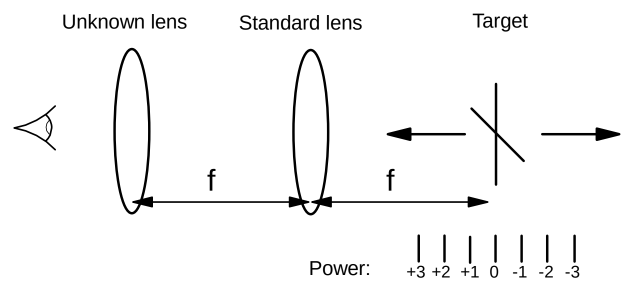
# XIX.OPTHALMIC INSTRUMENTS: OPTICAL PRINCIPLES

A. Trial lenses
  1. Additivity
    a) Combination of lenses should add correctly
    b) Curves, thicknesses, spacing must be correct
    c) Trial frames designed for best additivity of trial lenses
      (1) Proper use of trial frames
        (a) High power sphere - rear cell
          (i) Also important for vertex distance measurement
        (b) Cylinder - middle cell
        (c) Low power lenses - front cell
    d) Additivity error also a problem in phoropters
      (1) Up to 4 lenses may add together
  2. Wearing trial frames does not fully simulate new glasses
    a) Different aperture
    b) Different magnification
    c) Spectacle lenses have corrected curves
      (1) Front and back curves chosen to minimize astigmatism of oblique incidence
    d) Result - patient may still complain despite in-office trial of new Rx

B. Geneva lens clock
  1. Measures radius of curvature of lens surface
    a) Detects deflection of a movable pin
      (1) Caution - some pins can scratch plastic lenses
    b) Allows determination of
      (1) Base curve
      (2) Front- vs. back-surface cylinder
      (3) Lens power (subtract back surface power from front surface power in each principal meridian)
  2. Converts radius of curvature to power using presumed index of refraction
    a) Most are calibrated for crown glass (n=1.523)
    b) Need conversion factor for other materials to determine refractive power
  3. Relevance of base curve: Dissatisfied refraction patient
    a) Change in base curve
      (1) Changes magnification of spectacle lens
    b) Change from back-surface cylinder to front-surface cylinder

C. Lensmeter
  1. Measures power of glasses and contact lenses
    a) Lens power
    b) Prism power
  2. Four main components **(Figure 19.1)**
    a) Illuminated target
      (1) Cross pattern enhances detection of astigmatism
        (a) Uses vernier acuity to detect axis

b) Optometer ("Standard" or "Fixed") lens
   - (1) Without optometer lens, lensmeter dial would not be linear
     - (a) Would require large turn of dial to go from 1 D to 2 D
     - (b) Microscopic turn of dial to change from 14 D to 15 D
   - (2) Optometer principle gives linearity to lensmeter dial
     - (a) "Standard" plus lens
       - (i) Unknown (spectacle) lens at placed at primary focal point
       - (ii) Illuminated target placed at secondary focal point
     - (b) If unknown lens power is zero, parallel rays of light emerge from fixed lens when target at zero (focal) point
     - (c) If unknown lens has some power, target must be moved closer to or farther from fixed lens until parallel rays of light emerge
       - (i) Dial moves same amount whether from 1 to 2 D or from 14 to 15 D




19.1 Lensmeter

c) Platform for unknown lens

d) Astronomical telescope
   - (1) Helps detect when target is in focus (parallel rays of light emerging from fixed lens)
   - (2) Improves focusing precision
   - (3) Prevents examiner's refractive error from causing error in measurement

