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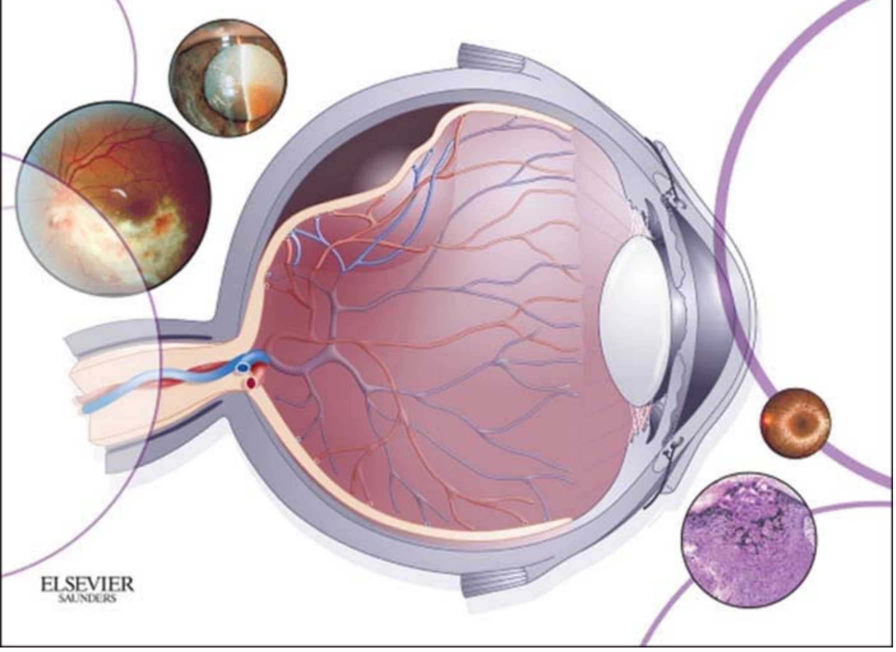
Review of Ophthalmology

SECOND EDITION

William Trattler • Peter K. Kaiser • Neil J. Friedman



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Review of Ophthalmology

SECOND EDITION

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Contents

Preface

Developing an effective textbook that can be used in preparation for written examinations has been a labor of love. We have enjoyed building and designing this book in a way that provides the maximum amount of information in a concise and clear manner. Based on your feedback and reviews, we know we are delivering a text book that can provide the essential information for a comprehensive understanding of each topic, as well as covers the esoteric topics that often appear on tests. We have also updated the material in each chapter to stay current with new information.

The overall goal and layout of Review of Ophthalmology has remained the same. The book is organized into 11 clearly divided chapters which cover the essential topics that ophthalmologists are required to master. We have also included sidebars that focus on the core knowledge base, as well as the results from important clinical trials. New medical and surgical treatments have also been included in the new edition. At the end of each chapter, we have developed additional multiple choice questions that are designed to test your knowledge and to help you prepare for future examinations.

We hope that the improvements and new material contained in this edition will strengthen your review experience, and we wish you success in your future careers.

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1 Optics

PROPERTIES OF LIGHT

Light behaves both as waves and as particles (photons)

Its **speed** (velocity) (v) is directly proportional to wavelength (λ) and frequency (ν): $v = \lambda\nu$

In any given medium, speed of light is constant ($v_{vacuum} = c = 3.0 \times 10^{10}$ cm/s); therefore, wavelength and frequency are inversely proportional

Light slows down in any substance other than air or vacuum, amount of slowing depends on medium; frequency of light remains unchanged, but wavelength changes (becomes shorter) (Figure 1-1)

Its **energy** is directly proportional to frequency and inversely proportional to wavelength: $E = h\nu = h(c/\lambda)$

Index of refraction (n): ratio of speed of light in a vacuum to speed of light in specific material ($n = c/v$)

Air = 1.00, water = 1.33, aqueous and vitreous = 1.34, cornea = 1.37, crystalline lens = 1.42, intraocular lens (IOL) (silicone = 1.41; polymethyl methacrylate (PMMA) = 1.49; acrylic = 1.55), glass = 1.52, high index lenses = 1.6-1.8

Interference: overlapping of light waves; may be constructive or destructive

Constructive: peaks of 2 waves overlap, resulting in maximum intensity at that wavelength

Destructive: peak of 1 wave overlaps with trough of another, obliterating both waves

Example: antireflective coatings (destructive interference, ¼ wavelength apart); interference filters (allow only green light out of the eye during fluorescein angiography); laser interferometry (retinal function test; optical coherence tomography [OCT])

Coherence: ability of 2 light beams to cause interference (large white source has a coherence close to zero)

Example: OCT

Polarization: each light wave has an electrical field with a particular orientation

Nonpolarized light: electrical field of each wave has a random orientation

Polarized light: all electrical fields have same orientation

Example: Haidinger's brushes (polarizing filter rotated in front of blue background produces rotating image like a double-ended brush or propeller; type of entopic phenomenon; test of macular function), Titmus stereo testing, polarized microscopy, polarizing sunglasses

Diffraction: bending of light waves around edges; change in direction of light wave is related to wavelength (the shorter the wavelength, the less the change in direction); amount of diffraction is related to size of aperture (the smaller the aperture, the greater the diffraction); interference of new waves with original rays forms a diffraction pattern

Example: Airy disc (diffraction pattern produced by a small, circular aperture; occurs when pupil size is <2.5 mm; diameter of central disc increases as pupil size decreases); pinhole (reduces refractive error and improves vision by increasing depth of focus, but limited by diffraction; optimal size is 1.2 mm; may correct for up to 3 D; smaller aperture limits visual acuity; squinting is method of creating a natural pinhole to improve vision; pinhole can also improve vision in eyes with corneal or lenticular irregularities; pinhole can reduce vision in eyes with retinal disorders)

Scattering: disruption of light by irregularities in light path; shorter wavelengths scatter to a greater extent

Example: Opacity (corneal scar or cataract) scatters light, causing glare and image degradation; in atmosphere, scattering involves particles (Rayleigh scattering) and blue light (scattered to the greatest extent; therefore, sky appears blue)

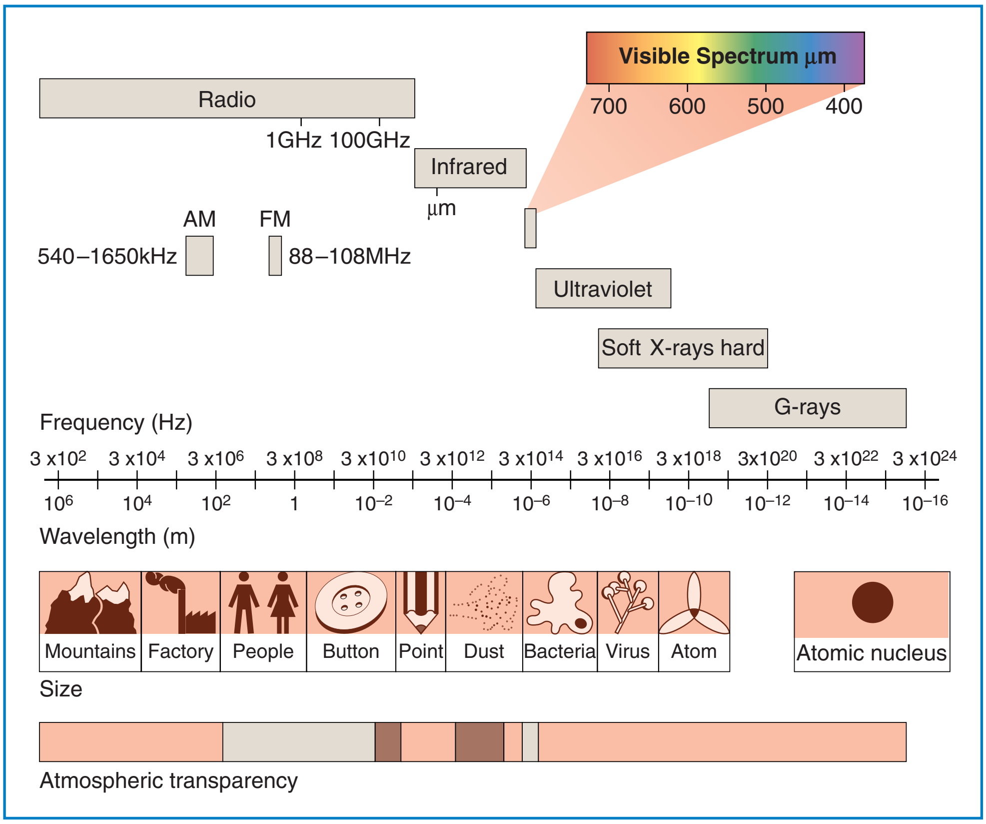


Figure 1-1. The electromagnetic spectrum. The pictures of mountains, people, buttons, viruses, and so forth, are used to produce a real (i.e. visceral) feeling of the size of some of the wavelengths. (From Miller D, Burns SK: Visible light. In: Yanoff M, Duker JS (eds) Ophthalmology, 2nd edn. St Louis, Mosby, 2004.)

