پزشک آموز

به من نگاه کن

پزشک آموز

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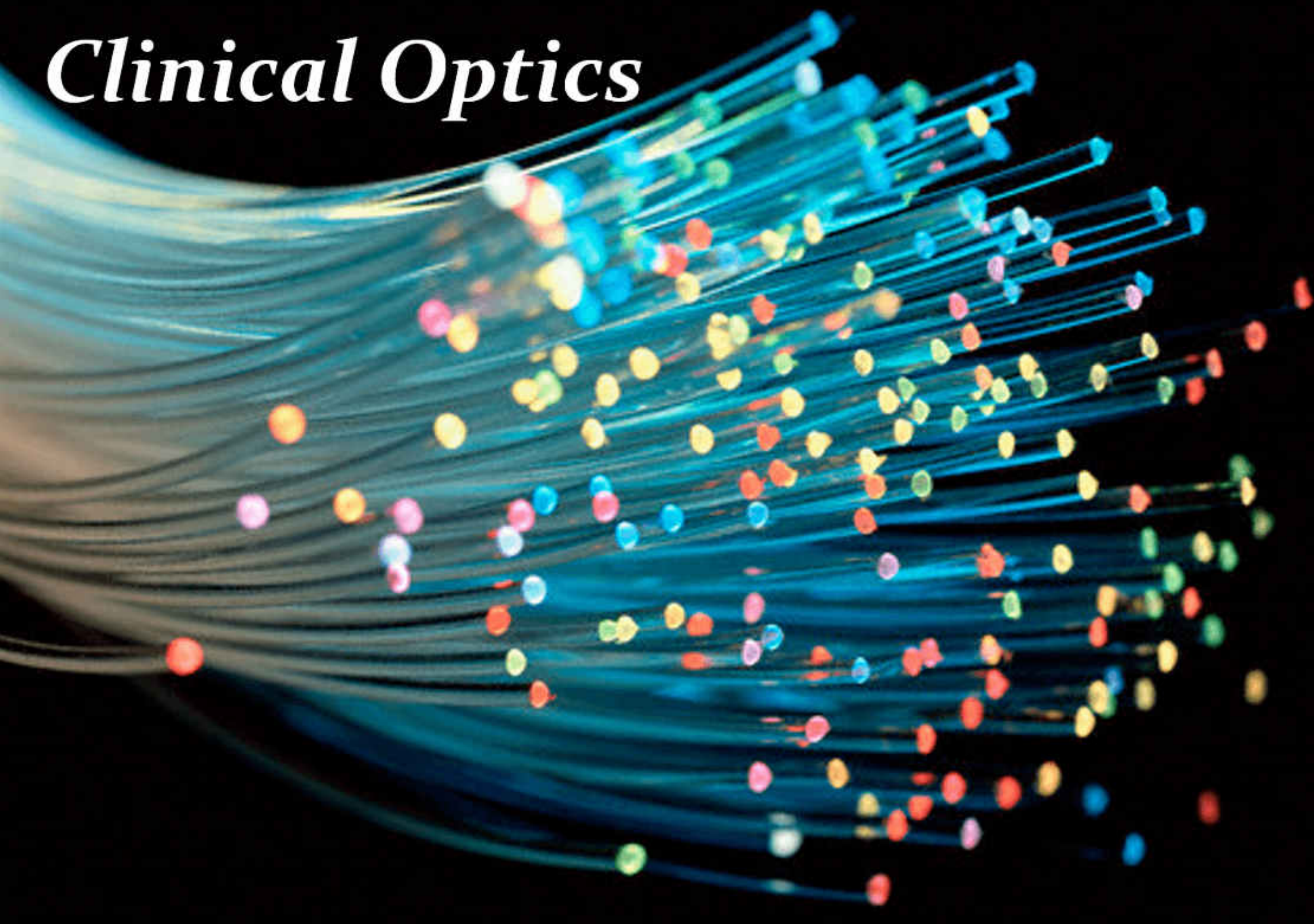
Study Notes

Clinical Optics



Main sources:

1- Clinical optics by **Elkington**

2- El Refaay Clinical Optics

LIGHT

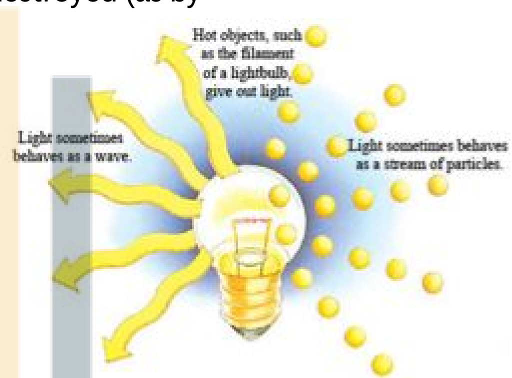
➢ ***Definition:***

- Light is the radiant energy to which the human eye is sensitive.
- Is electromagnetic radiation that is visible to the human eye

➢ ***Nature of light:*** (The exact nature of visible light is a mystery that has puzzled man for centuries)

Light has a dual nature:

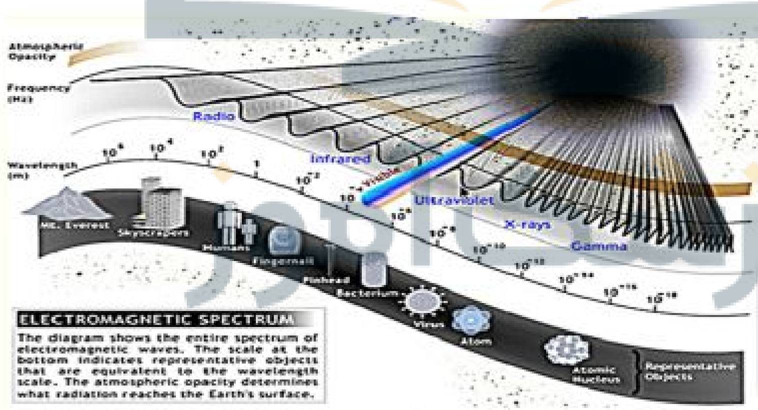
1) A wave model (the electromagnetic wave): ➔ When light propagates in space.
2) A particle model (the photon): ➔ When light is created or destroyed (as by photoelectric lamp).



➢ Velocity of light: The speed of light in vacuum, commonly denoted c is 300,000 Km/sec

➢ ***Electromagnetic spectrum (energy spectrum):***

- Is the range of all frequencies of the electromagnetic radiations.
- Is the electromagnetic radiations of waves which extend from the cosmic rays with the shortest wavelength to (the gamma, X, ultraviolet, infrared, radar, television and) radio waves with the longest wavelength (Fig.1. 1).



Electromagnetic spectrum.

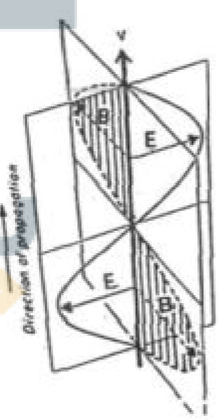


Fig.I.2: Electromagnetic wave.

➢ ***Electromagnetic radiations:***

- Is a form of energy emitted and absorbed by charged particles which exhibits wave-like behavior as it travels through space.
- EMR has both electric and magnetic field components which oscillate in phase perpendicular to each other and perpendicular to the direction of energy and wave propagation.

- ***<u>Electromagnetic fields:</u>***
  - *Definition:*
    - Physically, electric and magnetic fields are ➔ force fields that act upon charged particles.
  - *Importance:*
    - These two force fields Electric field E and magnetic field B have a magnitude and a direction and are perpendicular to each other and to the direction of the wave v (Fig.1.2),➔ a property which is important in the discussion of polarization (with electric fields in the same direction).

- ***<u>Optical radiation:</u>***
  - It lies between X-rays and microwaves in the electromagnetic spectrum (Fig. 1.1), and is subdivided into seven wavebands.
  - Each of these seven wavebands group together ➔wavelengths which elicit similar biological reactions.
  - *These seven domains are:*
    - ① Ultraviolet C (UV-C), 200– 280 nm.
    - ② Ultraviolet B (UV-B), 280–315 nm.
    - ③ Ultraviolet A (UV-A), 315–400 nm.
    - ④ Visible radiation, 400–780 nm.
    - ⑤ Infrared A (IRA), 780–1400 nm.
    - ⑥ Infrared B (IRB), 1400–3000 nm.
    - ⑦ Infrared C (IRC), 3000–10000 nm.
  - As with all electromagnetic radiation, the shorter the wavelength, the greater the energy of the individual quanta, or *photons,* of optical radiation.

- ***<u>Visible spectrum:</u>***
  - The visible spectrum is ➔ the visible part of electromagnetic spectrum which is only a tiny portion near the center and has a wavelength between 400-780 nm (nanometer) i.e. between 4000-7800 A° (Angstrom unit).
  - *Wave length (WL) units*:
    - 1 millimeter (mm) = 1000 micrometer.
    - 1 micrometer (μm) = 1000 nanometer.
    - 1 nanometer (nm) = 10 Angstrom (A°).
    - *1 millimeter = 1000 micrometer = 1,000,000 nanometer = 10,000,000 angstrom.*

- ***<u>Wave length discrimination (color spectrum):</u>***
  1. Colour sense: The ability of the normal eye to discriminate between light of shorter and longer wavelength within the visible spectrum

- *Light of shortest to the longest wavelength:* is violet➔, indigo,➔ blue,➔ blue-green,➔ green➔, yellow➔, orange and➔ red (VIBBGYOR as in rainbow colour pattern).
- *Sunlight:* Contains light of different wavelengths.
- *White light:* is a mixture of the wavelengths of the visible spectrum.
- *The pigment epithelium of the iris:* Absorbs light of most wave lenghts.

2. Radiation of shorter or longer wavelengths than the visible spectrum: Is delectable to man in other ways e.g.
    - infrared rays (in heat),
    - ultraviolet rays (in aphakic eyes)

3. Ultraviolet radiations in the sunlight (A, B and C):
    1. UV-A (315-380nm): ➔Can enter the eye and are absorbed by the crystalline lens and so the retina is not sensitive to these rays in the normal human eye but
        - ↳ In aphakic patients, these rays can reach the retina and absorbed be the pigment epithelium with retinal damage).
    2. UV-B (280-315 nm): ➔Cannot enter the eye but
        - ↳ May cause skin burn, blistering and photophthalmia (due to disruption of the corneal epithelium).
    3. UV-C (100--280 nm): ➔Cannot reach the earth surface.

4. Clinical points:

✓ Aphakic eyes are sensitive to these wavelengths which give rise to the sensation of blue or violet colour. Newly aphakic patients frequently remark that everything looks bluer than before the operation.

✓ The cornea and sclera of the eye absorb essentially all the incident optical radiation at very short wavelengths in the ultraviolet (UV-B and UV-C) and long wavelengths in the infrared (IR-B and IR-C).

✓ The visible wavelengths stimulate the retinal photoreceptors giving the sensation of light while the near infrared may give rise to thermal effects.

- ➲ Because the refractive surfaces of the eye focus the incident infrared radiation on the retina, it can cause eclipse blindness which may lead to macular burn.

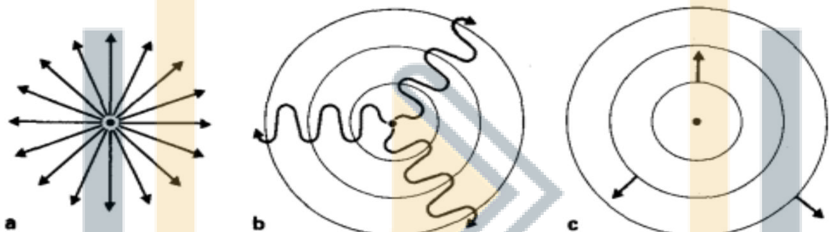
➢ *Wave Theory of Light:*

1- Path of light as waves through space: Although the path of light is often represented diagrammatically as a straight arrowed line or parallel rays travelling from left to right on the page (Fig. 1.3a), it really travels (passes) through space as waves (Fig. 1.3b).

2- Wave fronts: Are the combined effect of many rays which is drown as concentric circles through the crests of the waves (Fig. 1.3c).

✓ *The explaining example:*

- The same effect is seen if a stone is dropped into still water. Viewed from above, circular waves travel outwards from the point of impact (wave fronts in Fig. 1.3c). If the process were viewed in cross-section, the waves would appear as ripples travelling away from the centre of disturbance (wave motion in Fig. 1.3b).



- Fig. 1.3 Light leaving a point source. (a) Light represented as rays; (b) light represented as waves; (c) light represented as wave fronts.

3- Wave motion (Fig. 1.4): is a disturbance or energy passing through a medium. The medium itself does not move, but its constituent particles vibrate at right angles to the direction of travel of the wave (Fig. 1.4).

- (Imagine a ribbon tied to a rope along which a wave is 'thrown'. The crest of the wave moves along the length of the rope, but the ribbon moves up and down at one point on the rope.)

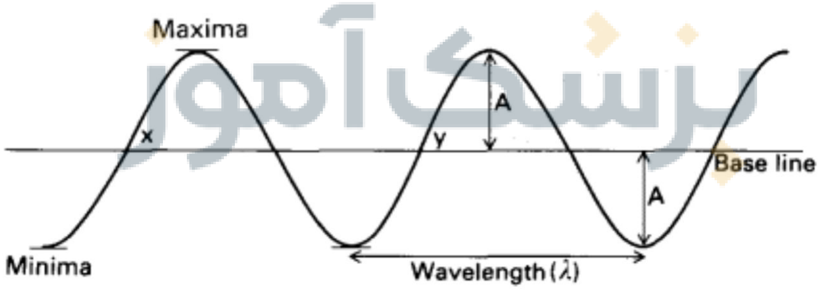


Fig. 1.4 Wave motion.

- *Wavelength (λ):* Distance between two symmetrical parts of wave motion.
- *Cycle:* One complete oscillation and occupies one wavelength e.g. x y.
- *Amplitude (A):* Is the maximum displacement of an imaginary particle on the wave from the base line.
- *Phase:* Any portion of the cycle is called a phase.

4- Phase difference: If two waves of equal wavelength are travelling in the same direction but are out of step with each other, the fraction of a cycle or wavelength by which one leads the other is known as the phase difference (Fig. 1.5):

- ✓ Light waves that are out of phase are called ⍰ incoherent.
- ✓ Light waves that are exactly in phase are called ⍰ coherent.

- Fig. 1.5 Wave motion (phase difference): shows two waves of equal wavelength which are out of phase by one-quarter of a wavelength (phase difference equals 90°, the complete cycle being 360°).

PROPERTIES OF LIGHT

(1) REFRACTION:

- ***REFRACTION:***
  - It is the bending of light as it passes from one transparent material to another with a different refractive index
  - The change in the direction of the propagation (bending) of light upon its passage from one transparent material to another with a different refractive index.

- **INDEX OF REFRACTION**:
  - It is the optical density of a medium
    - I.e. when light propagates through a transparent medium such as glass or air;➔ it induces oscillations of the constituent particles of that medium, which in turn decreases the velocity of light.
  - It's a way of telling how light slows down when it passes through a surface.
  - It's a ratio of the speed of light in the vacuum : to the speed of light in some material

- ***Types of the refractive index:***
  - Absolute Index of refraction of a medium (n):
    - ✓ *Definition:*
      - It is a unitless number that describes the new velocity relative to the velocity of light in air.
      - Absolute index of retraction of a medium n (air n medium)

$$= \frac{Velocity\ \text{of light in air}}{\text{Velocity of light in medium}}$$

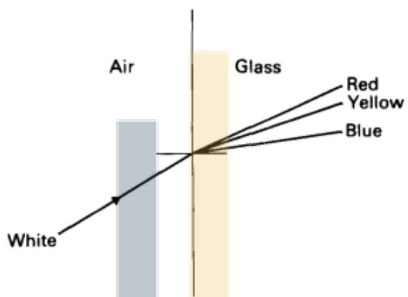
    - ✓ *Examples:*

Air	=1.00	Crystalline lens	=1.38-1.42
Water (aqueous)	= 1.33	Crown glass	= 1.52-1.60
Cornea	= 1.37	Flint glass	=1.70-1.90

  - Relative Index of refraction (n2 / n1):
    - Definition: It is the comparison of velocity of light in two media other than air.
    - Example: water n glass = n glass / n water = n2 / n 1.

(2) DISPERSION:

- *Definition:*
  - Dispersion of white light into component of wavelength when it meet an optical interface
  - The refractive index of any medium differs slightly for light of different wavelengths as light of shorter wavelengths ➔ is deviated more than light of longer wavelengths
    - i.e. blue light is deviated more than red (Fig. 2.1).



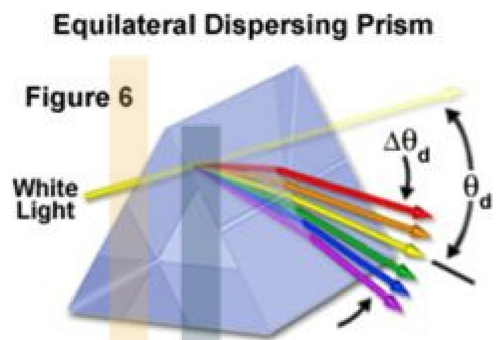


Fig. 2.1: Dispersion of light through a medium.

- *Angle of dispersion:*
  - Is the angle formed between the wavelengths of different colours dispersed through the medium.

- *Dispersive power of a medium:*
  - Is indicated by the angle of dispersion (not related to the refractive index of the medium).

- Abbe Number: (also known as the V-number)
  - is a measure of dispersion of transparent medium.
  - the Abbe number V is defined as

$$V = \frac{n_D - 1}{n_F - n_C}$$

where

n_d, n_p, and n_c are the refractive indices of the Fraunhofer D, F, and C spectral lines (589.2 nm, 486.1 nm, and 656.3 nm, respectively).

  - Low-dispersion materials, (i.e. low chromatic aberration),➔ have high V & vice versa.
  - Abbe numbers for common optical media typically range from 20 to 70.