3. Use of lensmeter

a) Focus eyepiece
   - (1) Before trying to measure glasses
   - (2) Set lensmeter dial to zero before looking at target
   - (3) Adjust eyepiece (from fogged direction) until target is in focus

b) Measure distance Rx
   - (1) Temples away from you ("back vertex power")
   - (2) Measure sphere
     - (a) Adjust dial to bring one arm of cross into focus
       - (i) Plus cylinder - bring narrow lines into focus first
       - (ii) Minus cylinder - bring three lines into focus first
     - (b) Rotate target dial as necessary until arm of cross has no breaks
     - (c) Record measurement - this is power of sphere
   - (3) Adjust focusing dial to bring other arm of cross into focus
     - (a) This is cylinder power
     - (b) Axis is indicated on dial

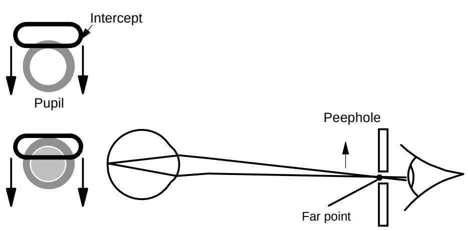
c) Measure add
   - (1) Measure difference between top and bottom segments
   - (2) For high plus lenses, turn temples toward you ("front vertex power")
     - (a) Not as important with other lenses

d) Measure prism
   - (1) Place glasses on subject's face
   - (2) Use marker to mark intersection of line of sight with spectacle lens
   - (3) Place lens in lensmeter with mark in center
     - (a) This is the prismatic power seen by the patient
     - (b) Will detect prism caused by displaced optical centers
   - (4) Note displacement of center of cross pattern
     - (a) What you see is what it is:
       - (i) Displaced up = base up prism
       - (ii) Displaced in = base in prism

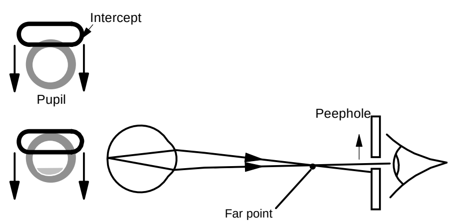
(b) Circles on cross target indicate prismatic power
(i) Maximum is about $5^{\Delta}$
(ii) If more than $5^{\Delta}$, need to use neutralizing prism of equal power and OPPOSITE direction
(iii) Neutralizing prism can go anywhere in pathway between spectacle lens and telescope

## D. Retinoscopy

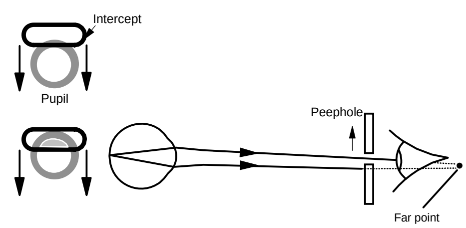
1. Detects location of far point of eye
2. Illumination system creates streak (intercept) of light
a) Light bulb filament is linear
(1) Can bend if you drop retinoscope when lit
(a) Creates lopsided streak
b) Mirror (directs light toward eye)
c) Sleeve (adjusts separation of filament from mirror)
(1) Creates divergent vs. convergent light
(2) Almost always want divergent light during retinoscopy
(a) Sleeve up for some retinoscopes, sleeve down for others
(b) If not sure, aim intercept toward your sleeve (shirt sleeve, that is)
(c) Move retinoscope closer to and further from your arm
(i) If filament comes into focus at *any* distance, retinoscope sleeve is in wrong position
(3) Convergent light focuses streak
(a) Helpful when determining cylinder axis



19.2 Retinoscopy - neutralization



19.3 Retinoscopy - "against" movement



19.4 Retinoscopy - "with" movement

3. Detection system
a) Peephole
(1) All returning light will pass through peephole only if subject's eye is in perfect focus at peephole **(Figure 19.2)**
(a) Subject's pupil appears to fill with light
(b) This is "neutralization"
(2) Otherwise only part of the returning light passes
(a) Peephole blocks remainder of light
(b) Returning light appears as a streak
(c) "Against" movement **(Figure 19.3)**
(i) Far point between peephole and patient
(ii) Light from top of patient's pupil "crosses over" at far point and enters bottom of examiner's eye
(d) "With" movement **(Figure 19.4)**
(i) Far point beyond peephole (behind examiner)
(ii) Light from top of patient's pupil enters top of examiner's eye