Reflection: bouncing of light off optical interfaces; the greater the refractive index difference between the 2 media, the greater is the reflection; also varies with angle of incidence

Example: Asteroid hyalosis (asteroids reflect light back into examiner's eye, creating glare; patient is asymptomatic)

Transmission: percentage of light penetrating a substance (%T); can vary with wavelength

Absorption: expressed as optical density (OD)$=$log $1/T$

Illumination: measure of incident light

Luminance: measure of reflected or emitted light (lumen/m^2); apostilb$=$diffusing surface with luminance of 1 lumen/m^2 (used in Humphrey and Goldmann visual field testing)

Example: contrast sensitivity is ability to detect small changes in luminance

Laser: light amplification by stimulated emission of radiation; excited material releases photons of same wavelength and frequency; process is amplified so that released photons are in phase (constructive interference); produces monochromatic, coherent, high-intensity polarized light; power can be increased by increasing energy or decreasing time ($P=E/t$); Q switching and mode locking (types of shutters that synchronize light phase) are methods of increasing laser power by compressing output in time

REFRACTION

Light changes direction when it travels from one material to another of different refractive index (e.g. across an optical interface); direction of refraction is toward the normal when light passes from a medium with a lower index of refraction to a medium with a higher one, and away from the normal when light passes from a more dense to a less dense medium (higher refractive index materials are more difficult for light to travel through, so light takes a shorter path [closer to the normal]); light does not deviate if it is perpendicular to interface (parallel to the normal)

Snell's law: $n \sin(i) = n' \sin(r)$; n=refractive index of material; i=angle of incidence (measured from the normal); r=angle of refraction (measured from the normal) (Figure 1-2)

Critical angle: angle at which incident light is bent exactly 90° away from the normal (when going from medium of higher to lower n) and after which all light is reflected

Example: Glass/air interface has a critical angle of 41°; critical angle of cornea=46.5°

Total internal reflection: angle of incidence exceeds critical angle, so light is reflected back into material with

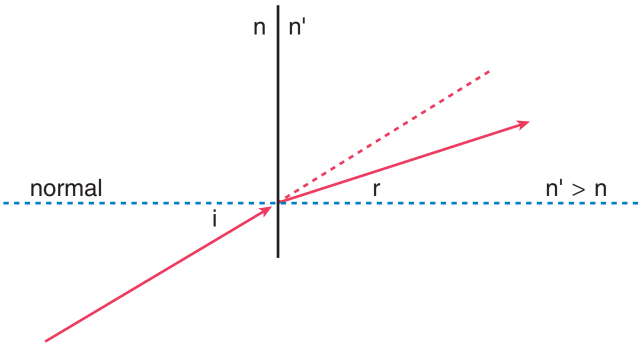


Figure 1-2. Refraction of light ray.

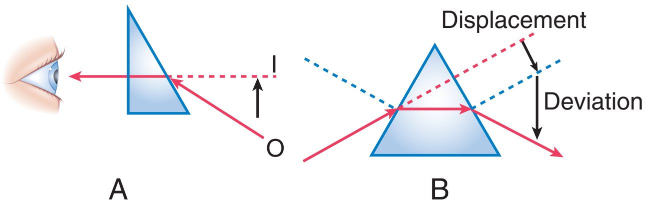


Figure 1-3. **A,** Displacement of image toward apex. **B,** Displacement and deviation of light by prism.

higher index of refraction; $n \sin(i_c) = n' \sin(90°)$; $\sin(i_c) = (n'/n) \times 1$

Example: Gonioscopy lens is necessary to view angle structures owing to total internal reflection of the cornea

PRISMS

Prisms displace and deviate light (because their surfaces are nonparallel); light rays are deviated toward the base; image is displaced toward the apex (Figure 1-3)

Prism diopter (PD, Δ): displacement (in cm) of light ray passing through a prism, measured 100 cm (1 m) from prism

Example: 15 Δ = ray displaced 15 cm at a distance of 1 m (1 Δ = 1 cm displacement/1 m); 1° ≈ 2 Δ (this approximation is useful for angles smaller than 45°)

Angle of minimum deviation: total angle of deviation is least when there is equal bending at both surfaces of prism

Plastic prisms are calibrated by angle of minimum deviation: back surface parallel to frontal plane

Glass prisms are calibrated in **Prentice position**: back surface perpendicular to visual axis

Prism placed in front of the eye creates a phoria in the direction of the base

Example: Base-out (BO) prism induces exophoria; to correct, use prism with apex in the opposite direction

Apex is always pointed in direction of deviation: base-out for esotropia, base-in for exotropia, base-down (BD) for hypertropia

Stacking prisms is not additive; 1 prism in front of each eye is additive

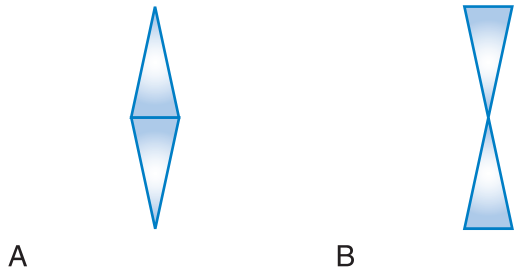


Figure 1-4. **A,** Plus lenses act like 2 prisms base to base. **B,** Minus lenses act like 2 prisms apex to apex.

Risley prism: 2 right-angle prisms positioned back to back, which can be rotated to yield variable prism diopters from 0 to 30 Δ; used to measure prismatic correction for tropias

Fresnel prisms: composed of side-by-side strips of small prisms; prism power is related to apex angle, not the size of the prism; available as lightweight, thin press-on prism to reduce base thickness of the spectacle prism; disadvantage is reflection and scatter at prism interface, causing decreased visual acuity

Prismatic effect of lenses (Figure 1-4): spectacles induce prism; all off-axis rays are bent toward or away from axis, depending on lens vergence

Perceived movement of fixation target when lens moves in front of the eye:

Plus lenses: produce **'against' motion** (target moves in opposite direction from lens)

Minus lenses: produce **'with' motion** (target moves in same direction as lens)

Amount of motion is proportional to the power of the lens

Prismatic effect of glasses on strabismic deviations: 2.5×D = % difference; minus lenses make deviation appear larger ('minus measures more'); plus lenses decrease measured deviation

Prentice's rule: prismatic power of lens = $\Delta = hD$ (h = distance from optical axis of lens [cm], D = power of lens [D])

Prismatic power of a lens increases as one moves farther away from optical center (vs power of prism, which is constant)

Example: Reading 1 cm below optical center: OD − 3.00; OS + 1.00 + 3.00 × 90

OD (*Oculus Dexter* – right eye): prism power = 1 cm × 3 D = 3 Δ BD

OS (*Oculus Sinister* – left eye): prism power vertical meridian: 1 cm + 1 D = 1 Δ BU (base-up) (Note: power of cylinder in 90° meridian is zero)

Net prismatic effect = 4 Δ (either BD over OD, or BU over OS)

Treatment of vertical prismatic effect of anisometropia:

1. Contact lenses (optical center moves with eyes)
2. Lower optical centers of lenses (reduce amount of induced prism)
3. Prescribe slab-off prism (technique of grinding lens [done to the more minus of the 2 lenses] to

remove BD prism [to reduce amount of induced prism])
4. Single vision reading glasses

Prismatic effect of bifocal glasses:
Image jump: produced by sudden prismatic power at top of bifocal segment; not influenced by type of underlying lens; as line of sight crosses from optical center of lens to bifocal segment, image position suddenly shifts up owing to base-down prismatic effect of bifocal segment (more bothersome than image displacement; therefore, choose segment type to minimize image jump)
Image displacement: displacement of image by total prismatic effect of lens and bifocal segment; minimized when prismatic effect of bifocal segment and distance lens are in opposite directions
Prismatic effect of underlying lens:
Hyperopic lenses induce BU prism, causing image to move progressively downward in downgaze
Myopic lenses induce BD prism, causing image to move progressively upward in downgaze
Prismatic effect of bifocal segment:
Round top (acts like BD prism): maximum image jump; image displacement less for hyperope than for myope
Flat top (acts like BU prism): minimum image jump; image displacement more for hyperope than for myope
Executive type or progressive lenses: no image jump (optical centers at top of segment)
Plus lens: choose round top
Minus lens: choose flat top or executive type (for myopes, image jump is very difficult to ignore because it is in same direction as image displacement, so avoid round tops in myopes)

Chromatic effects: prismatic effect varies with wavelength
Shorter wavelengths are bent farther, causing chromatic aberration
White light shines through prism: blue rays closer to base (bend farthest), red rays closer to apex
In the eye, blue rays come to focus closer to lens than do red rays; difference between blue and red is 1.5–3 D

Duochrome test: red and green filters create 0.5 D difference; use to check accuracy of refraction
If letters on red side are clearer, focal point is in front of retina (eye is 'fogged' or myopic)
If letters on green side are clearer, focal point is behind retina (eye is overminused or hyperopic)
Technique: start with red side clearer and add minus sphere in 0.25 D steps until red and green sides are equal (focal point on retina); works in colorblind patients because it is based on chromatic aberration rather than color discrimination

Vector addition of prisms: prismatic deviations in different directions are additive, based on pythagorean theorem ($a^2+b^2=c^2$) (Figure 1-5)

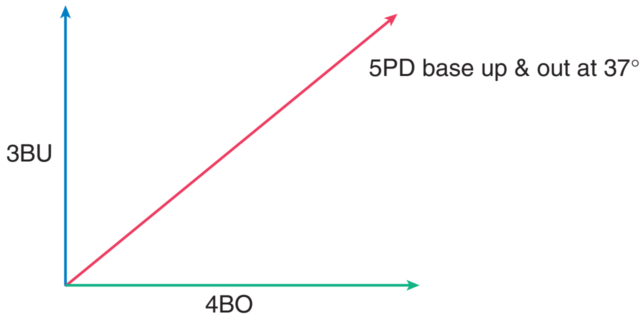


Figure 1-5. Addition of BU and BO prisms.