(3) INTERFERENCE:

- *Types:*
  - When two waves of light travel along the same path, ➔ an interference effect is produced which depends upon whether or not the waves are in phase:

1. Constructive interference:
   - If the waves are in phase, the resultant wave will be summation of the two (Fig. 2.2a).

2. Destructive interference:
   - If the two waves are of equal amplitude and out of phase by a ➔ half cycle, they will cancel each other out (Fig.2.2b).

3. Intermediate interference:
   - Phase differences of less than half a cycle result in a wave of intermediate amplitude and phase (Fig. 2.2c).

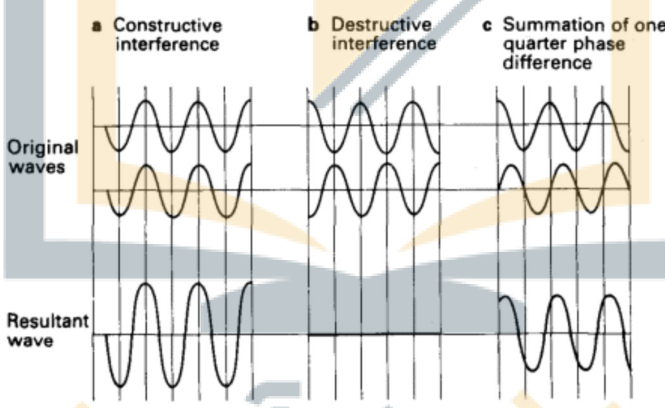


Fig.2.2: Interference of two waves.

- *Clinical applications:*

① *Collagen bundles of the corneal stroma:*
   - Are so spaced that any light deviated by them is eliminated by destructive interference.

② *Antireflection coating of lens surfaces:*
   - is a thin layer of transparent material of appropriate thickness ➔ light reflected from the superficial surface of the layer and the light reflected from the deep layer eliminate each other by destructive interference.

③ *Laser interferometer:*
   - To estimate the visual acuity of media as cataract by the use of coherent laser light with the phenomenon of interference (Chapter 25).

④ *Laser refractor:*
   - To determine the refractive error by the use of coherent laser light with the phenomenon of interference (Chapter 25).

(4) DIFFRACTION:

Definition:

- Diffraction is the spread of light when a wave front of light encounters t
  - the edge of an obstruction (Fig. 2.3) or
  - a narrow opening
    - In which the edge of the obstruction acts as a → new Centre from which → secondary wave fronts (from the main wave front) are produced which are out of phase with the primary waves.

- Diffraction is the property of waves not particles.

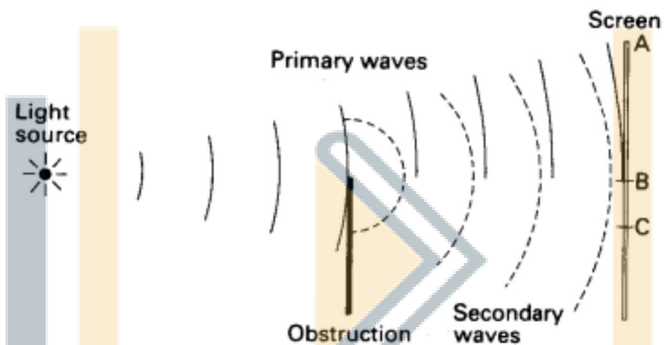


Fig. 2.3 Diffraction (exaggerated).

Diffraction through → the edge of obstruction:

- The intensity of the light falling on zone AB is reduced to some extent by interference between the primary and secondary waves.
- The light falling on zone BC is derived from secondary waves alone and is of much lower intensity.

Diffraction through → A circular aperture:

- When light passes through a circular aperture, → a circular diffraction pattern is produced (Fig. 2.4).
  - This consists of: a bright central disc *(Airy disc)* surrounded by alternate dark and light rings.

  - Properties of the Bright central airy disc:
    - The airy disc is 0.01 mm when the pupil is 2 mm in diameter (less with larger pupil and more with smaller pupil).

    - 83% of energy of the point source will be focused on the airy disc and so the smaller the airy disc the more accurate the image with greater resolving power.

Fig.2.4: pupil diffraction

↳ ***Clinical applications:***

① The most efficient diameter of the pupil is 2.5 mm:

- *Below that* ➔ Diffraction effects limit the resolution.
- *Above that* ➔ Spherical and peripheral aberrations limit the resolution.

② The pinhole test used in refraction to estimate visual acuity:

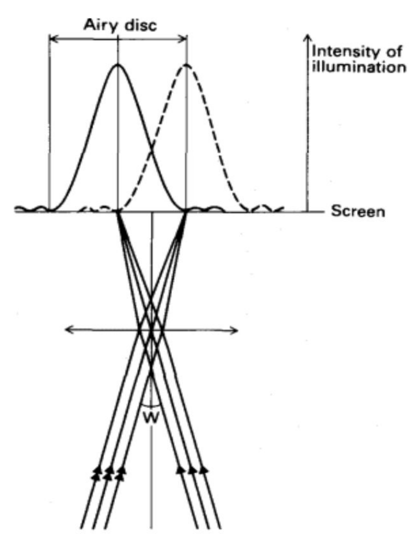
- The pinhole test will improve the visual acuity of an eye with refractive errors (not with eye disease) to 6/9 only because of the diffraction effects which limit resolution.

③ Diffraction is used in the design of some multifocal intraocular lenses.

(5) RESOLUTION:

- ***Resolving power*** (angle of resolution):
  - The smallest angle of separation (w) between two points which allows the formation of two discriminable images by an optical system (Fig. 2.5).

- *The limit for resolution:*
  - The limit of resolution is reached when two airy discs are separated so that the centre of one falls on the first dark ring of the other (Fig. 2.5).



- *The angular resolving power of the normal eye:*
  - Is about ➔ *1 minute of an arc*.

- *Clinical applications:*
  - The test types in visual acuity (resolving power) test ➔ subtends a known angle at the eye when viewed from the appropriate distance (Chapter 13).

(6) SCATTERING:

➢ ***Definition:***

- When light travels through a medium with many small particles in it (as a dusty room or dusty air) ➔ the light that happens to hit any of the particles is reflected off the particles in a new direction,

➢ ***Applications:***

A. Ocular scattering:

- *Normal ocular scattering:*
  - *Cornea:* Corneal stroma scatters 10% of light incident upon it (that is why we see corneal structures with the slit-lamp).
  - *Lens:* Due to the presence of the faint yellow pigment in the lens.
  - *Retina:* Due to the presence of Muller's fibres.

  - NB1: Blue iris colour ➔ is due to scattering of light by stromal fibres.
  - NB2: Scleral whiteness: ➔ is due to scattering of light by collagenous bundles which are surrounded by ground substance of a different refractive index.

- *Abnormal ocular scattering:*
  - *Cornea:*
    - Stromal oedema.
    - Endothelial or epithelial oedema,
    - Corneal scars.
  - *Lens:* Cataract.

NB: Sensitivity to glare: is increased in presence of increased corneal or lenticular scattering (cataract test).

B. Sunlight blue scatter:

1. The sky looks blue.
2. The sun seams red at nightfall (especially with air pollution) as the sunrays travel a longer distance.

(7) POLARIZATION:

- If a number of light waves are travelling in the same direction,➔ <u>their electric fields</u> (wave motion) may or may not be parallel to each other:
  - ➲ If the electric field directions are randomly related to each other,➔ the light is unpolarized.
  - ➲ If all the electric fields are in the same direction (parallel), ➔ the light is linearly polarized (electric fields are perpendicular on magnetic fields).

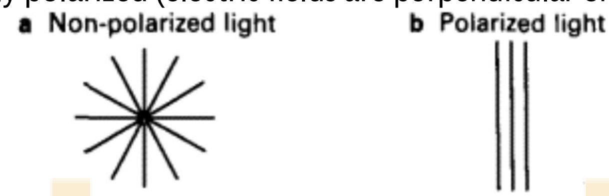


Fig. 2.6 Cross section of beam of light to show plane of wave motion.

➯ *<u>Polarized light:</u>*

- Is a light beam with parallel electromagnetic wave motion which is produced from ordinary light by intersecting it with a polarizing substance (as polarized plastic) with a polarizing angle (Brewster angle) of the substance.

➯ Mechanism of creation of polarized light:

1- Transmission:

➲ through a polarizing substance.

☛ Polarizing substances, e.g. calcite crystals,➔ only transmit light rays which are vibrating in one particular plane..

☛ A polarising medium reduces radiant intensity but does not affect spectral composition.

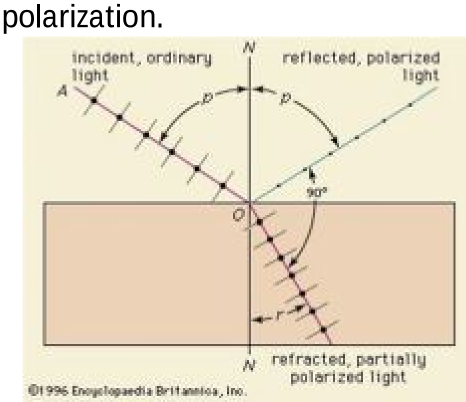
2- Reflection:

a) From a plane surface (such as water) with the direction of polarization parallel with the surface ➔if the angle of incidence is equal to the polarising angle for the substance.

➲ Polarized sun glasses exclude ➔ the reflected <u>horizontal polarized light</u> and so useful in reducing glare from the sea or wet roads.

3- Scattering: of light molecules in the atmosphere.

➲ If there are clouds in the atmoephere: □ light reaches the eye after multiple scatterings in the clouds which destroy the polarization.



➯ *<u>The polarizing angle:</u>* (Brewster angle)

☛ A particular angle for every interface, at which ➔ only 1 polarization is reflected

➯ *The plane of polarization of the reflected light* from such a surface is ➔ parallel with the surface.

- *The angle* Is dependent on➔ The refractive index of the substance comprising the reflecting surface.

- At other *angles of incidence* ➔ *the reflected light* is partly polarized, i.e. a mixture of polarized and non-polarized light.

- *Clinical applications:*
  1. *Polarized glasses:* To reduce glare from the sea or wet roads.
  2. *Polarized light in ophthalmoptic Instruments:* (As the ophthalmoscopes and slit-lamps) to reduce the reflected glare from the cornea.
  3. *To produce Haidinger's brushes in pleoptics*: An entoptic phenomenon used in foveal training.
  4. *To dissociate eyes in assessment of binocular vision:* By polarizing glasses.
  5. *To examine lenses for stress:* In optical lens making.

(8) FLUORESCENCE:

- *Definition:*
  - The property of a molecule to spontaneously emit light of a longer wavelength when stimulated by light of a shorter wavelength.

- *Mechanism:*
  - Light may be absorbed by an electron in ground state➔ raising the electron into an excited state➔ Electron in the excited state is unstable and it tend to return spontaneously into the ground state, ➔ By emitting a photon (light energy) that is less energetic and so of longer wavelength ➔ fluorescence.

- *Clinical applications:*

A. the orange dye fluorescein sodium:

  - *The property:*
    - When excited by blue light (465–490 nm) emits yellow–green light (520–530 nm) (Fig. 2.7).

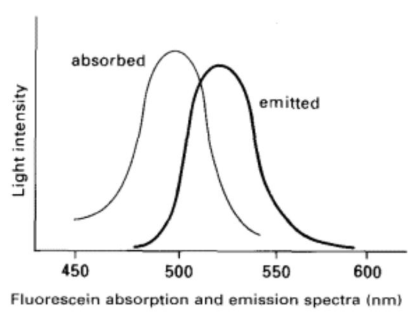


Fig. 2.7 Absorption and emission spectra of fluorescein.

  - *Uses:*

    I. *Fluorescein angiography:*

- Mechanism:
  - White light from the flash unit of a fluorescein camera passes through a blue 'excitation' filter illuminate the fundus with blue light (Fig. 2.8).
  - The wavelengths transmitted by the excitation filter approximate to the absorption spectrum of fluorescein.
  - Most of the light is absorbed, some is reflected unchanged, and some is changed to yellow–green light by fluorescence.
  - The blue reflected light and yellow–green fluorescent light leaving the eye are separated by a yellow–green 'barrier' filter in the camera. This blocks blue light and exposes the camera film only to yellow–green light from the fluorescein, thereby delineating vascular structures and leakage of dye.

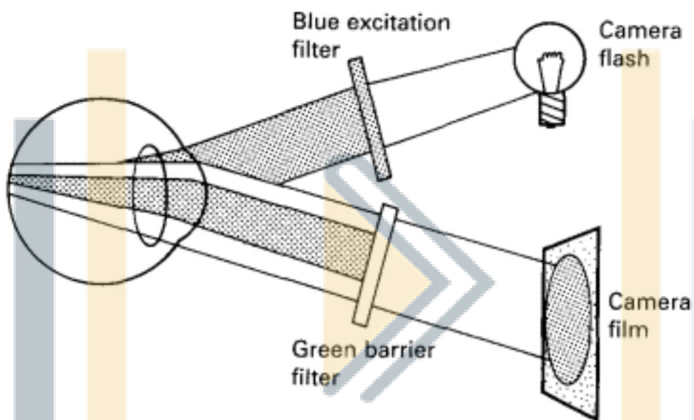


Fig. 2.8 Filter system for fundus fluorescein angiography.

- Fluorescence before injection of dye may be termed autofluorescence or pseudofluorescence.
  - The phenomenon of pseudofluorescence occurs if there is an overlap in the spectral transmission of the excitation and barrier filters. This allows reflected wavelengths at the green end of blue to pass through the barrier filter and appear as fluorescence.

II. *Other important applications:*

1. The staining of ocular surface defects.
2. Anterior segment angiography.
3. The measurement of aqueous humour production and outflow.
4. In light microscopy, the localization of tissue constituents using fluorescein bound to specific immunoglobulin.

B. Indocyanine Green:

- *The properties:*
  - Indocyanine green (ICG) dye is a fluorescent substance which absorbs 805 nm and emits 835 nm infrared radiations.
  - The retinal pigment epithelium does not absorb these wavelengths, and it is therefore possible to observe fluorescence of the choroidal circulation after ICG is administered intravenously.
  - Only 4% of 805 nm radiation absorbed by ICG is emitted at 835 nm compared with the total fluorescence of fluorescein.

(9) ABSORBANCE:

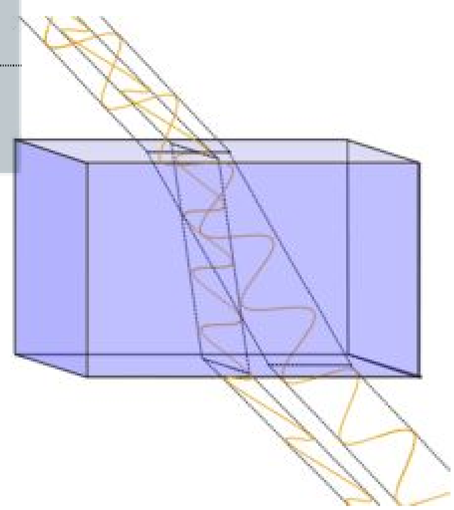
- ***Definition:***
  - When light falls upon an object it may be absorbed (or reflected, transmitted or undergo some combination of the above) by the object.

- ***Clinical applications:***
  a) *Optical devices:* As light filters and sun glasses.
  b) *Re-radiation:* Absorbed light is usually converted into heat by the absorbing electrons but it may be used to excite an electron into a higher level and be re-radiated (as in the case of fluorescence).

(10) BIREFRINGENCE:

- *Definition:*
  - The splitting of a light wave into → two unequally reflected or transmitted waves by an optically anisotropic medium (have two refractive indices) such as calcite or quartz. Also called double refraction.

> - Many transparent solids are optically isotropic, meaning that the index of refraction is equal in all directions throughout the crystalline lattice. Examples of isotropic solids are glass

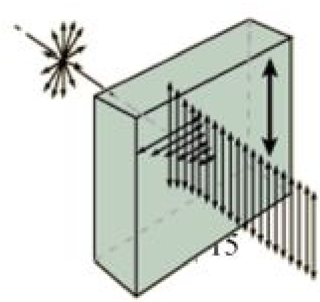


- *Example:*
  - Crystals of quartz have this property, which is known as birefringence.
    - Because they split incident unpolarised light into two polarized beams travelling in different directions, they have two refractive indices

(11) DICHROISM:

- *Definition:*
  - The molecular structure of dichroic substances completely blocks transmission of light waves not aligned with its structure by absorption.

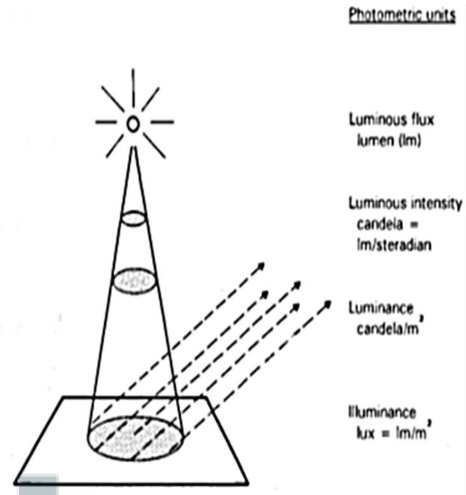
- *The property:*
  - Only one beam of polarized light emerges, much weakened in intensity compared with the incident non-polarized light.



- *<u>Example:</u>*
  - Tourmaline and Polaroid (the latter made from fine iodine and quinine sulphate crystals embedded in plastic) are dichroic substances, polaroid being commonly used in sunglasses.

- *<u>Clinical applications:</u>*
  1. *To produce Haidinger's brushes in pleoptics*: An entoptic phenomenon used in foveal training.
  2. *To dissociate eyes in assessment of binocular vision:* By polarizing glasses.
  3. *To examine lenses for stress:* In optical lens making.

(12) QUANTITATIVE MEASUREMENT OF LIGHT



The quantitative measurement of light is carried out in 2 different ways.

I. PHOTOMETRY:

✓ *Definition:*

- ➲ It is measurement of light in term of its perceived brightness to the human eye.
- ➲ The basic unit is ➔ candela

✓ *Photometry measurements of light:*

A. Luminous flux:

- ☛ Which is the total flow of light➔ in all directions from a source
- ☛ It is measured in lumens.