## E. Optical doubling

1. Difficult to measure moving object under high magnification
a) Will not stay still to line up with ruler (reticle)
2. Optical doubling uses prism to view object and image simultaneously

a) If prism power and distance are known, object size (separation) can be determined

b) Easy to adjust separation despite movement

(1) Object and image move simultaneously

(2) Separation does not change

3. Example: Measure height of child's sunglasses frame while child is jumping on trampoline **(Figure 19.5)**

a) Can't use ruler -- too hard to line up with moving target

b) Stand 100 cm from child

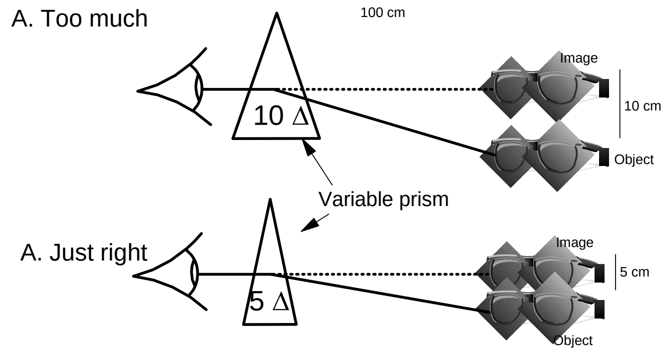
c) View sunglasses with vertical split field prisms

(1) Try different powers until top of object lines up with bottom of image

(a) At this point, power of prism = height of sunglasses frame

(b) If $5^{\Delta}$ prism were required, separation at 100 cm must be 5 cm, therefore glasses frames are 5 cm tall

(2) Can use other prism powers to measure height or width of child's head, hat, etc.




19.5 Optical doubling

4. Used in many ophthalmic instruments

a) Keratometer - size of reflected mires

b) Applanation tonometry - diameter of applanated area

c) Pachymetry - thickness of cornea and depth of anterior chamber

F. Corneal curvature assessment

1. Keratometer

a) Determines average corneal curvature in two meridians

(1) Measures size of reflected image (see Mirrors section)

(a) Measurement averages central 3 mm

(b) Can perform keratometry without difficulty in an eye filled with blood

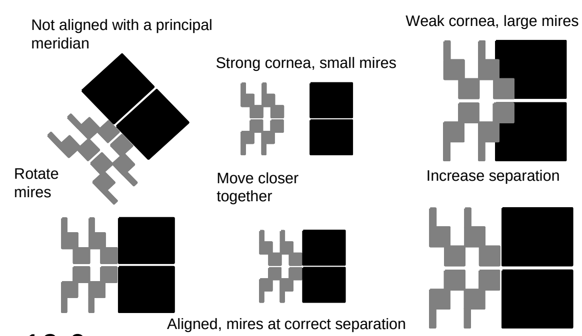
(i) Measuring reflecting power

(c) Uses object and image size to calculate magnification of corneal surface

(d) Uses magnification to calculate reflecting power of cornea

(e) Calculates corneal curvature using D=2/r

**Javal Schiötz mire adjustment**




19.6

(2) Converts corneal curvature to diopters of power using standardized refractive index

(a) D = (n'-n)/r

(i) n=1.3375, n=1

(b) Note that dioptric power is inferred

(i) If cornea has index of refraction other than 1.3375, power will be incorrect (but radius of curvature is still correct). This is a subtle point not likely to have any impact clinically.