VERGENCE

The amount of spreading of a bundle of light rays (wavefront) emerging from a point source

Direction of light travel must be specified (by convention, left to right)

Convergence (converging rays): plus vergence; rare in nature; must be produced by an optical system

Divergence (diverging rays): minus vergence

Parallel rays: zero vergence

Diopter: unit of vergence; reciprocal of distance (in meters) to point at which rays intersect; reciprocal of focal length of lens

Lens: adds vergence to light (amount of vergence=power of lens [in diopters])
Plus (convex) lens adds vergence; minus (concave) lens subtracts vergence

Basic lens formula: $U+D=V$ (U=vergence of light entering lens; D=power of lens; V=vergence of light leaving lens)
Power of a spherical surface in a fluid: $D_s=(n'-n)/r$ ($n'-n$=difference in refractive indices; r=radius of curvature of surface [in meters])
Example: Power of corneal surface: back=−5.7 D; front=+52.9 D (front: n'=1.37, n=1.00; back: n'=1.33, n=1.37; r=0.007)
Power of a thin lens immersed in fluid: $D_{air}/D_{fluid}=(n_{lens}-n_{air})/(n_{lens}-n_{fluid})$
Refracting power of a thin lens is proportional to difference in refractive indices between lens and medium

Objects and images:
Object rays: rays that define the object; always on incoming (left) side of lens
Image rays: rays that define the image; always on outgoing (right) side of lens
Objects and images can be on either side of lens: real if on same side as respective rays; virtual if on opposite side from rays (locate by imaginary extension of rays through lens)

If object is moved, image moves in same direction relative to light

Adding power to system also moves image: plus power pulls image against light; minus power pushes image with light

Lenses:

Real (thick) lenses (Figure 1-6):

6 CARDINAL POINTS: 2 principal planes (H and H'); 2 nodal points (N and N'); 2 focal points (F and F')

Refraction occurs at principal planes (U is measured from H; V is measured from H')

Focal lengths are also measured from principal planes

Nodal points coincide with principal planes (exception: if different refractive media are on opposite sides of the lens, then nodal points are both displaced toward the medium with the higher refractive index)

Central ray: passes through both nodal points (tip of object to N, across to N'; then, emerges parallel to original direction)

MENISCUS LENSES: difference between anterior and posterior curvature determines power

Steeper anterior curvature=convergent lens (+power); principal planes displaced anteriorly

Steeper posterior curvature=divergent lens (−power); principal planes displaced posteriorly

Power of lens is measured at posterior surface (posterior vertex power)

Conjugate points: each pair of object-image points in an optical system is conjugate; if direction of light is reversed, position of object and image is exactly reversed

Conjugate planes:

Example: Viewing a slide presentation (image of slide is formed on retina of each person in audience, and very faint image of each person's retina is projected on the screen), direct ophthalmoscope (patient's retina and examiner's retina are conjugate), indirect ophthalmoscope (3 conjugate planes [patient's retina, aerial image plane, examiner's retina]; any object placed at far point [aerial image] will be imaged sharply in focus on patient's retina)

Ideal (thin) lenses: special case of thick lens; as lens gets thinner, principal planes move closer together; in an ideal lens, principal planes overlap at optical center

2 FOCAL POINTS:

PRIMARY (f): object point for image at infinity (point on optical axis at which object is placed so parallel rays emerge from lens)

SECONDARY (f'): image point for object at infinity (point on optical axis at which incident parallel rays are focused)

FOCAL LENGTH: distance between lens and focal points; reciprocal of lens power ($f=1/D$)

Example: Focal length of +20 D lens is 1/20=0.05 m

NODAL POINT (N): point through which light ray passes undeviated; located at center of thin lens (optical center)

RAY TRACING: use to determine image size, orientation, and position

3 PRINCIPAL RAYS:

1. Central ray: undeviated ray passing from tip of object through nodal point of lens (or center of curvature of mirror) to tip of image; gives size and orientation of image (form similar triangles; thus, sizes of object and image are in same ratio as their distances from the lens)
2. Ray from tip of object through F emerges from lens parallel to optical axis
3. Ray from tip of object parallel to optical axis emerges from lens and passes through F' (Figure 1-7)

Lens effectivity: function of lens power and distance from desired point of focus; depends on vertex distance and refractive index of media in which lens is placed ($D_{air}=[n_{IOL}-n_{air}]/[n_{IOL}-n_{aqueous}]\times D_{aqueous}$); moving a lens forward away from eye increases effective plus power, so plus lens becomes stronger and minus lens becomes weaker; when vertex distance decreases, a more plus lens is required to maintain the same distance correction (i.e. as desired point of focus is approached, more plus power is needed); the more powerful the lens, the more significant is the change in position

Vertex distance conversion:

1. Focal point of original lens=far point
2. Distance of new lens from far point=required focal length of new lens
3. Power of new lens=reciprocal of new focal length

Example: +12.50 D spectacle lens at vertex distance of 13 mm; calculate contact lens (CL) power:

1. +12.50 D lens has focal point of 0.08 m=8 cm=far point
2. Distance of new lens (CL) from far point is 8 cm−13 mm=67 mm=required focal length of CL
3. Power of CL=1/0.067 m=+15 D

Approximation: $D_2=D_1+S(D_1)^2$ (S=vertex distance in meters)

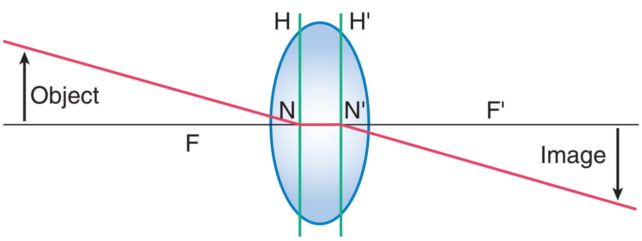


Figure 1-6. Conjugate points of real lens: each pair of object–image points in an optical system is conjugate; if direction of light is reversed, positions of object and image are exactly reversed.

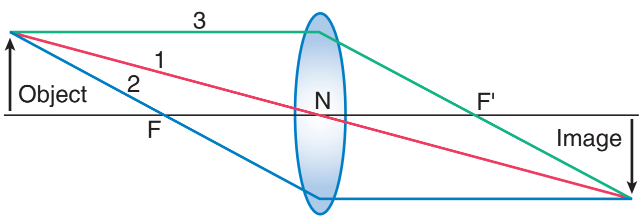


Figure 1-7. Three principal rays of ideal lens.

Pure cylindrical lens: power only in 1 meridian (perpendicular to axis of lens); produces focal line parallel to axis

Spherocylindrical lens: power in 1 meridian greater than other

Spherical equivalent: average spherical power of a spherocylindrical lens; equal to sphere plus ½ the cylinder; places circle of least confusion on retina

Conoid of Sturm: 3-dimensional envelope of light rays refracted by a circular spherocylindrical lens; consists of: vertical line → vertical ellipse → circle (of least confusion) → horizontal ellipse → horizontal line (Figure 1-8)

Circle of least confusion: circular cross section of conoid of Sturm, which lies halfway (dioptrically) between the 2 focal lines at which image is least blurred; dioptrically calculated by spherical equivalent

Interval of Sturm: distance between anterior and posterior focal lines

Cylinder transposition: converting cylinder notation (plus → minus; minus → plus)

New sphere = old sphere + old cylinder

New cylinder = magnitude of old cylinder but with opposite power

New axis = change old axis by 90°

Example: +3.00 +1.50×45 → +4.50 –1.50×135

Power cross diagram: depicts 2 principal meridians of lens with the power acting in each meridian (90° from axis), rather than according to axis (Figure 1-9)

Combining cylinders at oblique axis: complex calculation; therefore, measure with lensometer

Power of cylinder at oblique axis: power of the cylinder +1.00×180° is +1.00 @ 90°; +0.75 @ 60°; +0.50 @ 45°; +0.25 @ 30°; 0 @ 0°

Example:

JACKSON CROSS CYLINDER: special lens used for refraction to determine cylinder power and orientation; combination of plus cylinder in 1 axis and minus cylinder of equal magnitude in axis 90° away; spherical equivalent is zero (e.g.: –1.00+2.00×180)

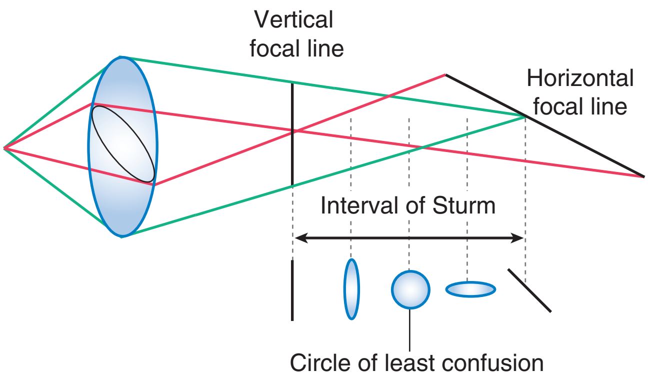


Figure 1-8. Conoid of Sturm.