B. The luminous intensity: (*candle-power)*

- ☛ Refers to the light ➔ emitted in a given direction of the source.
- ☛ It is measured in ➔ *lumen per steradian Or* candela.

1 candela = 1 lumen per steridian.

- – The size of the cone of light is measured in steradian, the steradian being the unit of solid angle.
- • *Luminous intensity is sometimes referred to as candle-power.*
- • *The candle:* The original unit of luminous intensity was, based on the emission from a wax candle of standard composition. Attempts to produce a more uniform and precise source of light by which others could be measured led to the current standard unit, the candela, whereby the luminous intensity per square centimeter of a black body radiator at the freezing point of platinum is defined as 60 candelas because the black body radiator is 60 times brighter than the standard candle.

C. Illumination:

- ☛ Refers to the light➔ arriving at a surface.
- ☛ Surface illumination is measured in ➔ Lux (lumen/m^2) or Foot candle (lumen / ft^2).

D. Luminance:

- ☛ Refers to The light being ➔ reflected or emitted from the surface,
- ☛ It is measured as the luminance by ➔ the foot Lambert or Abostilb

- o The eye is the original photometer, and it is most sensitive to yellow-green light, its sensitivity declining towards both ends of the visible spectrum. Thus, when viewing a spectrum, the yellow-green portion looks “brighter “than the red-orange or blue-violet bands.
- o Electrical photometers are designed so that their sensitivity to different wavelengths mimics that of the eye.

E. The Troland*:*

- ➜ Is a measure of retinal illumination when a surface luminance of one candela per square meter is viewed through an entrance pupil which measures one square millimeter after correction for the Stiles Crawford effect.

Table 1-1 **Principal Types of Photometric Light Measurement**

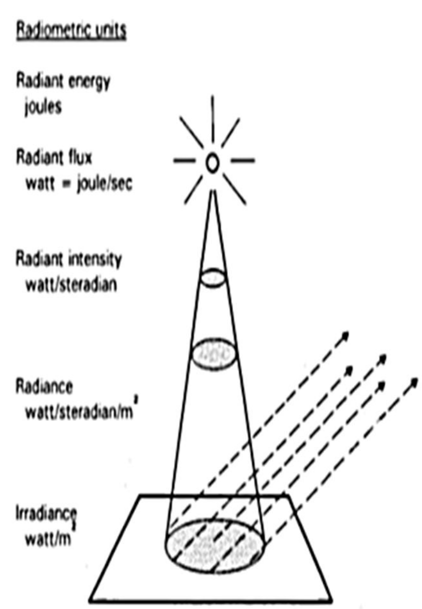
Description	Type	Units
Quantity of light leaving a source or passing through a region of space	Luminous flux	Lumens (1 candle emits 4π lm)
Light emitted per unit solid angle	Luminous intensity (candle power)	1 candela* = 1 lm/sr
Quantity of light per unit area incident on a surface or at an image	Illuminance	1 lux = 1 lumen/square meter 1 foot-candle = 1 lumen/square ft
Light reflected or emitted by a surface, per unit area and per unit solid angle	Luminance	1 apostilb = (1/π) lumen/square meter/sr 1 foot-lambert = (1/π) lumen/square ft/sr
Illuminance at the retina, adjusted for pupil size	Retinal illuminance	Trolands (luminance of 1 candle/square meter viewed through 1-square-mm pupil)

*A standard (new) candle is called a candela.

II. RADIOMETRY:

- *Definition:*
  - It is measurement of light in term of Power.
  - The basic unit is → Watt

- *Radiometry measurements of light:* (Fig. 2.8)



1. The radiant flux:
   - The total flow of light emitted in all directions from a source
     - *Radiant flux,* if measured in→ watts,

2. The radiant intensity:
   - The intensity of light emitted from a source is a measurement of the flow of light per unit solid angle of space extending away from it.
     - *Radiant intensity* measured in→ watts per steradian.

– The steradian: The size of the cone of light is measured in steradian, the steradian being the unit of solid angle.

3. Irradiance:
   - Refers to the light arriving at a surface.
   - It is measured in ➔ watts per square meter.

   - The illumination of a surface Depend on:
     1. The distance from the light source:
        ⇨ illumination of a surface is inversely related to the square of the distance of the surface from the source (the inverse square law)
     2. The angle of the incident light to the surface.

4. Radiance (brightness): measured in watts/sr cm2

Table 1-2 Radiometric Terminology for Medical Lasers

Term	Unit
Radiant energy	joule*
Radiant power	watt
Radiant energy density	joules/cm^2
Irradiance	watts/cm^2
Radiant intensity	watts/sr†
Radiance (brightness)	watts/sr cm^2

*1 joule = 1 watt × 1 sec.
†Steradian is the unit of solid angle. There are 4π steradians in a sphere.

- *The luminous efficiency of the radiation:*
  1. Radiometric and photometric units are related by a conversion factor specific for each wavelength
     - This conversion factor is determined by the sensitivity of the eye to it.

  2. The peak photopic sensitivity of the eye is to the wavelength of 555 nm (yellow–green), at which
     - 1 watt of monochromatic light ➔ has a photometric equivalent of 685 lumens.
     - This wavelength is therefore said to have maximum luminous efficiency.

  3. The sensitivity of the eye progressively falls to wavelengths towards each end of the visible spectrum. at which
     - 1 watt of monochromatic light ➔ has a photometric equivalent of less than 685 lumens.
     - These wavelength is therefore said to have lower luminous efficiency.

  4. The conversion factor falls towards zero outside the range 400–700 nm (visible light).
  5. The photometric equivalent of polychromatic light is calculated by ➔ summating the photometric equivalents of the constituent wavelengths.

LUMINANCE:

- ***Definition:***
  - Luminance is the measure of the mount of light reflected or emitted by a surface.

- ***Method of measurement:***

There are two ways of measuring luminance and therefore two sets of units in use:

1. *\`Lambert system\` (don't specifies the direction of view):*
   - A surface emitting or reflecting 1 lumen/cm^2 ➔ has a luminance of 1 foot-lambert.

2. *A method of measuring luminance that specifies the direction of view:*
   - Because the direction of the view is specified, ➔ the candela replaces the lumen as the unit of light.

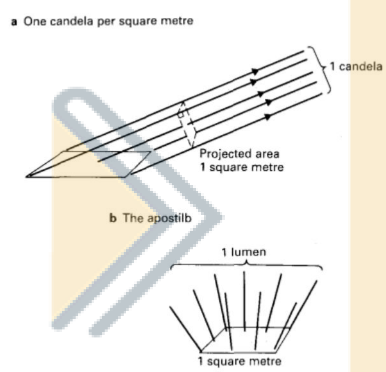


Fig. 2.9 Units of luminance.

✱ *The two sets of units are related to each other as follows:*

1 foot-lambert = 1 candela/ft^2.

- ***The perfect diffuser surface:***
  - Definition:
    - Is the one which reflects light equally in all directions. If, in addition, it reflects all the light which is incident, it is said to be ➔ a *perfect diffuser.*

  - Each reflecting point on such a surface behaves as a point source of light because it emits light equally in all directions.
    - ➜ Luminance is measured in ➔ foot lambert.
    - ➜ The radiometric equivalent, *radiance,* is measured in ➔ watts per steradian per square centimeter.

> o It is important to stress that the candela measures light reflected or emitted in only one direction and not the total amount leaving the surface in all directions.

  - For most purposes, the luminance of a surface is measured not in candelas but by comparing it with a uniform diffuser which emits a total flux in all directions of 1 lumen per unit area (Fig. 2.9b).
  - A luminous flux of one lumen per square meter corresponds to a luminance of one *apostilb.* (An alternative definition is 1 apostilb = 1/□□candelas per square meter.)

AUTOMATED PERIMETRY:

- *Definition:*
  - Perimetry measures the sensitivity of points on the retina to light by the ability of the patient to detect light stimuli of varying intensity presented in the visual field.

- *Test performance:*

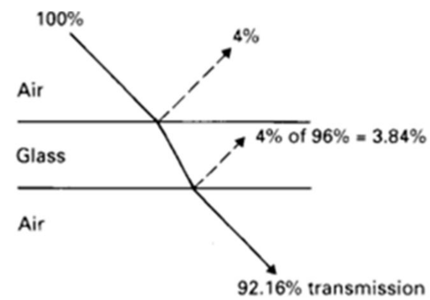
1. The most perimeters have ➔ a standard background luminance of 31.5 apostilbs (asb).

2. Light stimuli may vary in intensity between 0.8 and 10,000 asb.
   - This range can be expressed as a logarithmic scale and the log units are termed decibels (dB; 1 log unit equals 10 dB).
   - The range 0.8–10000 asb used in perimetry corresponds to 51 dB.

REFLECTION OF LIGHT

- When light meets an interface between two media, its behaviour depends on the nature of the two media involved:
  - Light may be absorbed by the new medium.
  - Transmitted onward through it.
  - It may bounce back into the first medium. This 'bouncing' of light at an interface is called *reflection.*

- *The reflection:* occurs, to some degree, at all interfaces even when most of the light is transmitted or absorbed. It is by the small amount of reflected light that we see a glass door and thus avoid walking into it.



Laws of Reflection:

- *These are the two laws which govern reflection of light at any interface:*
  - The incident ray, the reflected ray and the normal to the reflecting surface all lie in the same plane.
  - The angle of incidence i equals the angle of reflection r.
- *The normal:* Is a line perpendicular to the surface at the point of reflection.
- *The angle of Incidence:* Is the angle between the normal and the incident ray.
- *The angle of reflection:* Is the angle between the normal and the reflected ray.

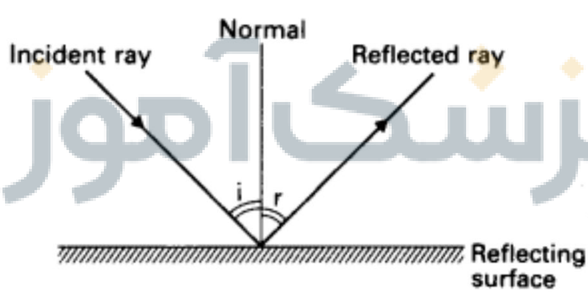


Fig. 3.1 Reflection at a plane surface.

Reflection at an irregular surface:

✓ When light encounters an irregular surface, it is scattered in many directions (Fig.3.2). This is called *diffuse reflection*.

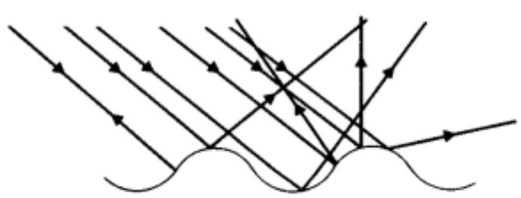


Fig. 3.2 Reflection at an irregular surface: diffuse reflection.

✓ It is by diffuse reflection that most objects (except self-luminous ones) are seen, e.g. furniture, etc. A perfect reflecting surface (free from irregularities causing diffuse reflection) would itself be invisible. Only the image formed by light reflected in it would be seen.

Reflection at a regular Surface:

Reflection at a Plane Surface (Plane Mirrors):

In Fig. 3.3, light from object O is reflected at the surface according to the laws of reflection. If the reflected rays are produced behind the surface, they all intersect at point I, the image of object O.

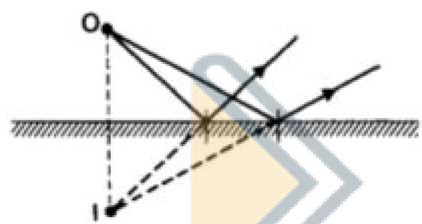


Fig. 3.3 Reflection at a plane surface: point object.

- The brain always assumes ➔ that an object is situated in the direction from which light enters the eye.
  - ☛ Light from object O appears to come from point I, the image of O.

- *The image Formed by a plane mirror of an extended object will be (Fig. 3.4):*
  - o Upright (erect), laterally inverted and Virtual.
  - o It lies along a line perpendicular to the reflecting surface.
  - o It is as far behind the surface as the object is in front of it.

> *If the observer actually goes to point I, there is no real image present: it could not be captured on a screen. Such images are called virtual. Images which can be captured on a screen are called real images.*

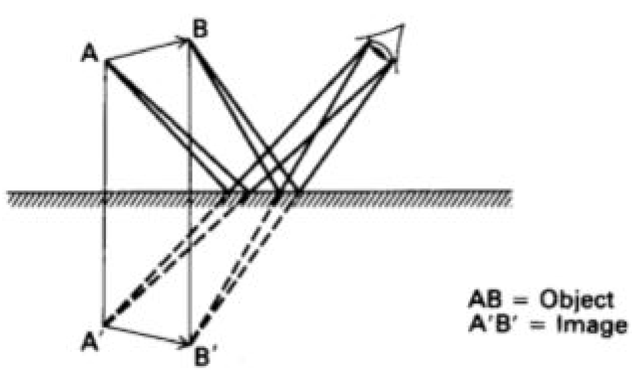


Fig. 3.4 Reflection at a plane surface: extended object.

- *Rotation of a Plane Mirror:* (Fig 3.5)
  - If a plane mirror is rotated while light is incident upon its centre of rotation, ➔the reflected ray is deviated through an angle equal to twice the angle of rotation of the mirror.

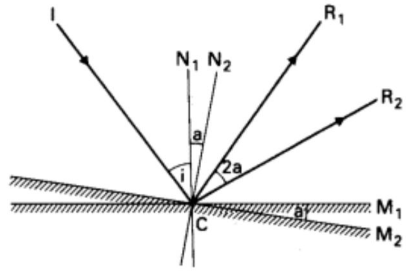


Fig. 3.5 Rotation of a plane mirror.

Reflection at Spherical Reflecting Surfaces (spherical mirrors):

- A spherical mirror: Is a reflecting surface➔ having the form of a part of a sphere.

- Types of spherical mirrors:
  - ✓ Concave mirror: If the reflecting surface lies on the inside of the curve.
  - ✓ Convex mirror: If the reflecting surface lies on the outside of the curve.

- Optical properties of spherical mirrors (Fig. 3.6):
  - *The centre of curvature C:* Is the centre of the sphere of which the mirror is a part.
  - *The pole of the mirror P:* Is the centre of the reflecting surface.
  - *The radius of curvature r:* Is the distance CP.
  - *The axis:* Is any line passing through the centre of curvature and striking the mirror:
    - o *The principal axis:* Is the axis passing through the pole of the mirror.
    - o *The subsidiary axis:* Is any axis not passing through the pole of the mirror.
  - *The principal focus F:* Is a point in front of the concave mirror or behind the convex mirror at which rays parallel to the principal axis are reflected into it.

  - *The focal length f:* Is the distance FP which is equal to half CP or 1/2 r.

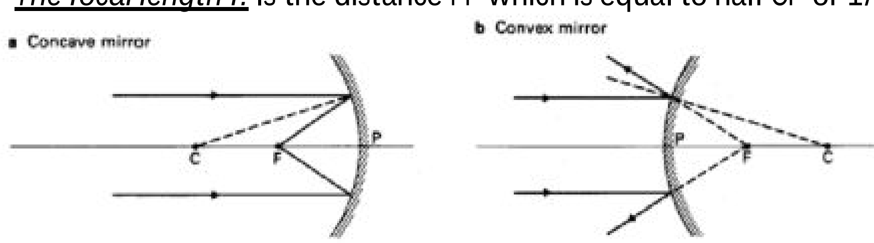


Fig. 3.6: Spherical mirror, Reflection of parallel rays.

- The image: formed by the concave mirror is real while that formed by the convex mirror is virtual.

- Construction of the image by spherical mirrors:
  - Diagrammatic construction of image using two rays (Fig. 3.7):
    - A ray parallel to the principal axis and reflected to the principal focus.
    - A ray from the top of the object passing through the centre of curvature and reflected back on its own path.

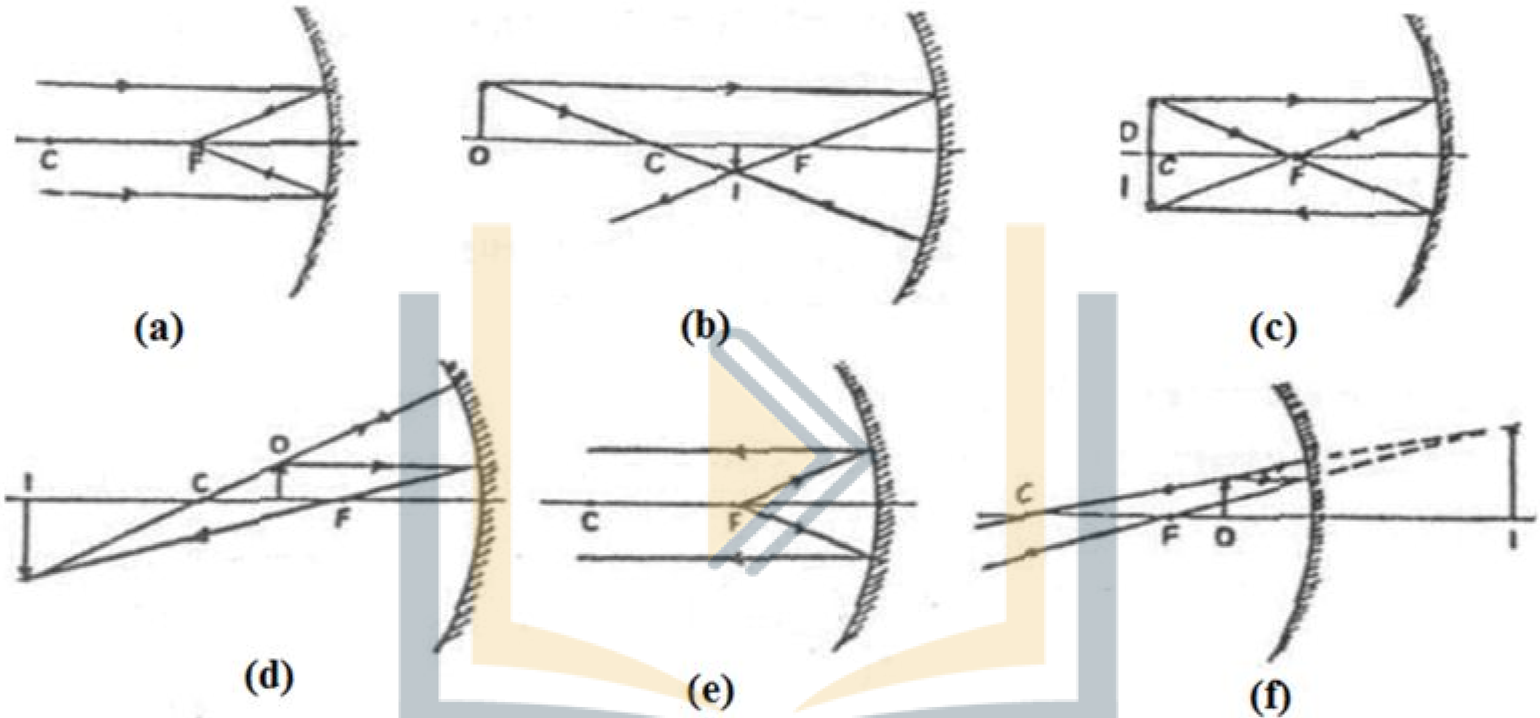


Fig. 3.7. Image formation by the concave mirror: (a) Object at ∞; (b) Object outside C (outside 2F); Image real, inverted, diminished (reduced in size), lying between C and principal focus F. (c) Object at C (at 2 F) ;(d) Object between 2Fand F; Image real, inverted, enlarged, lying outside the centre of curvature C. (e) Object at F; (*f*) Object inside F, Image erect, virtual and enlarged.