b) Javal-Schiötz Ophthalmometer (**Figure 19.6)**

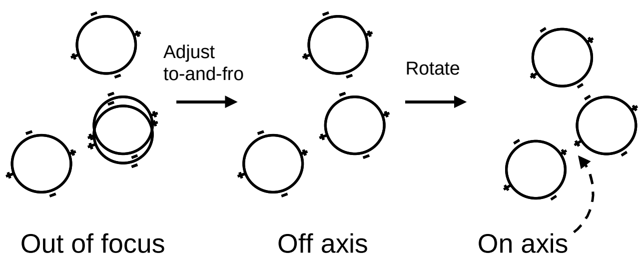
(1) Measures one meridian at a time

(2) Mires look like space invaders

(3) Knob changes separation of mires

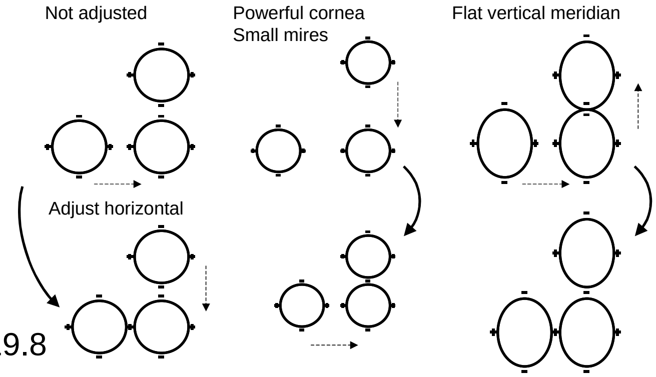
c) Bausch & Lomb Keratometer **(Figures 19.7, 19.8)**
   (1) Measures both meridians simultaneously
   (2) Circular mires
   (3) Knob changes power of doubling prism

**Bausch &Lomb mire adjustment**




19.7

**Bausch & Lomb mire adjustment**




19.8

2. Placido's disc
   a) Illuminated concentric circles
   b) Reflected by corneal surface
   c) Highlight areas of irregularity
3. Corneal topography
   a) Eye illuminated with concentric circles
   b) Image of reflected circles recorded by computer
   c) Distance between circles used to calculate curvature at multiple positions across entire corneal surface
   d) Computer produces map that provides more detail about subtle changes in corneal contour
      (1) Detection of early keratoconus
      (2) Evaluation before and after refractive surgery

G. Slit lamp
1. Illumination system
   a) Narrow slit produces optical cross section
2. Viewing system
   a) Binocular stereo microscope
   b) Variable magnification
      (1) Change eyepieces
      (2) Change objectives
      (3) Reversible Galilean telescope

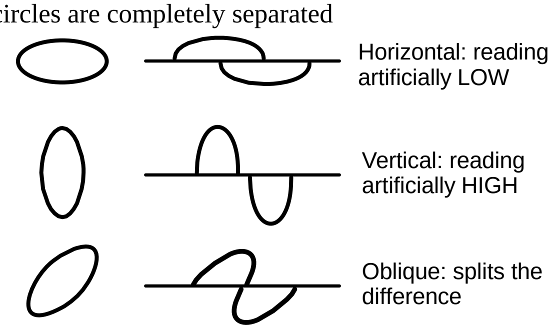
***3.*** Both imaged precisely over ***common pivot point***
   a) Centered illumination system to view by
      (1) Direct illumination
      (2) Specular reflection
   b) Decenter illumination system to view by
      (1) Retroillumination
         (a) Light directed behind object of interest)

(2) Sclerotic scatter
(a) Light directed into sclera and through cornea by total internal reflection
(b) Opacities in cornea deflect light toward examiner

H. Specular microscope
1. Provides view directly into reflected illuminating light
2. Can visualize interface between aqueous and endothelial cells
a) Makes it possible to count endothelial cells

I. Pachymeter
1. Measure thickness
a) Corneal thickness
b) Anterior chamber depth
2. Two methods
a) Optical
b) Ultrasonic (A scan)