Therefore, does not change the position of the circle of least confusion with respect to the retina; normally, have 0.25 D cross cylinder in phoropter; if patient's acuity is 20/40 or worse, must use larger power cross cylinder so patient can discriminate difference

TIGHT SUTURE AFTER CATARACT OR CORNEAL SURGERY: steepens cornea in meridian of suture, inducing astigmatism

Aberrations

Lenses behave ideally only near optical axis; peripheral to this paraxial region, aberrations occur

Spherical: shape-dependent aberration; periphery of lens has increasing prismatic effect; thus, peripheral rays refracted farther than paraxial ones, producing a blur interval along the optical axis (Figure 1-10)

Produces bull's-eye retinoscopic reflex

Reduce by avoiding biconvex lens shape; use plano-convex, meniscus, or aspheric lens surface

Eye has 3 mechanisms for reducing spherical aberration of lens:

1. Smaller pupil size eliminates a greater number of peripheral rays
2. Cornea progressively flattens in periphery
3. Nucleus of crystalline lens has higher index of refraction

Coma: comet-shaped image deformity from off-axis peripheral rays

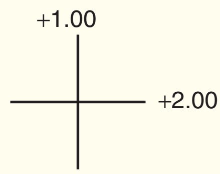
Cross cylinder notation:	+2.00 × 90; +1.00 × 180	
Power meridian notation:	+2.00 @ 180 / +1.00 @ 90	
Power cross:		
To convert to spherocylindrical notation: add and subtract a crossed cylinder		
Original cylinder notation:	+2.00 × 90	+1.00 × 180
Add/subtract crossed cylinder:	+2.00 × 180	–2.00 × 180
Spherocylinder notation:	+2.00 sphere	–1.00 × 180
Or		
Original cylinder notation:	+1.00 × 180	+2.00 × 90
Add/subtract crossed cylinder:	+1.00 × 90	–1.00 × 90
Spherocylinder notation:	+1.00 sphere	+1.00 × 90

Figure 1-9. Various lens notations.

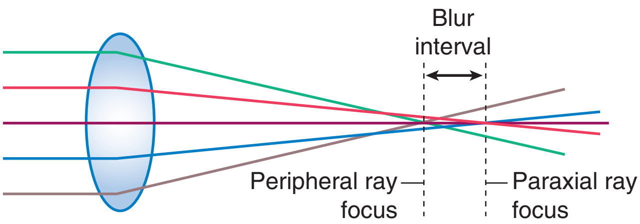


Figure 1-10. Spherical aberration.

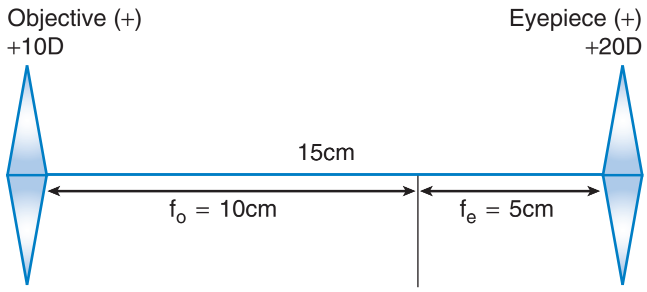


Figure 1-11. Astronomical telescope.

Curvature of field: spherical lens produces curved image of flat object

Astigmatism of oblique incidence: tilting spherical lens induces astigmatism (oblique rays encounter different curvatures at front and back lens surfaces)

Example: pantoscopic tilt (amount of induced sphere and cylinder depends on power of lens and amount of tilt)

Distortion: differential magnification from optical axis to lens periphery alters straight edges of square objects; shape of distortion is opposite of shape of lens (plus lens produces **pincushion** distortion; minus lens produces **barrel** distortion); effect increases with power of lens

Chromatic: light of different wavelengths is refracted by different amounts (shorter wavelengths are bent farther; chromatic interval between blue and red is 1.5-3.0 D)

Example: at night with Purkinje shift, chromatic aberration moves focal point of eye anteriorly, producing myopia

MAGNIFICATION

Transverse (linear or lateral): magnification of image size (away from optical axis); must be able to measure object and image size; ratio of image height to object height (or image distance to object distance); if image is inverted, magnification is negative $M_L = I/O$

Axial: magnification of depth; magnification along optical axis; equal to square of transverse magnification $M_{Ax} = M_L^2$

Angular: magnification of angle subtended by an image with respect to an object; useful when object or image size cannot be measured

Example: moon gazing with telescope

$M_A = xD = D/4$ (standardized to 25 cm [¼ m], the near point of the average eye)

Example: with direct ophthalmoscope, eye acts as simple magnifier of retina: $M_A = 60/4 = 15\times$ magnification

Size of image seen through glasses:

Shape factors: for any corrective lens, an increase in either front surface curvature or lens thickness will increase the image size (therefore, equalize the front surface curvatures and lens thickness for the 2 lenses)

FRONT SURFACE CURVATURE: every D of change will change image size by ½% (magnification decreases as plus power decreases)

CENTER THICKNESS: every mm of change in thickness will change image size by ½% (magnification decreases as lens thickness decreases)

Power factors:

VERTEX POWER (REFRACTIVE POWER): minus power lenses produce smaller images than do plus lenses

VERTEX DISTANCE: an increase in vertex distance will increase the magnification of plus lenses and decrease the magnification (increase the minification) of minus lenses

PLUS LENS: every millimeter increase in vertex distance will increase magnification by 0.1% per diopter of lens power

MINUS LENS: every millimeter increase in vertex distance will decrease magnification by 0.1% per diopter of lens power

Spectacle lens changes retinal image size by 2% per diopter of power at 12 mm vertex distance

Anisometropia: difference in power between the 2 eyes; every 1 D produces approximately 2% of aniseikonia

Aniseikonia: difference in image size between eyes from unequal magnification of correcting lenses

Up to 6–7% is usually well tolerated; corresponds to approximately 3 D of spectacle anisometropia; children can adjust to much larger degrees

Example: unilateral aphakia: 25% enlargement with spectacle lens; 7% with contact lens; 2.5% with IOL

Knapp's rule: when proper corrective lens is positioned at anterior focal point of eye, retinal image size will be equal in both eyes, no matter what the degree of anisometropia (applies only to axial ametropia)

Telescopes: magnify objects by increasing angle that object subtends on retina

Astronomical telescope (Keplerian): combination of 2 plus lenses; focal points coincide in intermediate image plane; distance between lenses is sum of focal lengths; use higher power as eyepiece; inverted image (Figure 1-11)

Galilean telescope: combination of a weak plus lens (objective) and a strong minus lens (eyepiece); distance between lenses is difference of focal lengths; erect image (e.g. surgical loupe) (Figure 1-12)

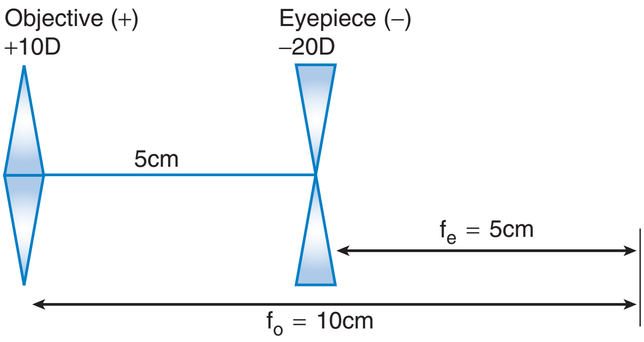


Figure 1-12. Galilean telescope.

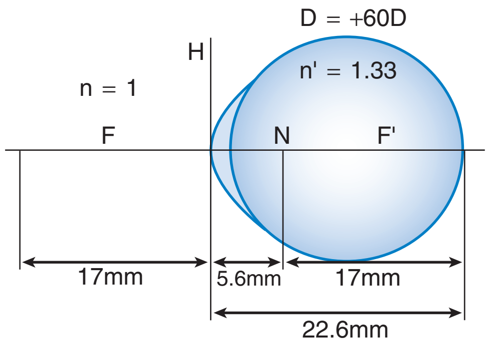


Figure 1-13. Schematic eye.