The image formation by the concave mirror:
- The characteristics of the image depend on the distance of the object, situated on the optical axis. From the mirror as seen Fig. 3.7.

The image formation by the convex mirror:
- If the object is at ∞, the image is at F.
- If the object is at any finite distance on the principal axis of the mirror the image is *virtual, erect* and *diminished* (Fig. 3.8) and *inside F*.

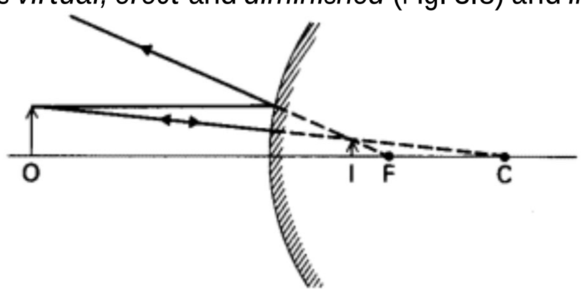


Fig. 3.8: Image formation by the convex mirror at any finite distance.

- Calculation of the position and size of image formed by spherical mirrors:

1) *Calculation of the position of image using the following formula:*

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}=\frac{2}{r}$$

➲ Where u is the distance of the object from the mirror, v is the distance of the image from the mirror, f is the focal length of the mirror, and r is the radius of curvature of the mirror.

2) *Calculation of the size of the image (magnification) using the following formula:*

The magnification produced by a curved mirror: the ratio of image size to object size.

$$\frac{i}{o}=-\frac{v}{u}$$

➲ Where M = magnification, i = image size, o = object size, v is the distance of the image from the mirror, and u is the distance of the object from the mirror.

- When using these formulae, the *sign convention* must be adhered to (Fig. 3.9).

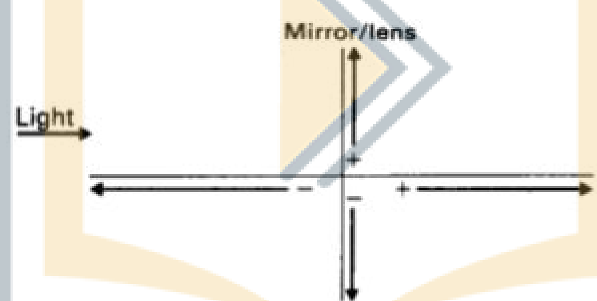


Fig. 3.9 Sign convention.

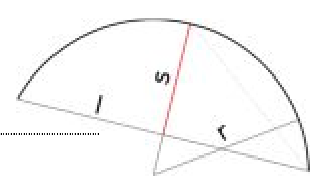
★ Distances: Are measured from the pole of the mirror or the vertex of the lens to the point in question:

- *Positive:*
  - Distances measured in the same direction as the incident light (light is assumed to travel from left to right) are +ve.
- *negative:*
  - Distances measured against the direction of incident light are -ve.
  - Values of f and r in convex mirrors and f in concave lenses are -ve.

★ Magnification:

- *+ve:* For erect images above the principal axis.
- *-ve:* For inverted images below the principal axis.

- Sagitta
  - The sagitta of a circular arc→ is the distance from the center of the arc to the center of its base.
  - In optics → it is used to find the depth of a spherical mirror or lens.
  - The name comes directly from Latin sagitta, meaning an arrow.



Clinical applications of the reflecting surfaces:

- ***Reflecting surfaces of the eye:***
  - *Keratometers:*
    - Using the principle that the anterior surface of the cornea acts as a convex mirror to measure the radius of curvature of the cornea.
  - *Catoptric images (Purkinje's images):*
    - Are the images formed by the reflecting surfaces of the eye.

- ***Reflecting mirrors:***
  - *Concave mirrors are of use in:*
    1. Distant direct method at 22 cm.
    2. Direct ophthalmoscopy.
    3. Indirect ophthalmoscopy.
  - *Plane mirrors are of use in:*
    1. Retinoscopy.
    2. Stereoscopes and synoptophores.

REFRACTION OF LIGHT

- *<u>Definition:</u>*
  - The change in direction of light when it passes from one transparent medium into another of different optical density. The incident ray, the refracted ray and the normal all lie in the same plane.

- *<u>Factors affecting the amount of refraction (bending of light rays):</u>*
  1. The density of the medium (refractive index).
  2. The obliquity of falling of light rays (angle of incidence).
  3. The wavelength of light (dispersion).

- *<u>The effect of the density of the medium on the velocity of light:</u>*
  - The denser the medium ➔ the slower the light passes through it.
  - When a beam of light strikes the interface separating a less dense medium from a denser one obliquely (Fig. 4.1),
    - ➜ The edge of the beam which arrives first, A, is retarded on entering the denser medium.
    - ➜ The opposite side of the beam, B, is meanwhile continuing at its original velocity. The beam is thus deviated as indicated in Fig. 4.1, being bent towards *the normal* as it enters the denser medium.

  - The normal: being a line perpendicular to the interface at the point of refraction.

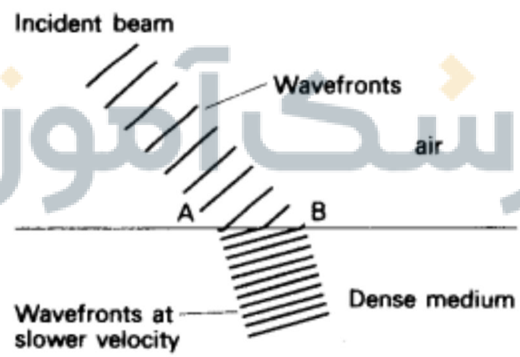


Fig. 4.1 Refraction of beam of light entering an optically dense medium from air.

- *<u>The absolute refractive index:</u>*
  - o The *optical density* of a medium: a comparison of the velocity of light in a vacuum and in another medium gives a measure the optical density of that medium.
  - o The absolute refractive index of any material can be determined using a➔ refractometer.

➢ *Refraction of a light ray entering an optically denser medium than air:*

- On entering an optically dense medium from a less dense medium, light is deviated *towards* the normal (Fig 4.2).
    - The normal: Is a line perpendicular to the interface at the point of refraction.
    - The angle of incidence i: Is the angle between the incident ray and the normal.
    - The angle of refraction r: Is the angle between the refracted ray and the normal.

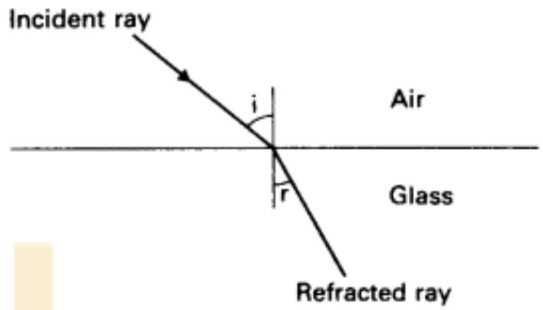


Fig. 4.2 Refraction of light entering an optically dense medium from air.

➢ *Snell's law:* If states that (Fig. 4.2):

- The Incident ray, refracted ray and the normal all lie in the same plane.
- The incident and refracted rays are on opposite sides of the interface.
- The angles of incidence i and refraction r are related to the refractive index n of the media concerned by the equations:

$$\frac{\text{medium 2 (n2)}}{\text{medium 1 (n1)}} = \frac{\sin i}{\sin \text{r}}$$

- Where the first medium is a vacuum, n is the absolute refractive index, and in air n is the refractive index.

➢ *Refraction of light through parallel-sided plat of glass (glass block):*

- *Principle (Fig.4.4):*
    - ☛ Light passing obliquely through a plate of glass is ➔ deviated laterally and the emerging ray is parallel to the incident ray (i.e. the angle of incidence equals the angle of emergence) and so the direction of light is unchanged but is laterally displaced.
    - ☛ Deviation of light is more with greater thickness of the glass plate (block) but its intensity is less.

- *Clinical applications:*
    1. A sheet of glass can be used as an image splitter: As in the teaching mirror of the indirect ophthalmoscope in which:
        - Most of light is refracted across the glass sheet to the examiner's eye.

- A small portion of light is reflected at the anterior surface of the glass sheet and enables an observer to see the same view as the examiner (Fig. 4.4).

2. Helmholtz ophthalmometer: see ophthalmoptic instrument.

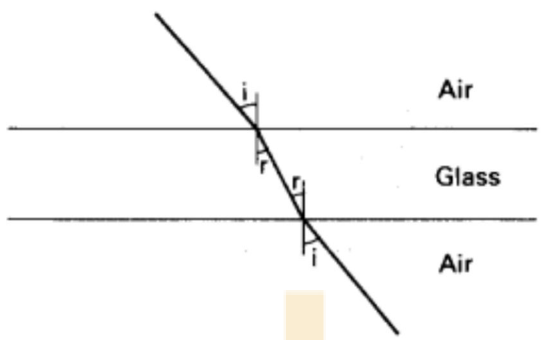


Fig. 4.3 Refraction of light through Parallel-sided slab of glass.

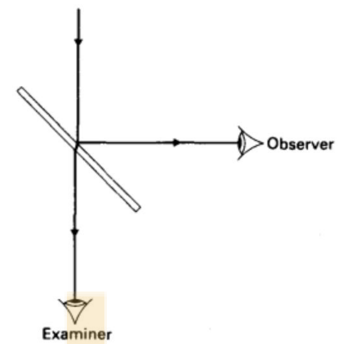


Fig. 4.4: Parallel sided glass Sheet used as an image splitter

- Some reflection also occurs at every interface (Chapter 2) even though in this case most of the incident light passes onwards by refraction.

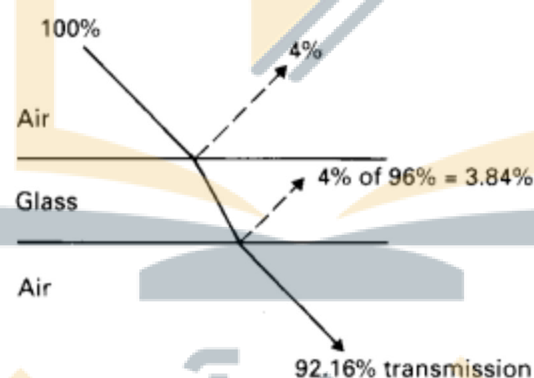


Fig. 4.5 Reflection and transmission of light by transparent media.

➢ *<u>Refraction of light at a curved interface (convex spherical surface as the cornea):</u>*

- *The refracting power of a convex surface:*
  1. <u>It is given by the formula:</u>

     Surface refracting power = n2 - nl / r.

     Where r = the radius of curvature of the surface in meters.
     n2 = Refractive index of the second medium.
     n1= Refractive index of the first medium.
  2. The surface refracting power is measured in dioptres which is +ve for converging surfaces and negative for diverging surfaces.
     - ➜ The anterior surface of the cornea is an example of such a refracting surface and its power accounts for most of refracting power the eye.

➢ ***<u>Real and apparent depth:</u>***

- Principle:
  - ★ Objects situated in an optically dense medium appear displaced when viewed from a less dense medium (Fig. 4.7) due to the refraction of the emerging rays.
  - ★ Objects in water seem less deep than they are)e.g. one's toes in the bath.

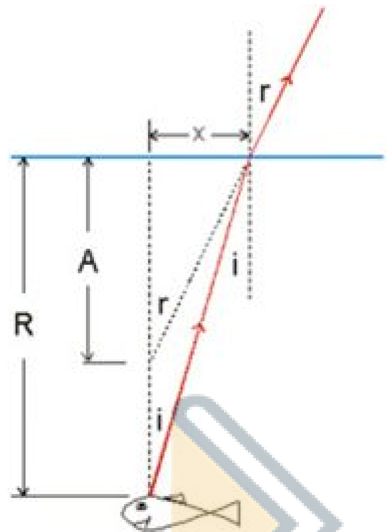


Fig. 4.7: Real and apparent depth.

Snells law: n(water) = Sin i/Sin r

The real depth of the fish is R and its apparent depth is A.

It is clear that Tan i = X/R, Tan r= X/A

For small angles Sin i = Tan I and sin r = Tan r

n = R/A.

  - ★ refractive index of water = $\dfrac{\text{velocity of light in air}}{\text{velocity of light in water}} = \dfrac{4}{3}$
  - ★ Practically it is not necessary to find the 2 velocities directly as both can be replaced by the real and apparent depth which are easily found and so,

    The real depth/Apparent depth= Velocity of light in air/Velocity of light in water.

- Clinical Application:
  - ➯ This principle applies to surgical instruments in the anterior chamber: For example, when making Graefe section, the knife in the anterior chamber appears to be more superficial than it really is (therefore the point of the knife is aimed at the opposite limbus to emerge 1 mm behind the limbus, Fig. 4.8).

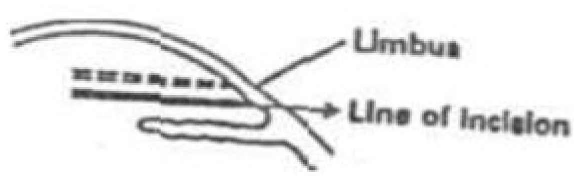


Fig. 4.8: Graefe knife in AC

- *Total internal reflection:*
  - Rays emerging from a denser medium to a rarer medium suffer a variety of fates, depending on the angle at which they strike the interface (Fig. 4.8):
    - Ray A,➔ strikes at 90° to the interface and is undeviated.
    - Ray B,➔ strikes at oblique angle ➔ emerges after refraction.
    - Ray C :➔ strikes at more oblique angle➔ the refracted ray, ray C, runs parallel with the interface:
      - The angle of incidence(C) is called ➔ the critical angle c.
      - The refracting angle at the critical angle is 90.
    - Ray D,➔ striking more obliquely fails to emerge from the denser medium and is reflected back into it (as from a mirror):
      - This is called total internal reflection.
      - The angle of incidence d is larger than the critical angle c.

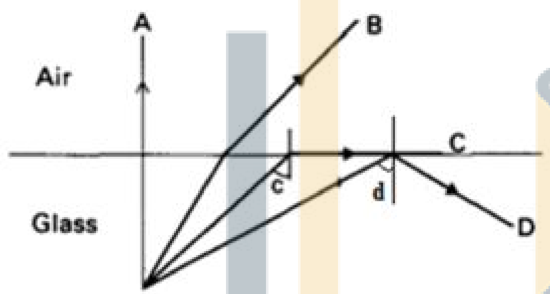


Fig.4.8: Total internal reflection.

Fig.4.9: Total internal reflection at cornea.

- Calculation:
  - The critical angle is determined by the refractive indices of the media involved and can be calculated using Snell's law.
  - To get the index of refraction n of a medium by measuring the critical angle c:

$$n = \frac{\sin \mathrm{i}}{\sin \mathrm{r}} = \frac{\sin \mathrm{c}}{\sin 90}$$

  - The critical angle for the tear film/air interface is 48.5°, and for a crown glass/air interface the critical angle is 41°.

- Clinical applications:

1. Angle of AC:
   - The total internal reflection occurs at the cornea-air interface and prevents visualization of parts of the eye as:
     - The angle of the anterior chamber (Fig. 4.9).
     - The periphery of the retina.
   - This problem is overcome by applying a contact lens made of a material with a higher refractive index than the eye and filling space between the eye and lens with saline to destroy cornea-air refracting surface and allowing visualization of (Fig 4.10):
     - The anterior chamber angle by gonioscopy.
     - The retinal periphery by a 3-mirror contact lens.

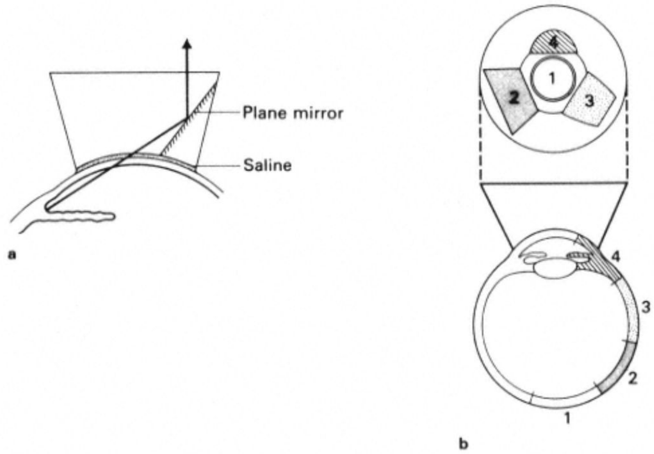


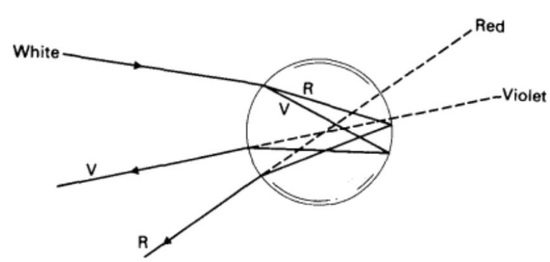
Fig. 4.10 (a) Gonioscopy lens. (b) three-mirror contact lens.