J. Applanation tonometer
1. Flattens small portion of cornea
a) Tear film visibility enhanced with fluorescein
(1) Too little fluorescein causes artificially high reading
(2) Too many tears cause artificially low reading
b) When diameter of applanated circle = 3.06 mm, intraocular pressure = 10 times applanation force (in dynes)
(1) If applanation force too low, circle is too small
(2) If applanation force too high, circle is too big
c) How to tell when 3.06 mm has been applanated
(1) Key is optical doubling
(2) Split-field plastic prism separates half fields by 3.06 mm
(a) When circle too small, inner edges of semicircles are completely separated
(b) When circle too large, inner edges of semicircles overlap too far
(c) When circle just the right size, inner edges of semicircles are perfectly aligned
(i) Takes advantage of vernier acuity
d) Astigmatic cornea
(1) Applanated area is an ellipse rather than a circle **(Figure 19.9)**
(a) Two ways to compensate
(i) Measure pressure with doubling prism at 180 degrees, then at 90 degrees. True pressure is average of two readings
(ii) Rotate prism to align red mark with axis of the minus cylinder correction. Places axis of doubling prism at 43 degree angle to major axis of astigmatic ellipse
(b) 4 D of corneal cylinder causes only 1 mm Hg error

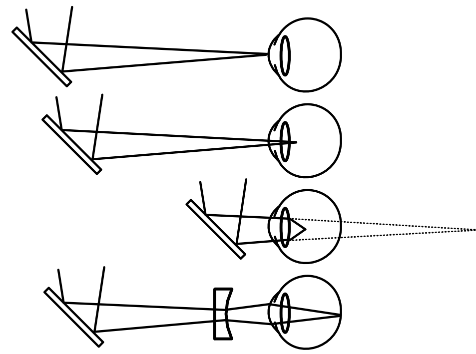


19.9
Applanation tonometry with high astigmatism

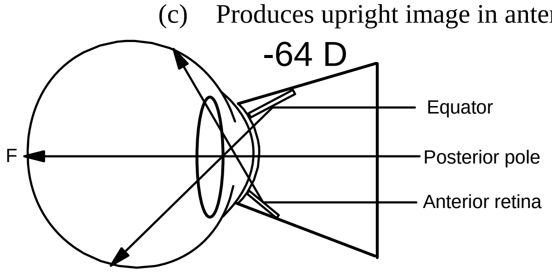
e) Fat cornea
(1) Increased corneal thickness may cause artificially high applanation measurements
(a) Some now advocate corneal pachymetry in glaucoma suspects

K. Slit lamp fundus lenses

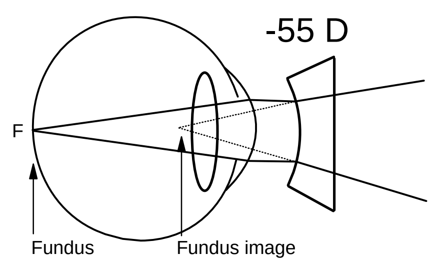
1. Only possible to view 1/3 - 1/2 way into eye using slit lamp **(Figure 19.10)**
   a) +60 D power of eye does not let light pass back any further
2. Two approaches to getting around power of front of eye to see retina from slit lamp
   a) Defeat corneal power
      (1) Goldmann contact lens **(Figure 19.11)**
         (a) Changes cornea from curved surface to flat surface
         (b) -64 D power
         (c) Upright image
         (d) Coupling medium
            (i) Goniosol more viscous than necessary
            (ii) Can get good results with contact lens wetting solution. More comfortable for patient afterward. Allows fundus photography afterward
         (e) Extra mirrors give view of anterior chamber angle and fundus periphery
      (2) Zeiss 4 mirror gonioscopic lens
         (a) Has central area for viewing fundus
         (b) Same mechanism as Goldmann contact lens
      (3) Hruby lens **(Figure 19.12)**
         (a) -55 D lens
         (b) Sends divergent light into eye
         (c) Produces upright image in anterior 1/3 of vitreous