Angular magnification is the same for both telescopes (power of eyepiece/power of objective): $M_A = -D_e/D_o$

Accommodation through telescope: $A_T = A_N(M_A^2)$ (A_N = normal accommodation)

Example: for monocular aphakia, overcorrect aphakic CL by +3.00 D; then, correct induced myopic error with spectacle of –3.00 D. This produces an inverse Galilean telescope system that results in significantly smaller magnification difference between the 2 eyes than occurs with a CL alone

MIRRORS

Law of reflection: angle of incidence = angle of reflection (measured from the normal)

Objects and images: real if located on left side of mirror, virtual if on right side (inside) of mirror

Focal length: ½ the radius of curvature ($f = r/2$)

Reflecting power: reciprocal of focal length ($D_r = -1/f = -2/r$)

Convex: positive radius of curvature (R); adds minus vergence; produces virtual, erect, minified image ('VErMin')

Example: rear view mirror; cornea (reflecting power of cornea $= -1/f = -2/r = -2/0.0077 = -260$ D [much stronger than refracting power])

Concave: negative r; adds plus vergence; image can be virtual or real, erect or inverted, magnified or minified, depending on object location with respect to center of curvature of mirror:

- At twice focal length (center of curvature): real, inverted, same size
- Between center and focal length: real, inverted, magnified
- At focal length: at infinity
- Inside focal length: virtual, erect, magnified

Plano: no change in vergence; image is virtual, erect, same size; field of view is double the size of the mirror

Example: dressing mirror needs to be only half of body length to provide view of entire self

Central ray: passes through center of curvature of mirror, not center of mirror

Primary and secondary focal points coincide

Purkinje-Sanson images: 4 images from reflecting surfaces of eye

1. Front surface of cornea (image of object at infinity is located at focal point of mirror $= 1/-260 = -3.85$ mm; thus, this is a virtual, erect, minified image 3.85 mm posterior to front surface of cornea)

Example: keratometry (see Figure 1-24)

2. Back surface of cornea (virtual, erect, minified image)
3. Front surface of lens (virtual, erect, minified image)
4. Back surface of lens (real, inverted, minified image)

(If patient has intraocular lens [IOL], Purkinje-Sanson images 3 and 4 are taken from front and back surfaces of the IOL, respectively; these are useful in assessment of mild degrees of pseudophacodonesis)

EYE AS OPTICAL SYSTEM

Model Eye

Gullstrand studied the eye's optical system and, based on average measurements (power = +58.64 D; F = 17.05 mm), he created a simplified model: the '**reduced**' or '**schematic**' **eye** (Figure 1-13): power = +60 D; F = 17 mm; F' = 22.6 mm

Example: calculate the diameter of the blind spot projected 2 meters in front of the eye (ON = 1.7 mm tall, thus by similar triangles: $1.7/17 = x/2000$; $x = 2000(1.7/17) = 200$ mm)

Vision Measurements

Minimum visible: presence or absence of stimulus; depends on amount of light striking photoreceptors

Minimum discriminable: resolving power of eye; depends on ability to detect differences in light intensity

Minimum separable: smallest angle at which 2 separate objects can be discriminated; detection of a break in a line

Vernier acuity: spatial discrimination; ability to detect misalignment of 2 lines (8 seconds of arc; smaller than diameter of photoreceptor)

Snellen acuity: based on angle that smallest letter subtends on retina; each letter subtends 5 minutes of arc at a specific distance (represented by the denominator [i.e. 20/40 letter subtends 5 minutes at 40 feet, 20/20 letter subtends 5 minutes at 20 feet]; the numerator is the testing distance); each stroke width and space subtends 1 minute (Figure 1-14)

Example: calculate the size of a 20/20 letter at 20 ft (6 m): tan=opposite/adjacent; tan 1′=0.0003 therefore, tan 5′=0.0015=x/6000; x=8.7 mm

ETDRS Chart: 5 letters per line; space between letters is equal to size of letter on that line; geometric proportion of optotype height (changes in 0.1 log unit increments)

Near acuity: must record testing distance

Acuity testing in children: optokinetic nystagmus (OKN), CSM (central, steady, maintain), preferential looking, Allen pictures, HOTV (letter symbols used in pediatric visual acuity testing), visual evoked potential (VEP)

Factors other than disease that reduce measured visual acuity: uncorrected refractive error, eccentric viewing, decreased contrast, smaller pupil size, older age

Legal blindness (in US): visual acuity (VA)=20/200 or worse or visual field (VF) < 20° in better-seeing eye

Visual acuity is influenced by pupil size: larger pupil limits vision owing to spherical and chromatic aberrations; smaller pupil limits vision owing to diffraction; optimal pupil size is 3 mm

Laser inferometer: helium neon laser beam is split and projected onto retina, producing interference fringes; spacing of fringes can be varied; retinal function is estimated by narrowest fringes discernible

Contrast sensitivity: ability to detect changes in luminance

Refractive Error

Secondary focal point (F') of eye is not located on retina (accommodation must be completely relaxed) (Figure 1-15):

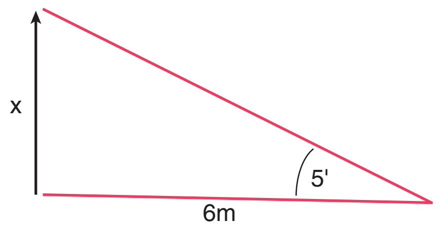


Figure 1-14. Calculation of Snellen letter size.

Emmetropia: focal point on retina
Myopia: focal point in front of retina
Hyperopia: focal point behind retina

total hyperopia =
manifest hyperopia (absolute and facultative) +
latent hyperopia (exposed with cycloplegia)

Axial vs refractive:

Axial myopia: length of eye too long (refractive power normal)
Refractive myopia: refractive power too strong (length normal)
Axial hyperopia: length too short (refractive power normal)
Refractive hyperopia: refractive power too weak (length normal)

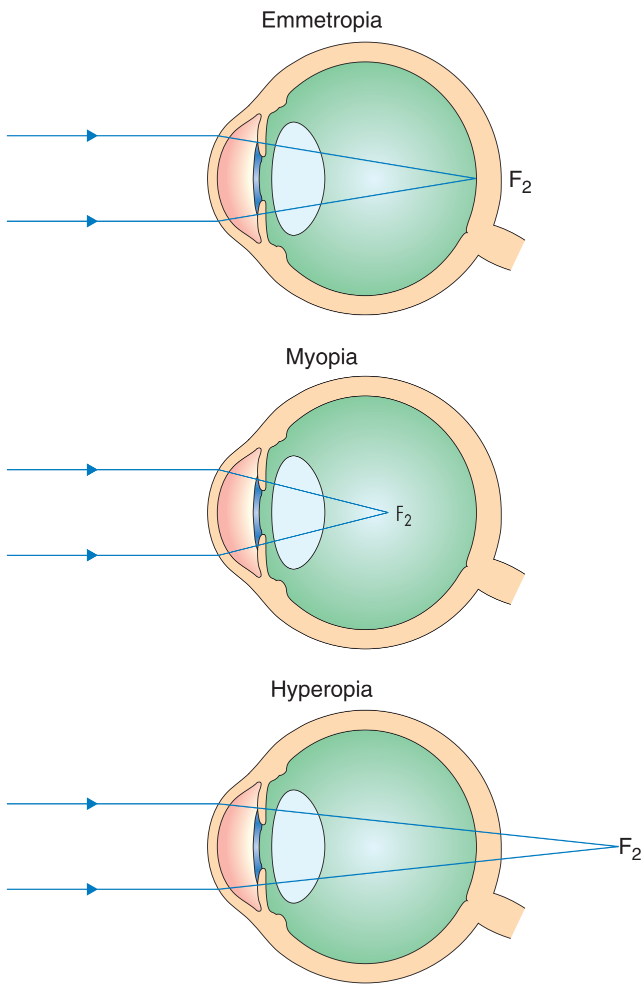


Figure 1-15. Emmetropia, myopia, and hyperopia. In emmetropia, the far point is at infinity and the secondary focal point (F_2) is at the retina. In myopia, the far point is the front of the eye, and the secondary focal point (F_2) is in the vitreous. In hyperopia, the secondary focal point (F_2) is located behind the eye. (Modified with permission from Azar DT, Strauss L: Principles of applied clinical optics. In: Albert DM, Jakobiec FA (eds) Principles and Practice of Ophthalmology, vol 6, 2nd edn. Philadelphia, WB Saunders, 2000.)