Fig.4.11: Fibroptic tubule.

2. Fibroptics (Fig.4.11):
   - Optical fiber consists of
     - A core of transparent solid material (as glass or plastic) with a high RI surrounded by
     - A caddling with a lower RI.
   - The high-index to low-index interface between the core and the glass tube is the cause of repeated total internal reflection of a ray.

➢ *__The Rainbow (Total Internal Reflection and Dispersion):__*

- When sunlight enters a raindrop it is dispersed into its constituent spectral colours (Fig. 4.12).
- Under certain circumstances, the angle of incidence is such that total internal reflection then occurs within the drop. The dispersed light finally emerges, each wavelength or colour making a different angle with the horizon. To see the rainbow, ➔ the observer must look away from the sun.



- The observer receives only a narrow pencil of rays from each drop, i.e. only one colour.
- The whole rainbow is the result of rays received from a bank of drops at increasing angle to the observer's eye (see Fig. 4.13).

- Violet, the colour making the smallest angle to the horizon, is received from the lower drops while red, making the greatest angle with the horizon, is received from the highest drops. Thus the red is on the outside of the primary rainbow.

- The secondary rainbow is formed by rays that have twice undergone total internal reflection within the raindrops, and the colours are seen in reverse order: violet is on the outside of the bow.

Fig. 4.12 Formation of the primary rainbow. Path of light within one raindrop.

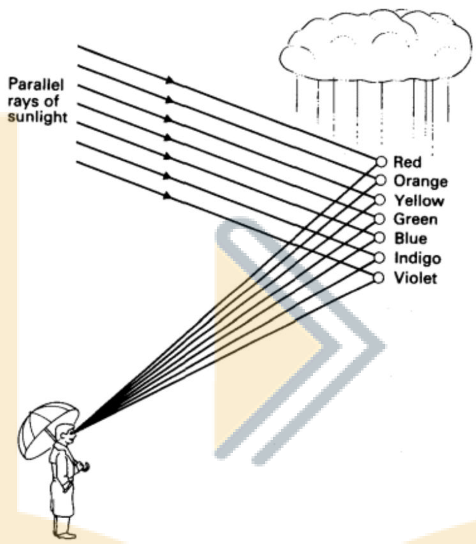


Fig. 4.13 Formation of primary rainbow (composite diagram).

REFRACTION BY PRISMS

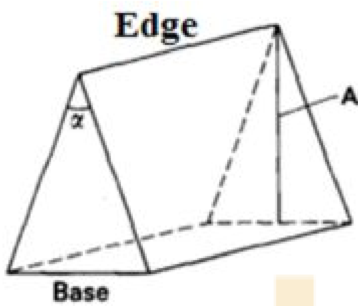


Fig. 5.1: Prism (refracting angle α).

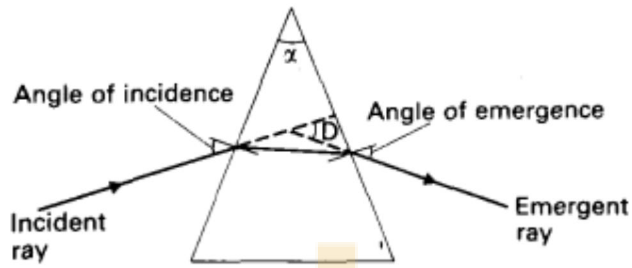


Fig.5.2: Light pass through a prism.

➢ *Definitions (Fig.5.1):*

- A prism:
  - Is a portion of a refracting medium bordered by two plane refracting surfaces which are inclined at a finite angle at the apex of the prism called the refracting (apical) angle **α**.
- The edge:
  - Is line of intersection of the 2 refracting surfaces at the apex of the prism.
- The axis:
  - Is a line bisecting the apical angle.
- The base:
  - Is the surface opposite to the apical angle.
- The orientation of prisms:
  - The orientation is indicated by the ➔ position of the base (as base-up, base-down, base-out or base-in).
- The angle of deviation (d):
  - ✓ The ray is deviated towards the base of the prism (Fig. 5.2).
  - ✓ The total amount of deviation between the incident ray and the emergent ray is called the angle of deviation d.
  - ✓ For a prism in air, the angle of deviation is determined by 3 factors (These three factors also determine the apical refracting angle):
    1. The refractive index of the prism material.
    2. The apical angle of the prism.
    3. The angle of incidence of the ray considered (its obliquity).

- The angle of minimum deviation:
  a. It is the Least angle of deviation when angle of incidence = angle of emergence.
  b. Refraction is called➔ symmetrical under these conditions.

➷ *Relation of the angle of minimum deviation(D) to the apical angle(α) :*

⭯ Prisms are symmetrical: In which the angle of incidence = the angle of emergence with the least angle of deviation and so light passes symmetrically.

1. *Prisms used in ophthalmoptics are made of ➔ thin glass with n=1.5.*
2. Prisms have an apical angle of less than 10° in which:
   - ✓ Sine the angle is the same value as the angle.

- Under these conditions the angle of deviation is given by the formula:

$$D = (n - 1)\alpha$$

- Thus, for a glass prism of refractive index 1.5,

$$D = (1.5 - 1)\alpha$$
$$= \frac{\alpha}{2}$$

- Thus d=l/2 *α* (d = angle of minimum deviation and *α* = apical angle):

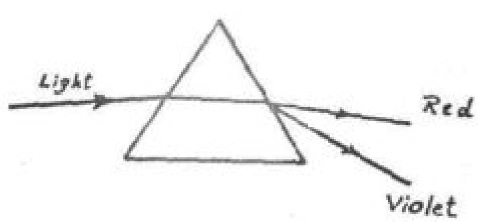
o In other words, the angle of deviation *(D)* equals half the refracting angle (**α**) for a glass prism.

➷ *Image formation by the prism (Fig.5.4):*

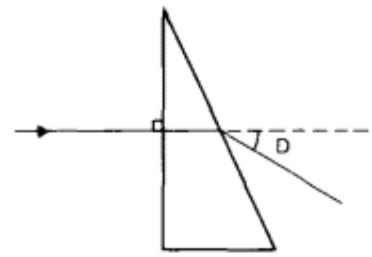
- Erect.
- Virtual.
- Displaced towards the apex of the prism (deviation is reduced to minimum when light passes through prism symmetrically).

➷ *Dispersion of light through prisms (Fig.5.5):*

- Spreading the white light into its component wavelengths by the different refractive indices of the prism occurs by dispersion.
  - ☛ Light of shorter WLs is deviated more than light of longer.
  - ☛ Dispersive power of a prism is not related to refractive power or index of prism.
  - ☛ The angle of dispersion is not the angle of refraction and not the angle of polarization (Browester angle)



- *<u>The positions of prisms (Fig. 5.6):</u>*
    - There are two primary positions in which the power of a prism may be specified,
        1. the position of *minimum deviation* and
        2. *The Prentice position*.



- In the Prentice position:
    - One surface of the prism is normal to the ray of light so that all the deviation takes place at the other surface of the prism (Fig.5.6).
    - The deviation of light in the prentice position is greater than that in the position of minimum deviation, because in the prentice position the angle of incidence does not equal the angle of emergence.
- Therefore the Prentice position power of any prism is greater than its power in the position of minimum deviation.

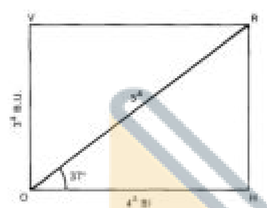
- Clinical applications:
    - The Prentice position power ➔is normally specified for glass ophthalmic prisms, e.g. trial lens prisms, while
    - The power in the position of minimum deviation ➔ is specified for plastic ophthalmic prisms, e.g. prism bars.
        - If a high-power prism is not used in the correct position, a considerable error will result.
        - In practice, plastic prisms may be held in the frontal plane as this is near enough to the position of minimum deviation to avoid significant inaccuracy.

For example, a 40 deportee plastic prism held in the frontal plane will have an effective power of 41 deports, but if it is held in the Prentice position its effective power becomes 72 deports.

- The relation of stacking of two prisms and the position of them:
    - It is not satisfactory to stack prisms➔ ~~one on top of another~~ (because the light entering the second and subsequent prisms will not be at the correct angle of incidence).
        - ➔ Thus the effective power of such a stack will be significantly different from the sum of the powers of the component prisms.
    - However, it is permissible to➔ place a horizontal and a vertical prism ➔ <u>one in front of the other</u>, because their planes of refraction are perpendicular and therefore independent of one another.

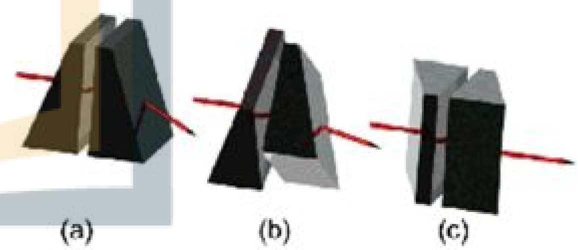
- *<u>Vector Addition of Prisms:</u>*
    - Sometimes a patient requires a prismatic correction in both the horizontal and the vertical directions.
        - This can conveniently be achieved by using one stronger prism mounted at an oblique angle.

- The required power and angle is calculated by ➔ vector addition, either graphically or mathematically (Fig.5.7).
  - Graphically,
    - o The required horizontal and vertical powers are drawn to scale and the rectangle completed (Fig. 5.7).
    - o The diagonal gives the power and the angle ROH the angle required for a single equivalent prism.
    - o The orientation must be specified in terms of the angle, base up/down, and base in/out.
  - Mathematically,
    - o The diagonal power is calculated using ➔ Pythagoras' theorem (the square of the diagonal equals the sum of the squares of the vertical and horizontal sides) and tan ROH = RH/OH.



- Thus, Fig.5.10 shows that a 5dioptre prism base-up and in, lying in the 37° meridian, is equivalent to a 4 deportee base-in prism plus a 3 deportee base-up prism.

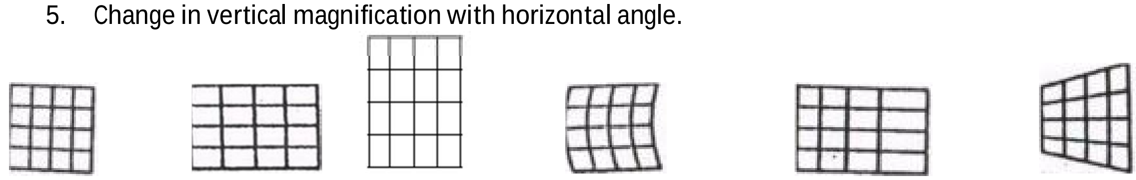
✱ *Risley Prism:*



- The Risley prism is another application of this principle.
- It consists of two prisms of equal power which are mounted ➔ one in front of the other in such a way that they can be rotated with respect to each other and the resulting power is indicated on a scale on the rim of the instrument.
- A Risley prism may be used
  1. in conjunction with a Maddox rod to measure phorias, and is
  2. included in the refractor heads (instead of a trial lens box).

✱ *Distortions of prisms (Fig. 5.8):*

1. Horizontal magnification.
2. Vertical magnification.
3. Curvature of vertical lines.
4. Asymmetrical horizontal magnification.
5. Change in vertical magnification with horizontal angle.



No distortion | horizontal magnification | vertical magnification | curvature of vertical lines | asymmetric horizontal magnification | change in vertical magnification with horizontal angle

Fig: 5.8: Distortion of prisms.

✱ *Notation of prisms:*

1. The prism dioptre (**Δ**):
    - A unit for specifying the amount light deviation produced by the prism.
    - A prism of one dioptre power (1 Δ) produces ➔ a linear apparent displacement of 1 cm of a tangent (of an object, O) situated at 1 m (Fig. 5.9).

        ➪ 10 **Δ** is not 10 times 1 Δ because the tangent of 10 Δ is not 10 times that of 1 Δ.

2. Angle of minimum (apparent) deviation (d°):
    - The apparent displacement of the object o can also be measured in terms of the angle of apparent deviation (θ) (Fig. 5.9).
        - ☑ In Ophthalmoptics, a prism of 1 Δ produces an angle of minimum (apparent) deviation of 1/2° and so 1Δ = 1/2°
3. The centrad ∇ :
    - ☛ It is the strength of a prism which produces ➔ an apparent displacement of 1 cm of an arc (of the object, O) situated at 1 m (Fig. 5.10).
4. The apical refracting angle:
    - ☛ The refractive index of the material must be known to get the apical refracting angle a (Fig. 5.1), but is not in use now.

- NB1: The centrad has the advantage that: 10 ∇ are 10 times ∇ (unlike the prism dioptre in which 10 Δ are not 10 times 1Δ.
- NB2: Centrad is slightly more than prism dioptre: so produces a slightly greater angle of deviation than the prism dioptre but the difference in practice Is negligible.

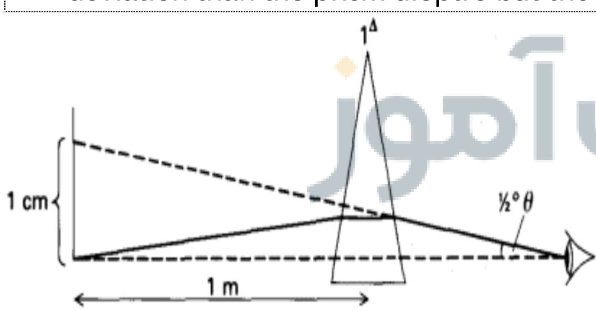


Fig. 5.9 The prism dioptre and angle of apparent deviation (⍰).

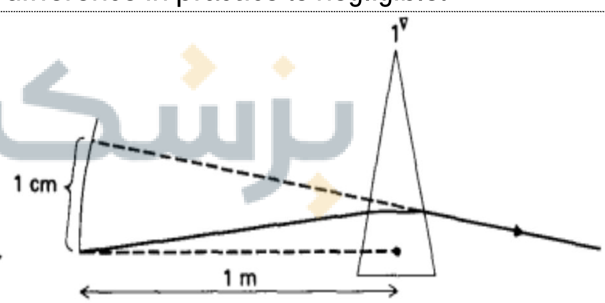
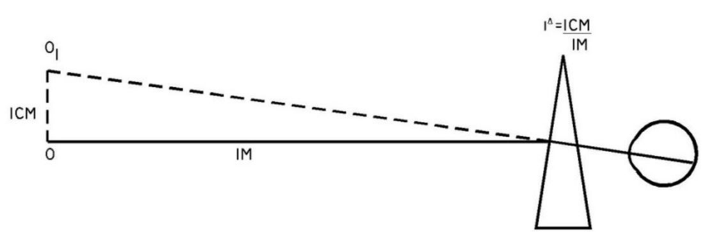


Fig. 5.10 The centrad (⍰).



✱ *Indications (uses) of prisms:*

A. *Diagnostic:*

1. Measurement of the angle of deviation in heterophoria:
   - o Maddox rod and prism test.
   - o Maddox hand frame (Maddox rod and rotatory prism) test.
   - o Prism (or prism bar) test.
2. Four diopter prism test for small degree of microotropia.
3. Prism vergence test to measure fusional reserve in heterophoria.
4. Estimation of the amplitude of convergence:
   - ▪ Positive convergence:
     - ✓ By the strongest prism base-out which is tolerated by the patient without diplopic.
   - ▪ Negative convergence:
     - ✓ By the strongest prism base-in which is tolerated by the patient without diplopic.
5. Assessment of the probability of occurrence of diplopia: After a proposed strabismus surgery in adults.
6. Assessment of simulated blindness: If a prism is placed in front of a seeing eye, the eye will move to regain fixation (in malingerers).

B. *Therapeutic:*

1. Exercising prisms: *to exercise the weak muscles in:*
   - *Heterophoria with the base of the prism towards the deviation:*
     - ☑ In exophoria: With prisms base-out.
     - ☑ In esophoria: With prisms base-in.
   - *Convergence insufficiency:*
     - ☑ The prisms are used base-out during the patient exercise periods for building up the fissional reserve (they are not worn constantly).

2. Relieving prisms: To relieve diplopia and eye strain as in:
   - A. Vertical heterophoria (with the base of the prism against the deviation):
     - ☑ The eye with hyperphoria with a prism base-down, and the other eye will hypophoria with a prism base-up.
   - B. Older presbyopes: with convergence insufficiency by either:
     - ▫ Prism base-in in the lens (is rarely used).
     - ▫ Decentring of the lens.
   - C. Nystagmus:
     - ⌖ Prisms can be prescribed binocularly with their bases against the null point to reduce nystagmus (improving visual acuity and minimizing head turn).

C. *In ophthalmoptic instruments:*

- Prisms are commonly used in ophthalmic instruments as reflectors of light.

- ☛ The prism is designed and orientated so that total internal reflection occurs within it.
- It can be seen that prisms give greater flexibility in dealing with an image than do mirrors. There are many possible systems available (Fig. 5.11).
- It is used in:
    1) Slit lamp microscope and applanation tonometer,
    2) Keratometer.
    3) Indirect ophthalmoscope.
    4) Telescopes (as Galilean telescope with prism binocular).
    5) Cameras.

D. *In ophthalmoptic appliances:*

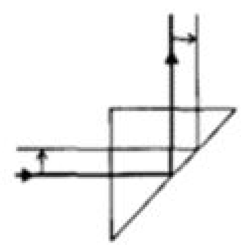
1. Spectacle glasses for special uses:
    - o Hemianopic glasses.
    - o Recumbent glasses.
2. Contact lenses:
    - o Prism ballast.
    - o Truncated lens.