19.10 Retinal viewing with slit lamp

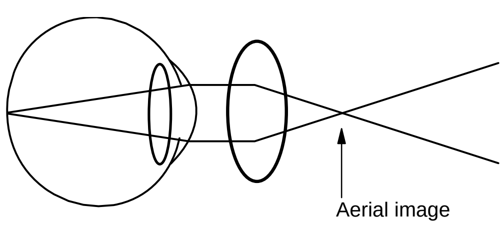



19.11 Goldmann contact lens




19.12 Hruby lens

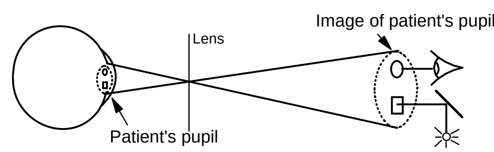
   b) Indirect ophthalmoscopy **(Figure 20.13)**
      (1) +78 D or +90 D lens
      (2) Inverted aerial image anterior to lens
         (a) Must pull slit lamp back to view image




19.13 78 D and 90 D lens

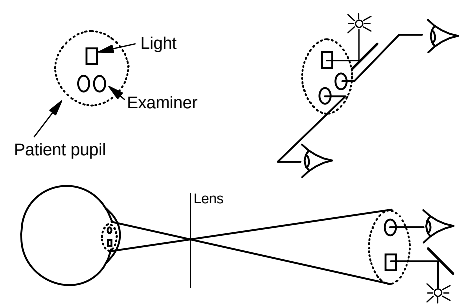
L. Operating microscope
   1. Illumination system
      a) Nearly coaxial
   2. Viewing system has three components
      a) Binoculars
         (1) Decrease pupillary distance
      b) Magnification changer
      c) Objective lens
         (1) Determines working distance

M. Direct ophthalmoscope
   1. Uses optics of patient's eye as simple magnifier (see magnification section)
      a) Myopic patient
         (1) Plus error lens in eye
         (2) Examiner must dial minus lens into ophthalmoscope
         (3) Result is Galilean telescope - image is magnified
      b) Hyperopic patient
         (1) Image is minified
   2. Field of view 7 degrees
      a) No condensing lens to collect peripheral rays of light
      b) Compare with 25 degree field of view with indirect ophthalmoscope

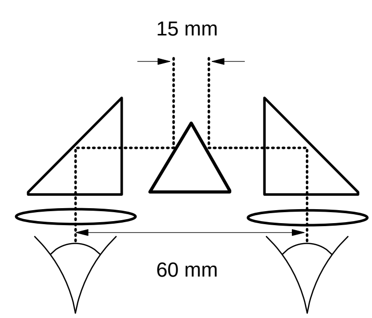



19.14 Indirect ophthalmoscope

N. Binocular indirect ophthalmoscope
   1. Illumination system **(Figure 19.14)**
      a) Mirror places light source close to examiner's pupils - nearly coaxial
      b) Passes through condensing lens
   2. Viewing system **(Figure 19.15)**
      a) Condensing lens forms inverted intermediate aerial image
         (1) Between examiner and lens
      b) Binocular eyepieces reduce the observer's pupillary distance from 60 down to 15 mm **(Figure 19.16)**
         (1) Four-fold reduction in stereo
   3. Transverse magnification
      a) (Power of the eye) / (Power of the condensing lens)
      b) Examples (60 D model eye)
      c) 20 D lens - transverse magnification = 3 X
      d) 15 D lens - transverse magnification = 4 X
      e) 30 D lens - transverse magnification = 2 X
      f) Refractive hyperopia