Far point: farthest-away eye can see clearly with accommodation completely relaxed (turn light around, start at retina, and trace rays backward through optics of eye; point at which rays intersect is far point)

Myopia: far point is centimeters to infinity in front of eye

Hyperopia: far point is behind eye (virtual far point)

Astigmatism: produces 2 focal lines rather than a single focal point (Table 1-1)

Classification: corneal or lenticular; regular (symmetric [mirror image axis between eyes] or asymmetric) or irregular

'With-the-rule': cornea is steepest in vertical meridian; axis of plus cylinder is 90° (±20°); usually young patients (elastic lids press on top and bottom of cornea)

'Against-the-rule': cornea is steepest in horizontal meridian; axis of plus cylinder is 180° ±20°; older patients

Correction of ametropia: choose lens with focal point that coincides with far point of patient's eye

Acquired hyperopia:

Decreased effective axial length: retrobulbar tumor, choroidal tumor, central serous chorioretinopathy

Decreased refractive power: lens change (posterior lens dislocation, aphakia, diabetes), drugs (chloroquine, phenothiazines, antihistamines, benzodiazepines), poor accommodation (tonic pupil, drugs, trauma), flattening of cornea (contact lens), intraocular silicone oil

Acquired myopia:

Increased lens power: osmotic effect (diabetes, galactosemia, uremia, sulfonamides), nuclear sclerotic cataracts, anterior lenticonus, change in lens position or shape (medication [miotics]), anterior lens dislocation, excessive accommodation)

Increased corneal power: keratoconus, congenital glaucoma, CL-induced corneal warpage

Table 1-1. Classification of astigmatism

Type	Location of focal lines	Corrective lens	
Compound myopic	Both in front of retina	–sph –cyl; –sph +cyl	(–sphere regardless of notation)
Simple myopic	1 in front, 1 on retina	–sph +cyl; plano –cyl	(–sphere or plano)
Mixed	1 in front, 1 behind	–sph +cyl; +sph –cyl	(–sphere or +sphere depending on notation)
Simple hyperopic	1 on retina, 1 behind	+sph –cyl; plano +cyl	(+sphere or plano)
Compound hyperopic	Both behind retina	+sph +cyl; +sph –cyl	(+sphere regardless of notation)

Increased axial length: congenital glaucoma, posterior staphyloma, after scleral buckle, retinopathy of prematurity (ROP)

Night myopia: increased myopia in dark

Pupil dilation: spherical aberration, irregular astigmatism uncovered

Purkinje shift: spectral sensitivity shifts toward shorter wavelengths at lower light levels, and chromatic aberration moves the focal point anteriorly

Dark focus: no accommodative target in dark; therefore, tend to overaccommodate for distance and underaccommodate for near

Length of refraction lane: shorter than 20 feet produces 1/6 D undercorrection (add minus 0.25 D to final refraction)

Acquired astigmatism: lid lesion (tumor, chalazion, ptosis), pterygium, limbal dermoid, corneal degenerations and ectasias, surgery (corneal, cataract), lenticular, ciliary body (CB) tumor

Accommodation

Eye gains plus power when crystalline lens becomes more convex

Accommodation response can be described as:

Amplitude of accommodation: total dioptric amount eye can accommodate

Near point: only for emmetropes

Prince rule: combines reading card with a ruler calibrated in centimeters and diopters to measure amplitude of accommodation

Technique: place +3.00 D lens in front of distance correction to bring far point to ⅓ mm (33 cm); then, measure how near patient can read and convert into diopters; subtract far point from near point to determine amplitude

Method of spheres: fixate on reading target (e.g. 40 cm), successively increase minus sphere until print blurs, then increase plus sphere until blurring occurs again; absolute difference between the spheres is the amplitude of accommodation

Example: range of –4.00 D to +2.00 D=amplitude of 6 D

Range of accommodation: distance between far point and near point; measured with tape measure or accommodative rule

Far point: point on visual axis conjugate to retina when accommodation is completely relaxed

Near point: point on visual axis conjugate to retina when accommodation is fully active

FOR MYOPIA: near point=amount of myopia+amplitude of accommodation

FOR HYPEROPIA: near point=difference between amplitude of accommodation and amount of hyperopia

Presbyopia: loss of accommodation with age; becomes symptomatic in early 40s with asthenopic symptoms and need for reading glasses

Table 1-2. Donder's table

Age (years):	8	12	16	20	24	28	32	36	40	44	48	52	56	60	64	68
Accommodation (D):	14	13	12	11	10	9	8	7	6	4.5	3	2.5	2	1.5	1	0.5

Theories of accommodation:

Helmholtz: zonular tension decreases, lens becomes more spherical, focusing power increases; presbyopia is due to loss of lens elasticity

Tscherning-Schachar: equatorial zonular tension increases, lens diameter increases, central lens steepens, focusing power increases; lens grows throughout life, decreasing the working distance between lens and ciliary body; presbyopia is due to decreased ciliary muscle effectivity

Donder's table: average accommodative amplitudes for different ages (Table 1-2)

Up to age 40, accommodation decreases by 1 D every 4 years (starting at 14 D at age 8)

At age 40, accommodation is 6.0 D (±2 D)

Between ages 40 and 48, accommodation decreases by 1.5 D every 4 years

Above age 48, accommodation decreases by 0.5 D every 4 years

Conditions that cause asthenopia (eye fatigue with sustained near effort): hypothyroidism, anemia, pregnancy, nutritional deficiencies, chronic illness

Premature presbyopia (subnormal accommodation): debilitating illness, diphtheria, botulism, mercury toxicity, head injury, cranial nerve 3 (CN 3) palsy, Adie's tonic pupil, tranquilizers; treat with reading add, base-in prism (helps convergence)

Color Vision

3 components of color: hue, saturation, brightness

Hue: main component of color perception; depends on which wavelength is perceived as dominant

Saturation: richness of color; vivid colors are saturated; adding white desaturates color (paler) but does not change hue

Brightness: sensation produced by retinal illumination; filters decrease brightness

Example: yellow light; correct mixture of green and red also results in yellow; mixing 2 complements produces white; add white light to yellow, still yellow

Bezold-Brucke phenomenon: as brightness increases, most hues appear to change

At low intensities, blue-green, green, and yellow-green appear greener; at high intensities, they appear bluer

At low intensities, reds and oranges appear redder; at high intensities, they appear yellower

Exception: blue of 478 nm, green of 503 nm, and yellow of 578 nm do not change with changes in intensity

Abney effect: as white is added to any hue, desaturating it, the hue appears to change slightly in color; all colors (except yellow) appear yellower

Luminosity curve: illustrates sensitivity to different wavelengths

Constructed by asking observer to increase luminance of lights of various wavelengths until they appear equal in brightness to a yellow light of fixed luminance

Light-adapted eye: yellow, yellow-green, and orange appear brighter than blues, greens, and reds; peak sensitivity = 555 nm

Dark-adapted: peak sensitivity = 505 nm (blue)

Afterimages: after a color is stared at for 20 seconds, it begins to fade (desaturate)

Then, with gazing at white background, the complement of the color appears (afterimage)

Example: red is perceived when a greater number of red cones are stimulated than green or blue cones; after 20 seconds, red cones fatigue (cannot regenerate pigment fast enough), so color fades; when white background is looked at, there is a relatively greater response by green and blue cones; therefore, a blue-green afterimage is seen (complement of red)

Color perception: white wall appears white because white paint reflects all photons equally well

Charcoal appears black because it absorbs most of the light that strikes it

Blue flower appears blue because it best absorbs red, yellow, and green; blue is absorbed least, so a greater number of blue photons are reflected

Green leaf appears green because chlorophyll absorbs blue and red and reflects green

Incandescent/tungsten light emits a relatively greater number of photons of longer (red) wavelength than shorter (blue) wavelength; conversely, fluorescent light emits a relatively greater number of blue and green wavelengths; therefore, a purple dress may appear redder under incandescent light and bluer under fluorescent light

PRESCRIBING GLASSES

Use cycloplegia in children and hyperopes to uncover full refractive error

Infants average 2 D of hyperopia; myopic shift between ages 8 and 13; most adults are emmetropic

Children (Table 1-3): give full cycloplegic refraction

Table 1-3. Guidelines for prescribing glasses for children

Hyperopia:	≥+5 D
Anisometropia	≥1.5 D
Myopia:	
Up to age 1	≥−5 D
Ages 1–6	≥−3 D
Age >6	≥−1 D
Anisometropia	≥3 D
Astigmatism:	
Up to age 1	≥3 D
Ages 1–6	≥2 D
Age >6	≥1 D
Anisometropia	≥1.5 D

Adults: give manifest refraction; may not accept full astigmatic component, so if cylinder is decreased, adjust sphere to keep spherical equivalent constant; be careful about changing axis

Minus cylinder grinding: placing astigmatic correction on rear surface (closer to eye) is optically preferable

Astigmatic dial: 12 spokes corresponding to clock hours are projected on screen; spokes parallel to principal meridians of eye's astigmatism are sharp (corresponding with focal lines of conoid of Sturm); the others are blurred

Match base curves: when prescribing new glasses, keep base curve same as that of old lenses

Geneva lens clock: measures base curve of lens; direct dioptric power of convex, concave, or aspheric lens surface is read on the dial of the clock; calibration is based on the refractive index of crown glass (1.52)

Binocular balance: equally controls accommodation in both eyes (visual acuity must be equal)

Methods:

1. *Prism dissociation:* 3 Δ BU over one eye and 3 Δ BD over the other (use Risley prism in phoropter)
2. *Balanced fogging:* fog both eyes and alternate cover until equally fogged
3. *Duochrome test:* red–green balance both eyes (vision must be 20/30 or better)

Bifocal add: place segments as high as practical in relation to optical centers of the distance lenses

Measure accommodation: perform monocularly, then binocularly

Near point of accommodation (use refractive correction)

Accommodative amplitude (use Prince rule)