✱ *Forms of prisms:*

1. *Forms of prisms used in diagnosis:*
    1) Single unmounted prisms.
    2) The prisms from the trial lens set.
    3) Prism bars.
    4) Rotatory (rotary or double) prism.
    5) Fresnel prism.
2. *Forms of therapeutic prisms:*
    1) Temporary wear:
        - ✓ Clip-on spectacle prisms for trial wear.
        - ✓ Fresnel prism.
    2) Permanent wear:
        - ☛ *Permanent incorporation of a prism into spectacles can be achieved by:*
            - ▪ Decentring of the spherical lens already present.
            - ▪ Mounted prisms in spectacles.
3. *Forms of prisms used in optical instruments (Fig. 5.11):*

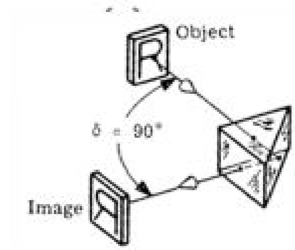
I. *Right angle prism with 90° deviation:*

- The incident parallel rays strike ➔the surface on the side of the right angle of the prism with 90° deviation and so emerge from the surface on the other side of the same angle.



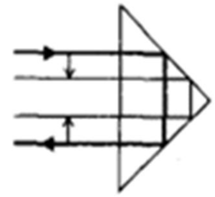
➔ the image is transposed left to right (later inversion of image).

⟲ Example: ➔ the 2 reflecting prisms in the eyepieces of the indirect ophthalmoscope.

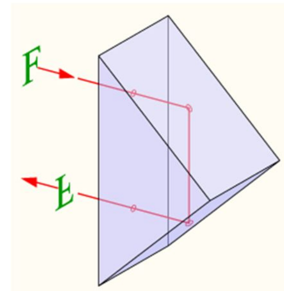


⌖ The angle of incidence is 45° (greater than the critical angle of glass which is 42°) and so total internal reflection occurs.

II. *Right angled prism with 180° deviation (Porro prism):*



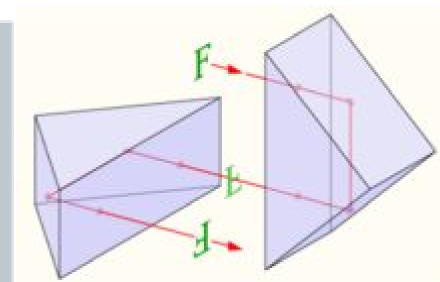
- The incident parallel rays strike➔ the surface opposite the right angle of the prism (hypotenuse) with 180° deviation and so emerge from the same surface (hypotenuse).



➔ The image is inverted but not transposed left to right.

⟲ Example: ➔ Porro Prism is used to (slit lamp): Used between the objective and eyepiece to shorter the tube length and to reinvert the inverted image.

III. *Two right angled prisms (2 Porro prisms) with their edges at right angle to each other: (Porro–Abbe prism)*



1 . The first prism with its edge in a vertical position:
   - The incident parallel rays strike the base of the prism with 180° deviation and so emerge from the same surface but are transposed left to right (lateral transposition or lateral inversion).

2 . The second prism with its edge in a horizontal position:
   - The emergent rays are inverted (image inversion) with 180° deviation.

> - *NB:* Two right angled prisms (2 Porro prisms) are placed between each eyepiece (concave lens) and objective (convex lens) of the Galilean telescopic system, slit-lamp, fundus camera and operating microscope.

IV. *Dove prism (apex removed) ➔ with no deviation:*

➔ The image is inverted but not laterally transposed.

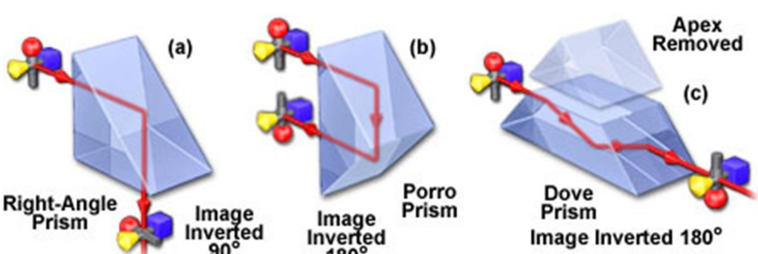


Figure 2

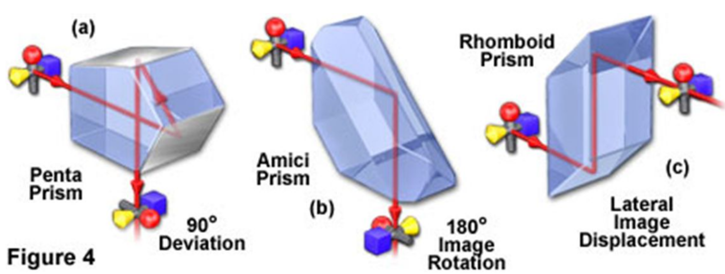


Figure 4

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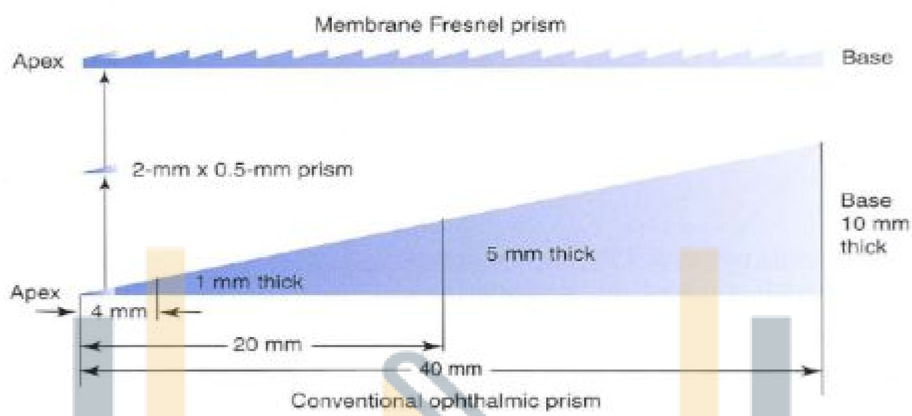
✱ <u>*Fresnel prism:*</u>

- Definition:
  - ✓ A thin flexible plastic membrane of parallel tiny prisms of identical optical (refracting) angles and is made of clear polyvinyl chloride (PVC).
  - ✓ Known as ➔ Press on prism.



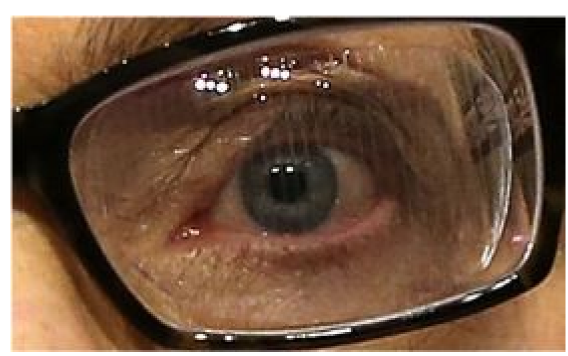
- Optical principles: *Fresnel principle is based on*
  - – Removal of the non-refracting portions of a conventional prism➔ to get a light weight, larger diameter optical element.
  - – *Reducing a prism size to 4 mm:* Will result in a base thickness of 0.8 mm.

- Advantages:
  1. *Cosmetically superior to a conventional prism:* Thin (0.8 mm) and light weight.
  2. *Large diameter (64 mm):* So can be cut to conform to the shape of most spectacle.
  3. *A range of powers (0.5-30 prism diopter) are available*: for treatment of strabismus.
  4. *Refractive index is 1.525:* Which is nearly similar to that of crown glass.
  5. *Localized use on spectacles:* Can be pressed onto a portion or bifocal segment of spectacle lenses.
  6. *In-office application:* With easy removal, modification and successive applications.

     ⟲*Application of the membrane:* It can be cut with scissors to the appropriate shape and can be stuck simply with water to the back surface of the glass or plastic spectacle lenses.

     ⟲ NB: The membrane adheres to the lens for the same reason that two flat pieces of glass bound together when air layer between them has been removed.

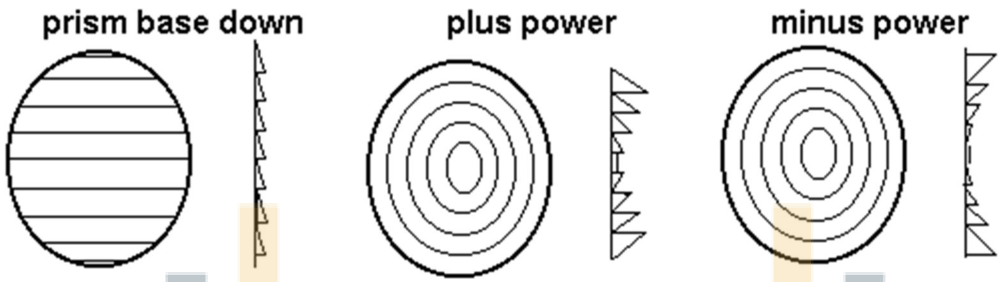
- Disadvantages:
  1. Moderate loss of contrast.
  2. Slight loss of visual acuity.
  3. Reflections and scattering of light from the prism facets.
  4. Visibility of the grooves.



- Indications (uses):
  1. <u>*As a substitute of conventional prisms:*</u>
     1. Diagnostic uses.
     2. Therapeutic uses.

3. Special glasses (hemianopic and recumbent glasses).

2. *<u>Localized use on spectacles:</u>*
    - Pressed onto a bifocal segment of a high plus reading lenses as a low vision aid to allow the addition of base-in prism without decentration.
    - Pressed onto the appropriate portion of the spectacle lens in certain directions of gaze in paralytic strabismus.



✱ *<u>Interpretation of Orthoptic Reports:</u>*

- ✱ Armed with the knowledge that 1 prism dioptre = 1/2°, orthoptic reports become intelligible to the clinician.
- ✱ A prism of 10° apical angle deviates light through 5° and has a power of 10 Δ or 10 ∇ .

✱ *<u>Notes on Prescription of Prisms:</u>*

- ✱ Generally, when prescribing prisms, the correction is split between the two eyes (Fig.5.13). To correct convergence the prisms must be base-out, e.g. 8Δ base-out R and L (Fig.5.13).
- ✱ To correct divergence the prisms must be base-in, e.g. 6Δ base-in R and L (Fig. 5.14). To correct vertical deviation the orientation of the prisms is opposite for the two eyes, e.g. 2Δ base-down RE and 2Δ base-up LE for R hypertropia.

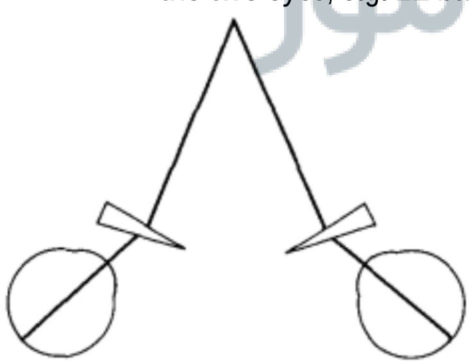


Fig. 5.13 Convergence with prismatic correction.

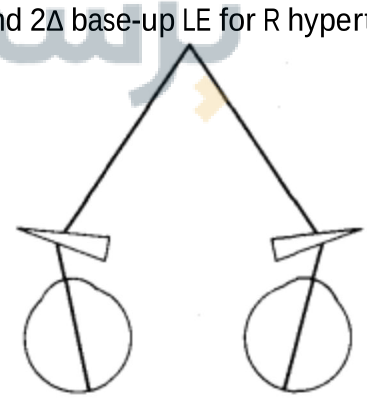


Fig. 5.14 Divergence with prismatic correction.

- The apex of the prism must always be placed towards the direction of deviation of the eye (Fig. 5.15).

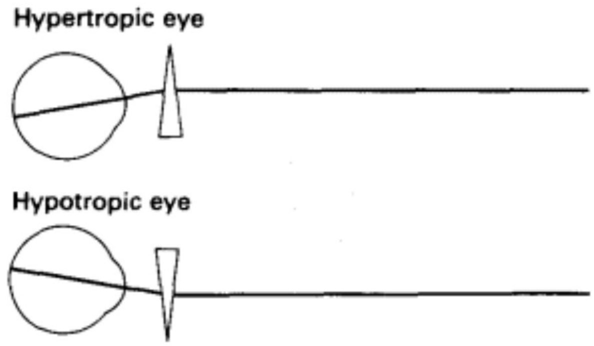


Fig. 5.15 Vertical deviation with prismatic correction.

REFRACTION BY LENSES

Definition:

- A lens is a portion of a refracting medium bordered by two surfaces which have a common axis and at least one of these two surfaces is curved.

Forms of lenses:

- Spherical lenses.
- Astigmatic lenses:
    - A. Cylindrical lenses.
    - B. Toric lenses.

(1) SPHERICAL LENSES:

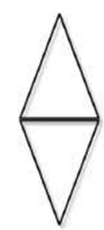
Definition:

- A spherical lens is a lens in which each spherical surface forms part of a sphere and so all meridians of each surface have the same curvature and the refraction is symmetrical about the principal axis.

Forms of spherical lenses :(Fig.6.1):

A. Convex lenses:

- A convex lens may be considered as a collection of prisms base to base i.e. it is built of prisms of gradually increasing angles
    - biconvex lens, plano-convex lens or convex meniscus (with both surfaces convex).



B. Concave lenses:

- A concave lens may be considered as a collection of prisms apex to apex i.e. it is built of gradually decreasing angles
    - i.e. biconcave lens, plano-concave lens or concave meniscus (with both surfaces concave).

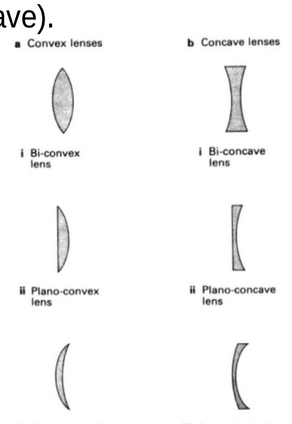


Fig. 6.1 Basic forms of spherical lenses.

➢ *<u>Optical properties of spherical lenses:</u>*

I. The principal axis: Is the axis on which the lens is centered (Fig. 6.2).

II. A secondary axis (Fig. 6.4):
  - Is the axis on which the emergent ray is parallel to the incident ray.
  - In thin lenses, rays passing through it may be considered undeviated.

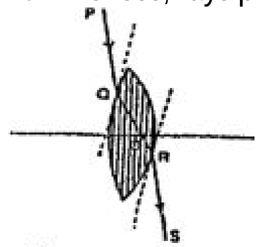


Fig. 6.4: A secondary axis.

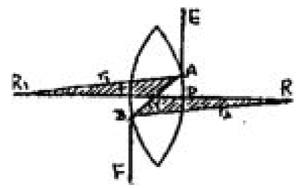


Fig.6.5: optical centre of lens.

III. The principal plane:
  - Is a line perpendicular to the principal axis and intersects with it at the principal point.

IV. The principal point or nodal point (N):
  - Is the point at which the principal plane and the principal axis intersect and through which light rays pass undeviated and its site coincides with the site of the optical centre.

V. The geometrical centre:
  - Is the point in the middle of the lens and is a relation of the placement of the lens in its frame.

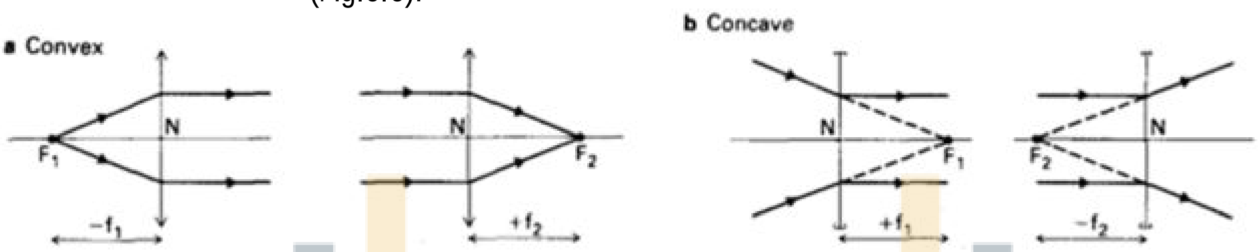
VI. The optical centre (O):
- *<u>Definition:</u>*
  - It is a point which forms the centre of the optical system of the lens, where all secondary axes meet the principal axis and through which all rays may be considered undeviated (as we deal with thin lenses in ophthalmoptics).
- *<u>The optical centre of a thick lens</u> is calculated from:*
  - The curvature of the lens surfaces.
  - The lens thickness.
  - The refractive index of the lens.
- *<u>The site of the optical centre of a lens</u> is (Fig. 6.5):*
  - Inside the lens in biconvex and biconcave lenses.
  - On the curved side in plano-convex and plano-concave lenses.
  - Outside the more curved side in convex and concave meniscus lenses.

VII. The principal focus (F):

- Is a point on the principal axis where parallel light rays to the principal axis are converged to or diverged from it.

VIII. The principal foci (F_1 and F_2):

- As the medium on both sides of the lens is the same (air), parallel light incident on the lens from the opposite direction (i.e. from the right direction) will be refracted in an identical way and so there is a principal focus on each side of the lens, equidistant from the principal point (Fig.6.6):



(a) convex lens. (b) concave lens.

Fig.6.6. the principle foci of thin spherical lenses.

- *<u>The first principal focus</u> (F_1):* Is the point of origin of rays which after refraction by the lens are parallel to the principal axis.

- *<u>The second principal focus</u> (F_2):* Is the point which incident light parallel to the principal axis is converged to or diverged from it.

I. The focal lengths (f_1 and f_2):

- *<u>The first focal length</u> (f_1):* Is the distance between the first principal focus F_1 and the principal point N.
- *<u>The second focal length</u> (f_2):* Is the distance between the second principal focus F_2 and principal point N.

1. *<u>The second focal length (f_2) by sign convention has:</u>*
   - A positive sign for the con vex lens.
   - A negative sign for the concave lens.