19.15 Indirect ophthalmoscope



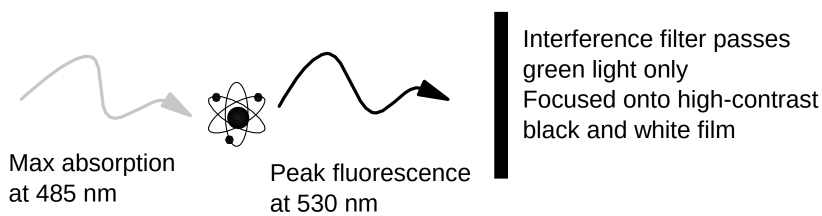

19.16 Indirect ophthalmoscope - pupillary distance

(1) Eye has less power
(2) Magnification is lower

4. Axial magnification
   a) Depth or height of fundus feature
   b) (Transverse magnification)$^2$
   c) But decreased pupillary distance decreases magnification by (60 mm / 15 mm) = 4 X
   d) 20 D lens - axial magnification = 9/4 = 2.25 X
   e) 15 D lens - axial magnification = 16/4 = 4 X
   f) 30 D lens - axial magnification = 4/4 = 1 X
5. Distortion of depth
   a) If (transverse magnification) / (depth magnification) > 1, image is artificially flattened
      (1) If < 1, depth is exaggerated
   b) 20 D lens - (transverse / depth) = 3/2.25 = 1.33
   c) 15 D lens: (transverse / depth) = 4/4 = 1.00
      (1) No distortion
   d) 30 D lens: (transverse / depth) = 2 / 1 = 2.00
      (1) Significant flattening
   e) Note refractive hyperopia gives lower magnification and therefore more flattening of image

O. Fluorescein angiography **(Figure 19.17)**

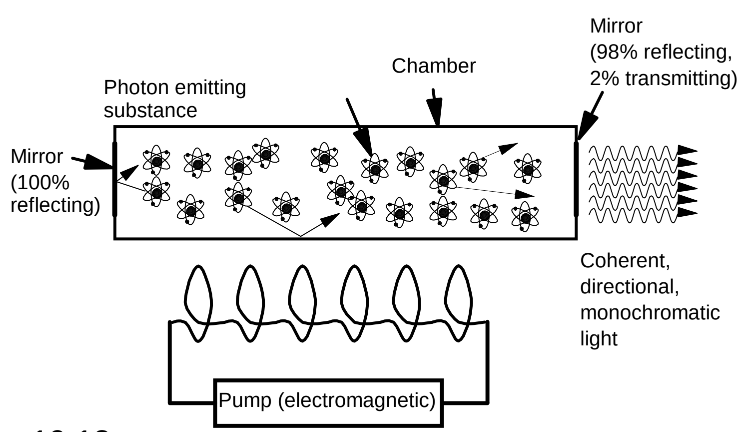
1. Sodium fluorescein dye is injected into a vein
   a) Absorbs at 485 nm
   b) Fluoresces at 530 nm
   c) Eye illuminated with blue light
   d) Blue-blocking interference filter prevents reflected blue wavelengths from entering camera
      (1) Allows yellow-green light to pass through to high-contrast black and white film.



19.17

P. Lasers

1. *L*ight *A*mplification by *S*timulated *E*mission of *R*adiation **(Figure 19.18)**
   a) Laser light is
      (1) Monochromatic
      (2) Coherent
         (a) Able to generate interference pattern
      (3) Polarized
      (4) Directional
         (a) Does not spread
      (5) Very bright
         (a) Capable of delivering a



19.18

lot of energy to a very small area.

2. Selection of proper wavelength allows more targeted delivery of energy
    a) *argon blue green (488 nm) and green (515 nm)*
        (1) Absorbed by RPE, xanthophyll, iris and hemoglobin
    *b) krypton red (647 nm)*
        (1) Absorbed by melanin (iris, RPE and choroid)
        (2) Poorly absorbed by hemoglobin and xanthophyll
            (a) Advantageous in presence of vitreous hemorrhage or cataract
    c) *diode (815 nm)*
        (1) Absorbed solely by melanin
            (a) Damage to surrounding tissues is by spread of thermal damage from pigment epithelium
        (2) Minimal absorption by sclera
            (a) Can treat retina through either pupil or the sclera.
    d) Nd-YAG laser
        (1) Creates 1064 nm infrared, nonvisible light
            (a) Aiming beam is 633 nm helium/neon laser
        (2) Does NOT rely on absorption
            (a) High power pulses cause plasma formation
            (b) Local mechanical disruption
            (c) Semitransparent membranes (e.g., posterior capsule) can be cut
    e) Excimer laser
        (1) High-power ultraviolet radiation
            (a) 193-351 nm
        (2) Light absorbed by all layers of the eye
        (3) Cornea is first thing (besides tears) encountered by light encounters.
3. Laser output measurement
    a) Power
        (1) Watt
            (a) Used with continuous wave lasers
        (2) Joule = 1 watt for 1 second
            (a) Used with pulsed lasers
    b) Brightness
        (1) Irradiance (watts/cm$^2$), or
        (2) Energy density (joules/cm$^2$)
        (3) If power stays the same, but spot size decrease, more laser energy will be packed into a smaller spot
            (a) Brightness (and damage) will increase