Determine accommodative requirement for near vision task

Example: reading at 40 cm=2.5 D

Hold ½ of measured accommodative amplitude in reserve to prevent asthenopic symptoms

Example: Prince rule measures 2.0 D of amplitude; thus 1.0 D is available to patient

Power of add is difference between accommodation (1.0 D) and total amount of accommodation required (2.5 D)

With calculated add in front of distance correction, measure accommodative range (near point to far point of accommodation); if range is too close, reduce add in steps of 0.25 D until correct range found

Kestenbaum's rule: used to estimate strength of plus lens required to read newspaper print without accommodation

Add power=reciprocal of best distance acuity

Reciprocal of add power=working distance (in meters)

Example: 20/80 vision; add=80/20=+4.00 D; working distance=1/4 (0.25 m)

Aphakic spectacles: disadvantages include magnification of 25%, altered depth perception, pincushion distortion, ring scotoma (prismatic effect at edge of lens causes visual field loss of 20%), 'jack-in-the-box' phenomenon (peripherally invisible objects suddenly appear when gaze is shifted)

CONTACT LENSES (CL)

Toric lens: lenses with different radii of curvature in each meridian

Front toric: anterior surface with 2 different radii of curvature, posterior surface spherical; corrects lenticular astigmatism

Back toric: cylinder on back surface only; corrects corneal astigmatism

Bitoric: minus cylinder on posterior surface, plus cylinder on anterior surface; corrects corneal and lenticular astigmatism

Ballasted lens: heavier base to orient lens by gravity; 2 types:

Prism: 1.5-2 Δ BD prism added

Truncated: flat along inferior edge

Sagittal depth/apical height: distance between back surface of lens center and a flat surface

Radius of curvature (base curve): curvature of posterior lens surface for a given diameter; the shorter the radius of curvature, the greater is the sagittal depth (the steeper the lens)

Overall diameter: for a given base curve, increasing diameter increases the apical vault

Example: to tighten a lens, reduce radius of curvature or increase diameter

Oxygen transmission: *DK* (relative gas permeability) value; D=diffusion coefficient; K=solubility of oxygen in material; oxygen transmissibility=DK/L (L=lens thickness)

Accommodative demand: depends on magnification, which varies with different lens powers and vertex distances

Hyperopes: decreased accommodative demand when CL are worn compared with spectacles (presbyopic symptoms appear earlier with spectacles)

Myopes: increased accommodative demand when CL are used (presbyopic symptoms appear earlier with CL). In high myopia, spectacles induce base-in prism with near convergence, lessening requirement for convergence

Fitting rigid CL: SAM-FAP rule ('steeper add minus, flatter add plus')

Fit steeper than corneal surface (forms a plus tear meniscus between cornea and CL, which alters required power of CL). Therefore, need to subtract power (add minus) at end of calculation; for each diopter, the base curve is made 'steeper than *K*'; subtract 1 D from the final CL power; if lens is fit flatter than *K*, a minus tear meniscus is formed, so must add plus power

Remember, a rigid lens with base curve of 44 D does not have a power of 44 D; rather, the radius of the CL's central posterior curve is equal to the radius of curvature of a cornea with a calculated power of 44 D

Power calculation: if trial lens not available for overrefraction

1. Measure refraction and keratometry
2. Choose base curve steeper than low *K* (usually +0.50 D steeper to form a tear lens; tear lens prevents apical touch)
3. Convert refraction to minus cylinder form and zero vertex distance; disregard the cylinder (minus cylinder is formed by the tears)
4. Power of CL is sphere from refraction adjusted for tear lens (subtract +0.50); 'SAM-FAP'

Evaluating fit:

Soft lens: evaluate movement (poor movement=too tight [too steep], excessive movement=too flat); choose power based on spherical equivalent

Rigid lens: assess fluorescein pattern (Figures 1-16–1-18)

LOW-VISION AIDS

Kestenbaum's rule: estimates strength of plus lens required to read newspaper print without accommodation

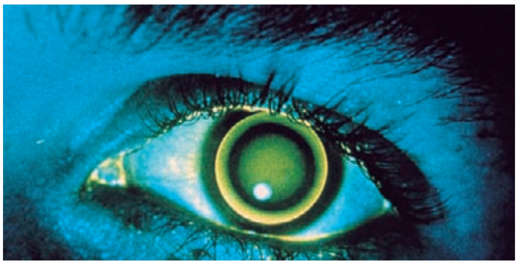


Figure 1-16. Fluorescein pattern of corneal contact lens fitted 1 D steeper than 'flat *K*.' Note the central clearance. (From White P, Scott C: Contact lenses. In: Yanoff M, Duker JS (eds) Ophthalmology. London, Mosby, 1999.)

Near devices:

High bifocal add or single vision reading glasses (up to+20 D): large field of view but short reading distance

Magnifiers: handheld (up to +20 D; small field of view) or stand (up to +50 D; bulky)

Loupes: long working distance but small field of view

Electronic displays: high magnification but expensive

Distance devices:

Telescopes: restricted field of view

INTRAOCULAR LENSES (IOL)

Formulas for IOL calculation (see Ch. 10)

Empiric: derived from clinical studies by regression analysis

1ST GENERATION: SRK, Gills-Lloyd

2ND GENERATION: SRK II, Thompson-M, Donzis

Theoretical: derived from optics by vergence formulas

1ST GENERATION: Binkhorst I, Fyodorov, Colenbrander

2ND GENERATION: Binkhorst II, Shamas

3RD GENERATION: Hoffer Q, Holladay 1, SRK/T

4TH GENERATION: Holladay 2, Haigis, Olsen

Newer-generation theoretical formulas are the most accurate

A rough estimation of lens power can be quickly obtained with the *SRK* formula:

IOL power for emmetropia $= P = A - 2.5\,L - 0.9K$

$A = A$ constant (related to lens type)

$L =$ axial length in mm; 1 mm error=2.5 D error in IOL power

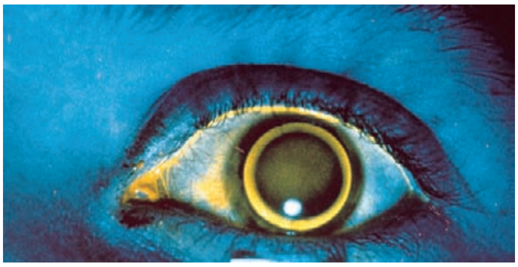


Figure 1-17. Fluorescein pattern of corneal contact lens fitted 'on *K*.' Note the central alignment. (From White P, Scott C: Contact lenses. In: Yanoff M, Duker JS (eds) Ophthalmology. London, Mosby, 1999.)

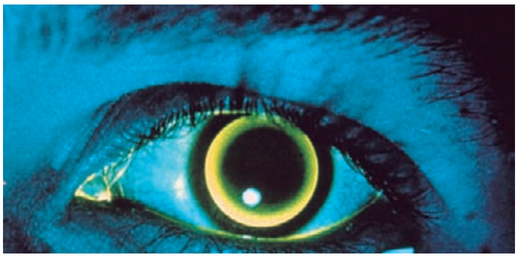


Figure 1-18. Fluorescein pattern of corneal contact lens fitted 1 D flatter than 'flat *K*.' Note the central touch. (From White P, Scott C: Contact lenses. In: Yanoff M, Duker JS (eds) Ophthalmology. London, Mosby, 1999.)

K = average keratometry value in D; 1.0 D error ≈ 1.25 D error in IOL power

Lens position is important: 1 mm error = 1.0 D change in power

Calculate IOL power for refractive target other than emmetropia: $D_{IOL} = P - (R/1.5)$ (R = desired refractive error)

IOL power for a different lens = original IOL power ± difference in A constants

Example: if instead of +20.0 D IOL with *A* constant of 118, you want to use a different style IOL with *A* constant of 118.5, equivalent power of the new IOL is +20.5 D

OPHTHALMIC INSTRUMENTS

Direct ophthalmoscope (Figure 1-19): coaxial light and lenses to neutralize patient and examiner refractive errors, so retinas become conjugate; examiner uses optics of patient's eye as simple magnifier ($M_A = 60/4 = 15\times$); field of view ~7°

Indirect ophthalmoscope (Figure 1-20): enlarged field of view (25°) with stereopsis by adding condensing lens

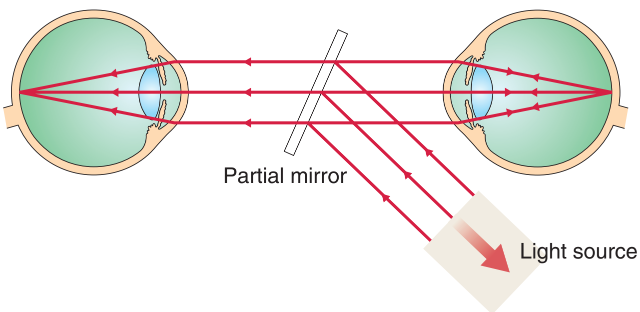


Figure 1-19. Optics of the direct ophthalmoscope. By using a mirror (either half-silvered or with a central aperture), the directions of the light of observation and the light incident to the patient are made concentric (coaxial). (From Miller D, Thall EH, Atebara NH: Ophthalmic instrumentation. In: Yanoff M, Duker JS (eds) Ophthalmology, 2nd edn. St Louis, Mosby, 2004.)