2. *<u>Lenses are designated by their second focal length (f_2):</u>*
   - Convex (converging) lenses are called plus lenses and are marked with +.
   - Concave (diverging) lenses are called minus lenses and are marked with –

3. *<u>Distances f1 and f2 may be equal or not equal according to:</u>*
   - $f_1 = f_2$ if the medium on either side of the lens is the same e.g. air.
   - f_1 is not equal to f_2 if second medium differs from first e.g. as in a contact lens.

✱ *The total vergence power of a spherical lens depends on:*

- The vergence power of each surface.
- The thickness of the lens:
  - A. Thin lenses:
    - The thickness factor may be ignored and the total power of a thin lens is the sum of the two surface powers (Fig. 6.3)
  - B. Thick lenses:
    - Refraction by thick lenses is more complicated.

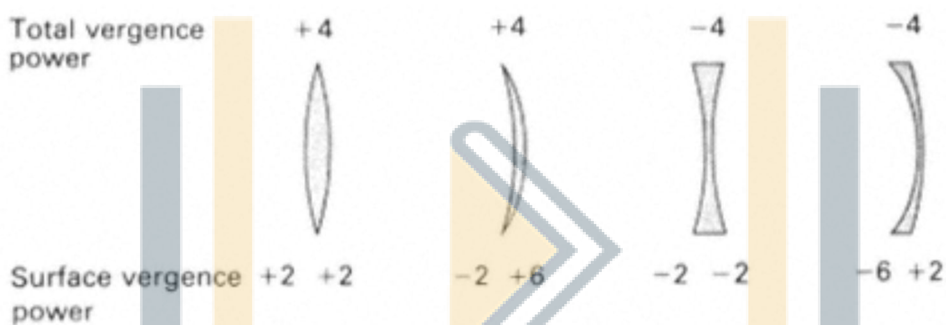


Fig.6.3: Vergence power of a thin lens.

- *The power of convex or concave meniscus: is the sum of the power of the two surfaces.*

➲ *Thin lens formula:*

$$U + P = V$$

Where;

P: power of the lens

U: intial vergence (vergence of light from luminous source)

V: final vergence (vergence of light from the lens)

$$\frac{1}{U} + \frac{1}{f2} = \frac{1}{V}$$

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_2}$$

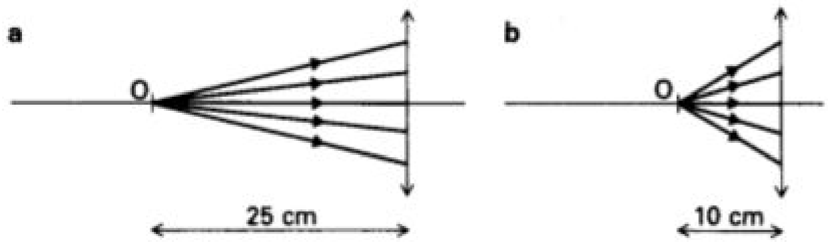
Where, v = Distance of image from principal point N.
u = Distance of object from N.
f_2 = Focal length.

Dioptric power of spherical lenses:

- Lenses of shorter focal length are more powerful than lenses of longer focal length.

$$F = \frac{1}{f_2}$$

Where, F = the vergence power of the lens.
f_2 = the second focal length in metres.



(a) Vergence at the lens. (b) Vergence at the lens

$$= \frac{1}{0.25} = 4 \text{ Dioptres}$$

$$= \frac{1}{0.10} = 10 \text{ Dioptres}$$

⇨ A converging (convex) lens of second focal length +5 cm has a power of:

$$+\frac{1}{0.05} \text{ or } +20 \text{ D.}$$

⇨ A diverging (concave) lens of second focal length -25 cm has a power of:

$$-\frac{1}{0.25} \text{ or } -4 \text{ D.}$$

✱ Vergence:

- A measure of the amount of spreading (or gathering) of a bundle of light rays (wavefront) emerging from (or heading to) a single point OR
- It is the measure of the amount of convergence or divergence of a bundle of light rays coming from or heading to a single point.
- 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;
- → the reciprocal of distance (in meters) to the point at which light rays intersect;
- → the reciprocal of the second focal length of the lens in metres
- → reciprocal of focal length of lens (in meters)
  - Lens: ➔ adds vergence to light (amount of vergence = power of lens [in diopters])

Refraction by spherical lenses:

- A convex lens causes convergence of incident light while a concave lens causes divergence of incident light (Fig.6.2).

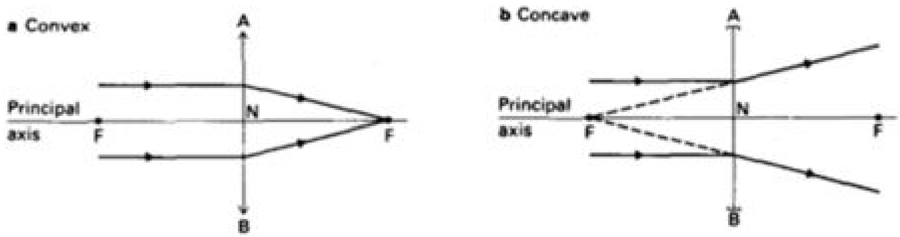


Fig. 6.2 Light passing through a lens obeys Snell's law at each surface.
(a) Convex lens; (b) concave lens.

Construction of the image by spherical lenses:

Diagrammatic construction of image using two rays (Fig. 6.7):

A. A ray parallel to the principal axis which after refraction passes either:
   - Through F_2 of a convex lens; or
   - Away from F_2 of a concave lens.

B. A ray from the top of the object: Which passes through the principal point undeviated.

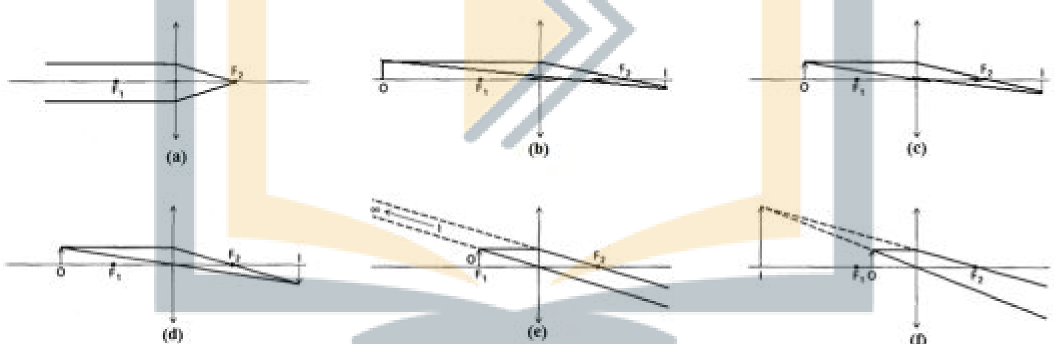


Table 6.1: Image formation by a convex lens.

Site of object on the principal axis:	Image			
	Nature	Position	Site	Magnification
(a) At ∞:			At F.	
(b) Outside 2 F:	Real.	Inverted.	Between 2F and F.	Diminished.
(c) At 2 F:	Real.	Inverted.	At2F.	Same size.
(d) Between 2F and F:	Real.	Inverted.	Outside 2F.	Enlarged.
(e) At F:			At ∞	
(f) Inside F:	Virtual.	Erect.		Enlarged.

- N.B: 2F in the lens = C in mirrors.

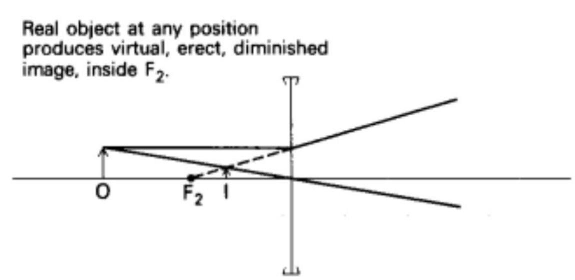
➔ *The image formation by a convex lens:*

✓ The characteristics of the image depend on the distance of the object situated on the principal axis, from the lens as seen in table 6.1 and Fig. 6.7.

➔ *The Image formation by a concave lens:*

☑ If the object is at ∞, the image is at F.

☑ If the object is at any finite distance on the principal axis of the lens: The image is virtual, erect, diminished and inside F_2 .



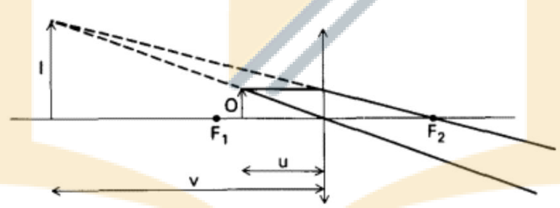
Magnification of a convex lens:

A. Linear magnification:

- *Definition:*
  - It is the ratio of the image height to the object height with measurements perpendicular to the optic axis (it is equivalent to the ratio of image distance to object distance).
- *Application:*
  - Linear magnification is applicable to lens and lens systems used in image formation as in cameras, projectors and other instruments not used directly in conjunction with the eye.
- *Calculation :*
  - Linear magnification is calculated from the formula (Fig.6.10):

$$M = \frac{I}{O} = \frac{v}{u}$$

Where, M = the linear magnification.
I = the image size.
O = the object size (object within the focal length of convex lens).
v =the distance of the image from the principal plane.u = the distance of the object from the principal plane.



B. Angular magnification:

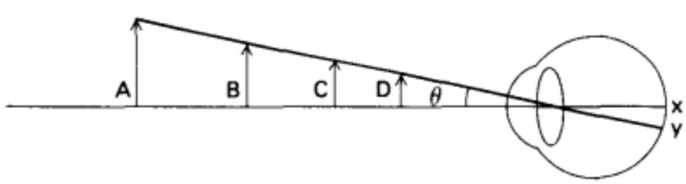
- The angle subtended at the eye is more important than the actual image and object size (because the angle subtended governs the retinal image size).

- *Application:*
  - Angular magnification is considered when a lens or an optical system (as the magnifying lens) is used in conjunction with the eye.
    (Because the angle subtended at the eye is more important than the actual image and object size).

  - It is the ratio of;

    Image seen by the eye with the optical system to
    Image seen by the eye without the optical system at a distance 25 cm from the eye.

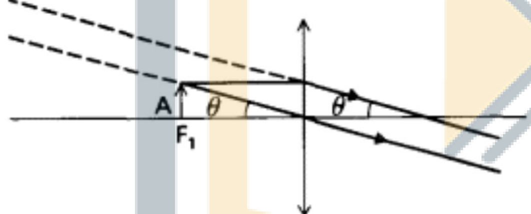
- *Principles:*
  A. *Angular or apparent size of objects:*



- Figure shows that objects A, B, C and D all subtend a same visual angle θ at the eye and produce a retinal image xy. ➔ They are all therefore of identical apparent size
  - Apparent size is given by the ratio of object or image size divided by its distance from the eye i.e. tan θ.
  - When considering the eye, the angles encountered are small. thus the value of tan θ can be taken to be equal to the angles themselves

B. *Angular magnification of a convex lens (loupe):*

- When the object is at the first principal focus of a convex lens, the image will be at infinity (Fig.6.12).
- The object and its infinitely distant image ➔ subtend the same angle **θ** at the convex lens and also at the eye if the eye is brought very close to the lens.



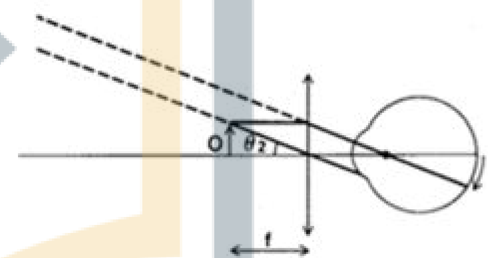


Fig.6.12: Image formation of a convex lens.

- The angular magnification is therefore unity i.e. apparent object size and apparent image size are the same.

- The magnifying power (M) of the convex lens can be calculated from: (Fig 6.13)

$$\text{Magnifying power} = \frac{\text{Apparent size of image}}{\text{Apparent size of object at 25 cm from the eye}}$$

OR

$$\frac{\text{Angle subtended by the image at the eye seen through the lens}}{\text{Angle subtended by the object at the eye seen without the lens at 25 cm from the eye}}$$

- Alternatively:

$$\text{Magnifying power, } M, = \frac{\tan\theta_2}{\tan\theta_1}$$

But:

$$\tan \theta_1 = \frac{O}{25}$$

And:

$$\tan \theta_2 = \frac{O}{f}$$

Thus:

$$M = \frac{O}{f} \times \frac{25}{O}$$

$$= \frac{25}{f}$$

But 25 cm = ¼ m, and = F dioptres, where F is the power of the lens in dioptres:

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

- Thus, the commonly used 8× loupe has a lens power of +32 dioptres.

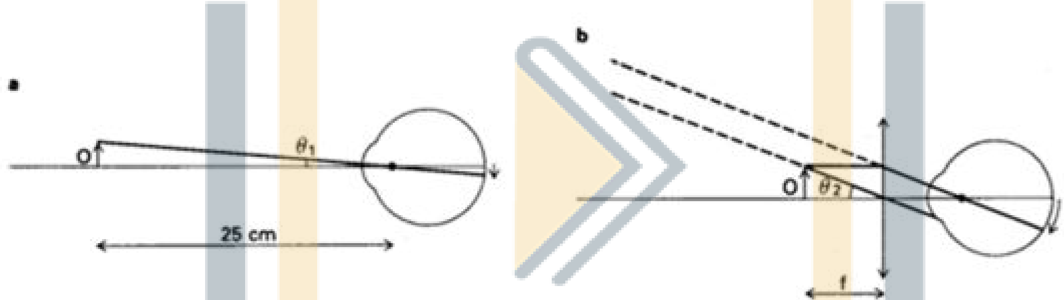
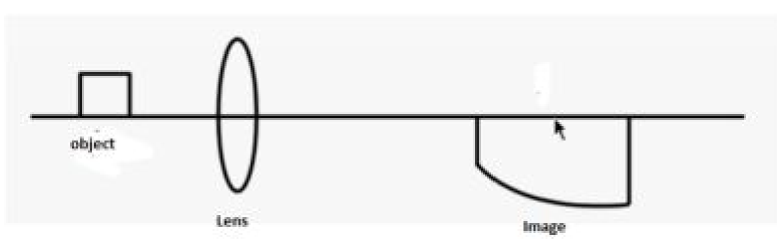


Fig. 6.13 The simple magnifying glass (the loupe). (a) Object viewed at near point of unaided eye, 25 cm, subtends angle θ_1 at the eye. (b) Object viewed close to the eye through a convex lens, with object at first principal focus of convex lens. Object and image subtend angle θ_2 at the eye.

- The magnifying power is increased by:
  - Occurs if the object moves closer to the eye (i.e. inside F1)
    1. *Additional angular magnification:*
       - Occurs if a second convex lens is placed between the object (which is brought closer to the eye) and the eye.
    2. *Total angular magnification:*
       - Equals the first magnification multiplied by the second additional magnification (M = M1 M2).

C. Axial magnification

- It is magnification in depth (i.e. magnification along the axis)
- Is the square of transverse magnification between any 2 conjugate points
- It causes distortion of the 3D images (e.g. In BIO)
  - Construction:
    - instead of using an arrow as an object ➔ we use a square
    - If the height of the image is twice ➔ then the depth (2^2) is 4 times and ➔ this causes distortion



Spherical lens decentration and prism power:

✱ Definition:

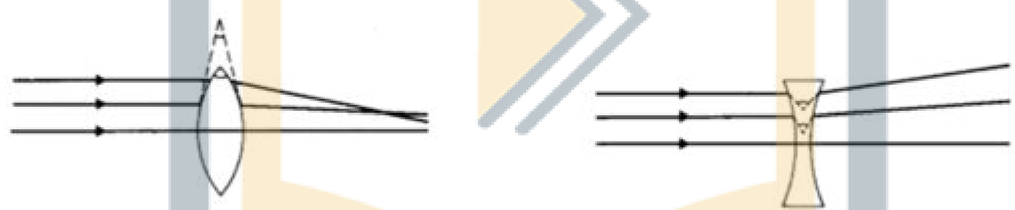
- The use of non-axial portion of the lens to gain a prismatic effect.

✱ Indication:

1. convergence insufficiency e.g.
   1. Old presbyobe
   2. High myope
2. Convergence excess.
3. In asymmetrical eyes:
   - ⇨ We bring the optical center to coincide with visual axis of each eye separately.

✱ The prismatic effect of a spherical lens:

- light rays passing through the peripheral portion of the lens is deviated more than those passing through its axial zone.
  - ☛ Therefore, the peripheral portion of the lens acts as a prism.
- The refracting angle grows larger as the edge of the lens is approached (Fig. 6.14).
  - ☛ Therefore, the prismatic effect increases towards the periphery of the lens.



(a)Convex lens (b) concave tens

Fig. 6.14. Prismatic deviation by spherical lenses.

✱ The prismatic power gained by decentration of a spherical lens (Prentice`s rule):

➔ Prentice`s rule: AT any point of spherical lens there is a prismatic effect except at the optical center

⇨ The prismatic effect is 1 Δ➔ for every 1 cm decentration per 1D lens power

$$\frac{P}{h} = \frac{100}{100/D} = \text{(Similar triangles). So, } P = D \times h$$

Where, P = the prismatic power in prism dioptres.

D = the lens power in dioptres.

h = the decentration (distance from the optical centre) in centimetres.

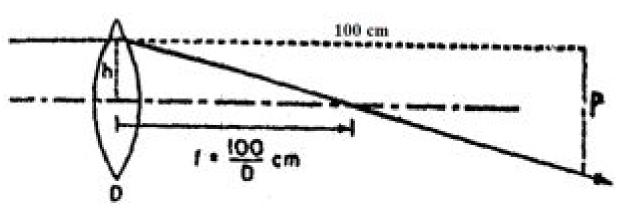


Fig. 6.15: Prentice's rule.

- ☑ The increasing prismatic power of the more peripheral parts of a spherical lens is ➔ the underlying mechanism of spherical aberration.
- ☑ Furthermore, it causes the troublesome ring scotoma and jack-in-the-box effect in high-power spectacle lenses.