# XX. OPTICS IN THE OFFICE

A. Monocular Diplopia
   1. Diagnosis
      a) Cover one eye
      b) Pinhole test
   2. Causes
      a) Refractive error
      b) Surface problem
      c) Irregular astigmatism
      d) Lenticular irregularity (cataract)
      e) Retinal problem (RARE)

B. Binocular diplopia
   1. Look for prism in glasses !
   2. Cover testing
   3. Red glass or other sensory test
   4. See strabismus section for details

C. New glasses are no good
   1. Obtain old glasses if possible
      a) Compare axis and power
      b) Compare base curves
      c) Look for prism!
         (1) Intentional (ground in)
         (2) Unintentional (shift in optical centers)
      d) Consider trauma to glasses
      e) Compare astigmatic grinding
         (1) Front vs. back surface
      f) Coatings and tints
   2. Check bifocals
      a) Segment height
      b) Design (progressive vs. flat top, etc.)
      c) Power
   3. Check refraction
      a) Sphere correct?
         (1) Consider cycloplegic refraction
      b) Look for big change in cylinder
      c) Look for rapid change (e.g. cataract)

D. Poor vision after refraction
   1. Pinhole over best refraction
   2. Refine correction with high power Jackson cross
   3. Check eye chart contrast

a) Bad lighting or dim bulb

4. Consider subtle disease

a) Latent nystagmus

(1) Recheck acuity with both eyes open

b) Dry eye

E. Headache and asthenopia

1. Cover testing

a) Look for phoria or tropia

2. Check for prism in glasses

3. Check refraction

a) Cycloplegic refraction

(1) Latent hyperopia - not enough plus

(2) Over-corrected - too much minus

4. Check accommodation

a) Early presbyopia

# XXI.RELATIONSHIPS TO REMEMBER

## Relationships to remember:
### The most basic

| | |
|---|---|
| Prentice's Rule | $\Delta = h * D$ |
| Vergence formula | $U + D = V$ |
| Focal length | $f = \frac{1}{D}$ |
| Spherical equivalent | (sphere) + (1/2)(cylinder) |

## Relationships to remember:
### Power calculations

| | |
|---|---|
| *Refracting* power of a spherical surface | $D_s = \frac{n'-n}{r}$ |
| Power of a thin lens immersed in fluid | $\frac{D_{air}}{D_{aqueous}} = \frac{(n_{IOL}-n_{air})}{(n_{IOL}-n_{aqueous})}$ |
| *Reflecting* power of a spherical mirror | $D_{reflecting} = \frac{2}{r}$ |
| IOL power (SRK) For AL >22 and <24.5 | A - 2.5(Axl) - 0.9(K) |

## Relationships to remember:
### Magnification

| | |
|---|---|
| Transverse magnification | $Mag = \frac{\text{Image distance}}{\text{Object distance}}$ |
| Axial magnification | $M_{axial} = (M_{tranverse})^2$ |
| Simple magnifier | $Mag = \frac{D}{4}$ |
| Telescope magnification | $Mag = \frac{D_{eyepiece}}{D_{objective}}$ |
| Spectacle lens | Mag = 2% per diopter of power |