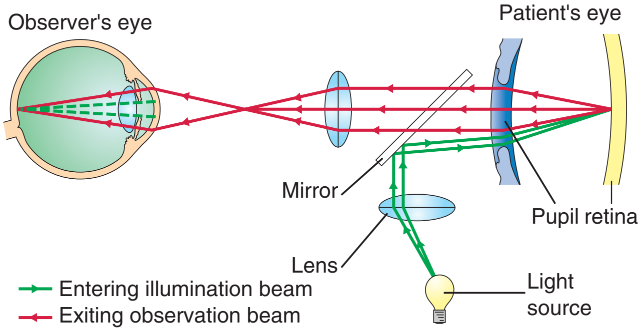


Figure 1-20. Theoretical optics of the indirect ophthalmoscope. The illumination beam enters a small part of the pupil and does not overlap with the observation beam; this minimizes bothersome reflection and backscatter. (From Miller D, Thall EH, Atebara NH: Ophthalmic instrumentation. In: Yanoff M, Duker JS (eds) Ophthalmology, 2nd edn. St Louis, Mosby, 2004.)

between patient and examiner; binocular eyepiece reduces interpupillary distance to 15 mm (~4×); $M_A = D_{eye}/D_{lens} = 60/20 = 3\times$; $M_{Ax} = 3^2 = 9$, but eyepiece reduces depth 4×; therefore $M_{Ax} = 9/4 = 2.25\times$

Retinoscope: instrument to objectively measure refractive state of eye

- The blurred image of the filament on the patient's retina is considered a new light source returning to examiner's eye; by observing the characteristics of the reflex, examiner can determine patient's refractive error
- If examiner is at far point of patient's eye, all light rays emanating from patient's pupil pass through retinoscope and examiner's pupil, and patient's pupil will appear uniformly illuminated (neutralization)
- If far point is between examiner and patient (myopic), reflex moves in direction opposite to retinoscope sweep ('against' motion)
- If far point is behind examiner (hyperopia), reflex has 'with' motion
- Use correcting lens to determine point of neutralization
- Correct for working distance to obtain patient's final refraction (add reciprocal of working distance to final finding)
- If poor, irregular retinoscopic reflex, try contact lens overrefraction or stenopeic slit refraction

Slit-lamp biomicroscope (Figure 1-21): illumination and magnification allow stereo viewing of ocular structures; illumination and viewing arms have common pivot point

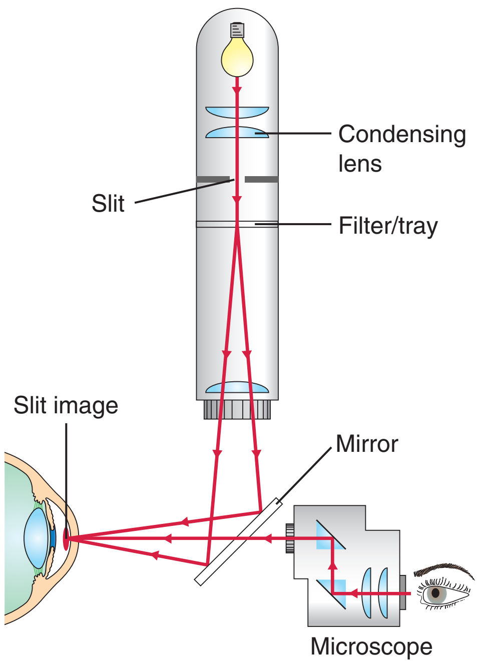


Figure 1-21. The slit lamp. Some slit lamps bring the light to a sharp focus within the slit aperture, and the light within the slit is focused by the condensing lens onto the patient's eyes. The observation system of a modern slit lamp has many potential reflecting surfaces – antireflection coatings on these surfaces help loss of light. (Modified from Spalton DJ, Hitchings RA, Hunter PA: Atlas of Clinical Ophthalmology. New York, Grower Medical, 1985.)

Lensometer: measures power of spectacle or CL using telescope to detect neutralization point; distance measurement is determined from back vertex power; add measurement is taken from front vertex power; prism measurement is derived from displacement of target pattern (Figures 1-22 and 1-23)

Keratometer: measures curvature of anterior corneal surface based on power of reflecting surface; measures only 2 paracentral points 3 mm apart; doubling of image prevents interference from eye movements (Figure 1-24)

Applanation tonometry: direct measure of IOP as force/area with split-field prism; at applanated diameter of 3.06 mm, corneal resistance to deformation and attractive force of tear surface tension cancel each other

A- and B-scan ultrasonography: measure acoustic reflectivity of interfaces to provide 2-dimensional picture of ocular structures

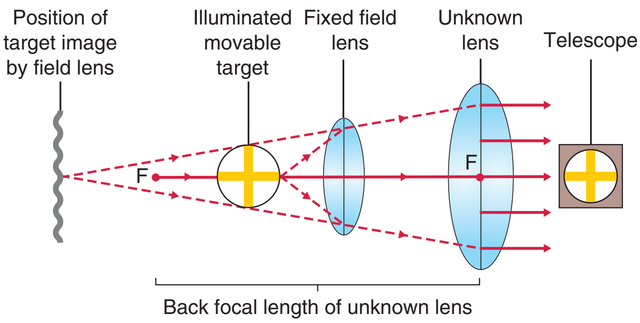


Figure 1-22. The lensometer resembles an optical bench. The movable illuminated target sends light to the field lens, with the target in the end-point position. Because the focal point of the field coincides with the position of the unknown lens, all final images are of the same size. (From Miller D, Thall EH, Atebara NH: Ophthalmic instrumentation. In: Yanoff M, Duker JS (eds) Ophthalmology, 2nd edn. St Louis, Mosby, 2004.)

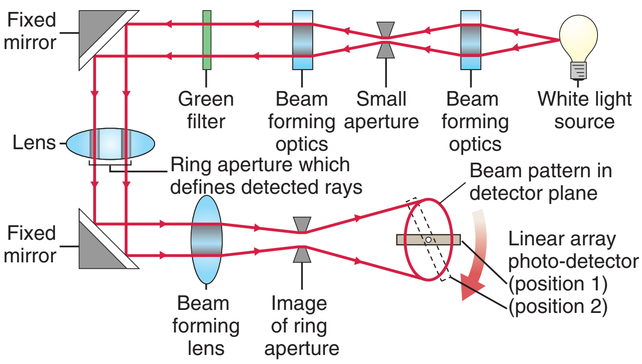


Figure 1-23. Optics of a typical automated lensometer. Parallel light strikes unknown lens. The refracted light rays (which are confined to a pencil beam within an annulus) ultimately strike an array of electronic photoreceptors. (From Miller D, Thall EH, Atebara NH: Ophthalmic instrumentation. In: Yanoff M, Duker JS (eds) Ophthalmology, 2nd edn. St Louis, Mosby, 2004.)

Ocular coherence tomography (OCT): measures optical reflectivity to provide cross-sectional image of ocular structures

EQUATIONS

Vergence formula:

$U + D = V$

U=object vergence, D=lens power, V=image vergence

Lens power (diopters):

$D = 1/f$

f=focal length (meters)

Snell's law:

$n\sin(i) = n'\sin(r)$

n=refractive index, i=angle of incidence, r=angle of refraction

Prismatic power:

$$\Delta = \frac{\text{image deflection (cm)}}{\text{meters}} = 100 \tan(\beta)$$

β=angle of deviation

Prentice's rule:

$\Delta = hD$

h=distance from optical axis (cm), D=lens power

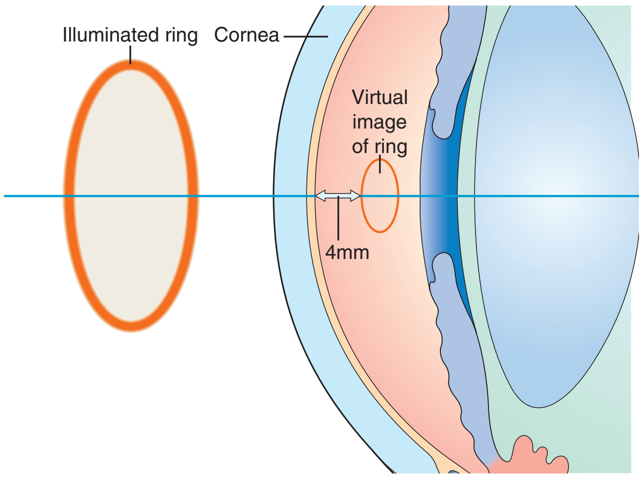


Figure 1-24. Keratometer principle. An illuminated ring is placed in front of the cornea, which acts as a convex mirror and produces a virtual image of the ring approximately 4 mm behind the cornea. (From Miller D, Thall EH, Atebara NH: Ophthalmic instrumentation. In: Yanoff M, Duker JS (eds) Ophthalmology, 2nd edn. St Louis, Mosby, 2004.)