✱ Method of Decentration:

- Decentering the whole frame (by changing the lens of the nasal side).
- Decentering the lens within the frame (better).

✱ *Fresnel lens:*

- Definition:
  - ➔ A thin flexible plastic membrane with concentric ridges on its surface forming a series of tiny prisms of increasing power from the axis to the periphery and is made of polyvinyl chloride (PVC).

- Optical principles:
  - ✓ *Fresnel principle is based on:*
    - Removal of the non-refracting portions of a conventional lens (as in Fresnel prism principle).
  - ✓ *The angle between the surfaces:*
    - Is considered as a series of tiny prisms of increasing apical (refracting) angle as one moves from the optical centre of the surface to the periphery (not the same as in Fresnel prism).
  - ✓ *Fresnel lens can be imagined to be a series of flat ridges in* the form of concentric rings on a surface
    - To form a thin membrane.
  - ✓ *Fresnel lenses are designed for in-office application and removal:* The same as in Fresnel prisms (chapter 5).

- Advantages:
  - As in Fresnel prism but Fresnel lens, powers are up to 20 D.

- Disadvantages:
  - As in Fresnel prism.

- Indications (uses):
  1. *Correction of spherical refractive errors:*
     - ✓ Permanent use: For high spherical errors.
     - ✓ Temporary use: For postoperative aphakia, transient ametropia and progressive myopia.
  2. *Underwater diving masks and gas masks:* To which the spherical equivalent of the refractive error is applied in a Fresnel lens.
  3. *Localized use in spectacle:* ➔ *bifocal segments in* presbyopes and in low vision aids.

(2) ASTIGMATIC LENSES:

Definition:

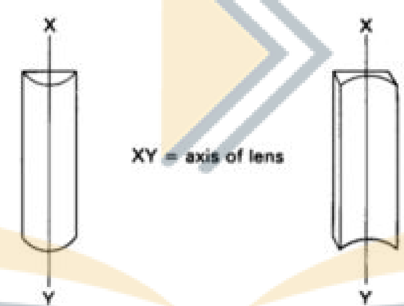
- An astigmatic lens is a lens in which all meridians do not have the same curvature and a point image of a point object cannot be formed.

Types of astigmatic lenses:

A. Cylindrical lenses

- Surfaces of a cylindrical lens: These lenses have one plane surface and the other forms part of a cylinder:
  - ✓ *The convex cylinder:* Is a part of a cylinder of glass cut parallel to its axis.
  - ✓ *The concave cylinder:* Is taken from a mould of a cylinder.

- The axis of the cylinder:
  - ➔ It is the meridian in which the lens has no vergence power (acts as a parallel plate of glass) and is parallel to that of the lens from which it is taken.



(a)Convex cylinder. (b)Concave cylinder

- Formation of a line image (focal line) for a point object: (Fig 6.17)
  - In the meridian perpendicular to the axis, ➔ the cylinder acts as a spherical lens while
  - In the meridian at parallel to the axis ➔ there is no vergence power.
    - Thus, a focal line (line image) is the image of a point object formed by a cylindrical lens and it is parallel to the axis of the cylinder and as a result, no distinct image is formed.
    - Maddox rod is a high powered cylindrical lens.

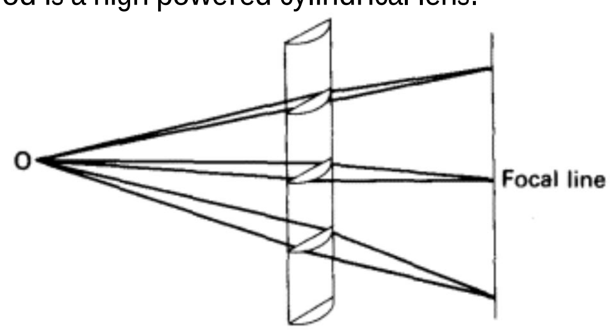


Fig. 6.17 Image formation by convex cylindrical lens of point object, O.

B. Toric lenses:

✱ *Toric surface:*

- *Definition:*
  - It is a surface formed by bending of a cylindrical surface so that the axis becomes an arc of a circle and the resulted surface will be curved in both horizontal and vertical meridians, but not to the same extent.

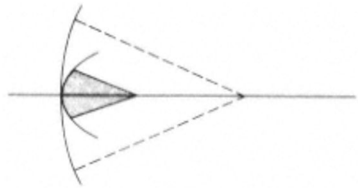
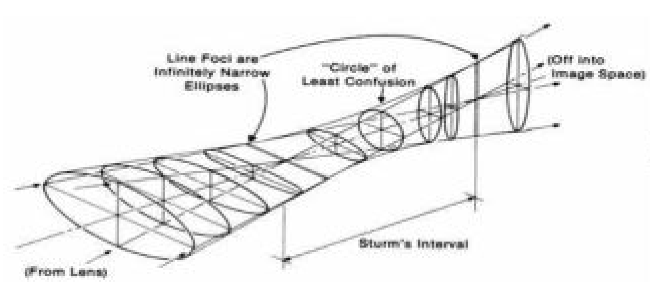


Fig. 6.18 Toric surface.
Principal meridians.with radii and centres of curvature

- *Principal meridians:*
  - These are the meridians of maximum and minimum curvature which are at 90° to each other in ophthalmoptic lenses.
- *The base curve:*
  - Is the principal meridian of minimum curvature and so of minimum power.

✱ *Toric lens (sphero-cylindrical lens):*

- Definition:
  - ☑ It is a lens with one toric surface.
- Image formed by a toric lens (Fig 6.19):
  - ☑ A toric lens does not produce a single defined image:
    - Because the principal meridians form separate line foci at right angles to each other.
  - ☑ Sturm 's conoid:
    - Is the figure formed by the rays of light between the two line foci.
    - It is 3D envelop of light rays formed by an astigmatic lens acting upon the rays of light from a point object.
  - ☑ Interval of Sturm:
    - Is the distance between the two line foci.
  - ☑ The circle of least diffusion:
    - Is the plane lying dioptrically between the 2 focal lines where the two pencils of light intersect (it is also called the circle of least confusion).



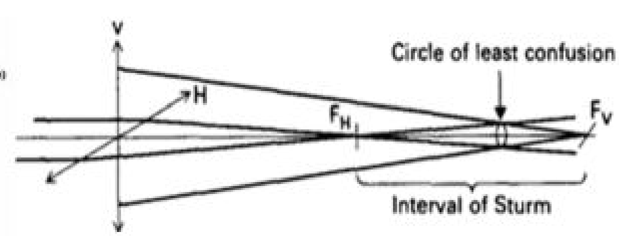


Image formed by toric astigmatic lens

- Clinical application of conoid:
    1. Image seen by astigmatic corneal surface
    2. Oblique astigmatism (as part of peripheral aberration)
    3. Cross cylinder
    4. Fogging method of refraction
    5. Spherical equivalent of spectacle prescriptions.

➔ Sphero-cylindrical fraction:

- A toric lens (sphero-cylinder lens) can be thought of as a spherical lens with a cylindrical lens superimposed upon it and so can be defined numerically as a fraction.
    - ★ For example, a toric lens with a power of +2 D in one principal meridian and +4 D in the other principal meridian can be regarded as a +2 D sphere with a +2 D cylinder superimposed. This is therefore written as +2.0 DS/+2.0 DC.

✱ Cross cylinder:

☛ *Is a Sphero-cylindrical lens (i.e. a type of a toric lens) with:*

- The power of the cylinder is twice the power or the sphere and of the opposite sign (Chapter 16).
- Addition of a cross cylinder can increase the conoid of Sturm and so decrease the visual acuity (or the reverse).

✱ *Spherical Equivalent:*

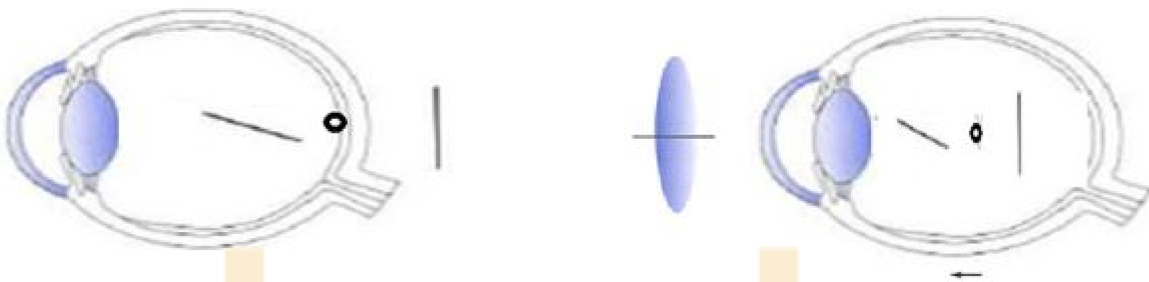
⟲ A spherical power whose focal point coincide with the circle of least confusion of a spherocylinderical lens.

- ❖ This reveals whether the eye is essentially hypermetropic, emmetropic or myopic.
- ❖ This consideration is especially important in the choice of intraocular lens power for the individual patient.
- ❖ The *spherical equivalent* power is calculated from the toric lens prescription by algebraic addition of the spherical power and half the cylindrical power, e.g. the spherical equivalent of +2.00 DS/+2.00 DC is +3.00 DS, while that of +2.00 DS/–2.00 DC is +1.00 DS.

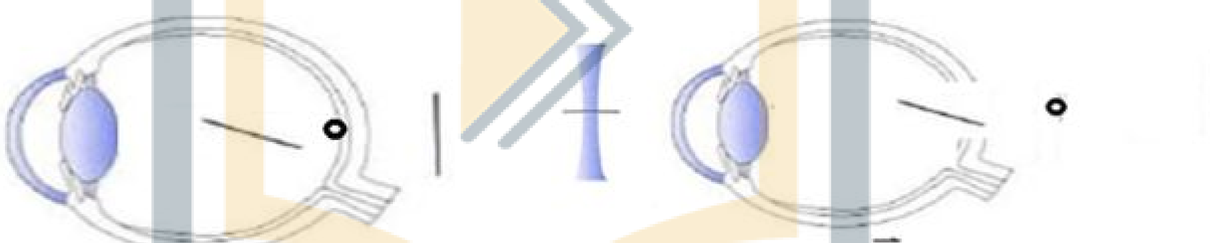
- Uses:
    1. Choice of IOL
    2. Fitting of contact lens
    3. Cross cylinder

Effect of Lenses on conoid

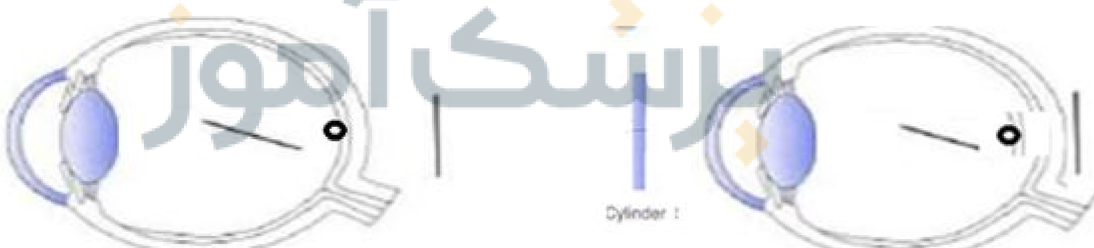
1. Plus lens:
    1. Move the entire conoid toward the lens &
    2. Decrease the interval of sturm



2. Minus Lens:
    1. Move the entire conoid away from the lens
    2. increase the interval of sturm

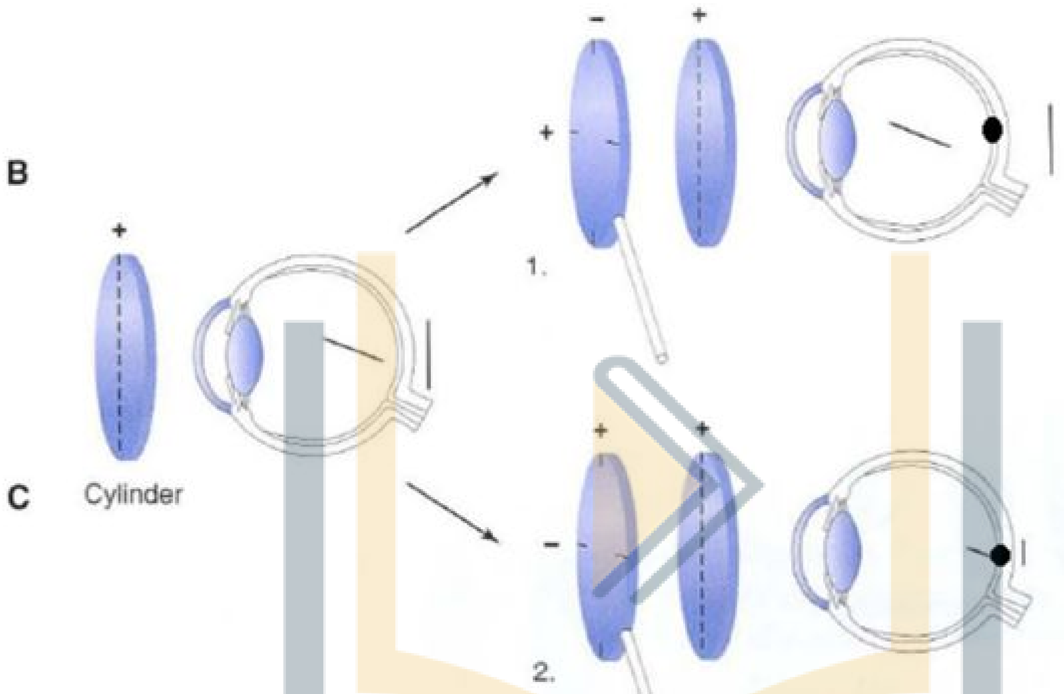


3. Cylinderical lens:
    - A. Plus Cylinder (Axis 90)
        - Affect the focal line that is parallel to its Axis & the circle of least confusion (i.e. moves the vertical line and the circle of least confusion closer to the lens)

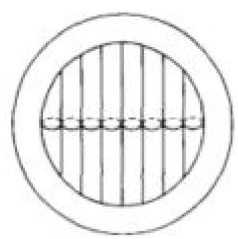


    - B. Minus Cylinder (Axis 180):
        - Affect the focal line that is parallel to its Axis & the circle of least confusion (i.e. moves the vertical line and the circle of least confusion away from to the lens)

4. Cross Cylinder:
Increase or decrease the interval of strum but the location of circle of least confusion remain unchanged
(i.e. increase or decrease the amount of cylinder but the spherical equivlant remain unchanged)

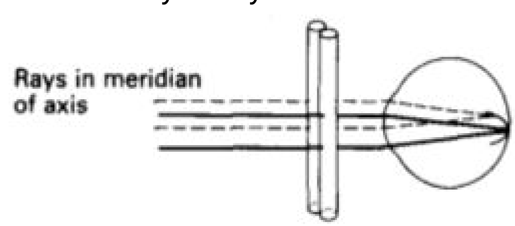


The Maddox rod:



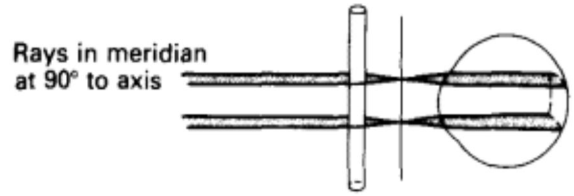
- *The Maddox rod:* Consists of a series of red powerful convex cylindrical lenses of glass placed side by side in a trial lens.

- *Principle of the Maddox rod:*
- *The Maddox rod acts by dissociating the images in the two eyes by changing the shape of one image as follows:*
  - The patient views a distant white point source of light through the Maddox rod which is placed in the trial frame.
    - Light in the meridian parallel to the axis of each cylinder:
      - It passes through undeviated and is brought to a focus by the eye into a focal line of light which lies at 90 to the axis of the Maddox rod.



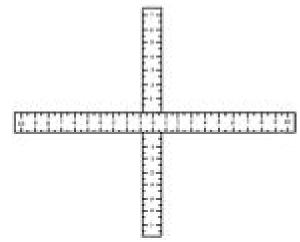
    - Light incident on Maddox rod in the meridian at 90° to its axis:
      - It is converged by each cylinder to a real line focus (real image) between the rod and the eye .

- This focus is too close to the eye for a distinct image to be formed on the retina (as this light is scattered over a wide area of the retina).



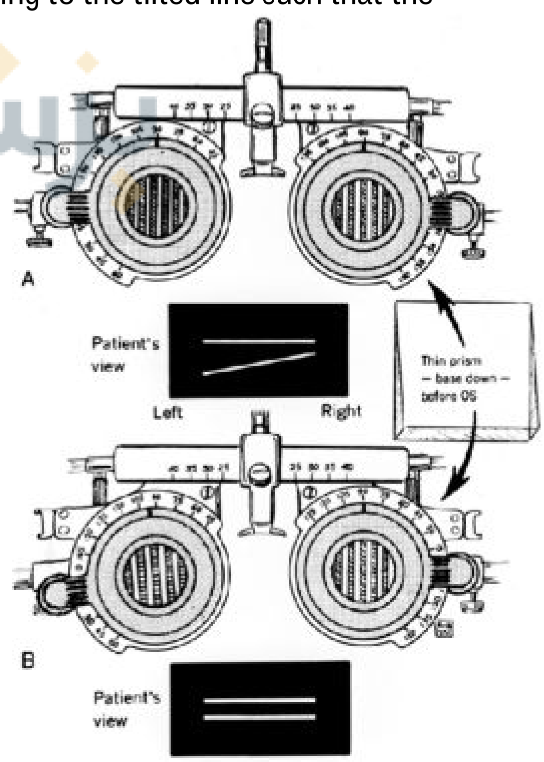
- *Indications:*

1- To test the muscle balance for distant vision.
2- Orthoptic exercises.
3- *Measurement of the angle of deviation:*
   A. *Maddox rod with a graduated tangent scale of Maddox.*
   B. *Maddox rod with prisms before the left eye.*



4- *The Maddox hand frame:*
   - It consists of a Maddox rod placed in front of right eye, and a rotating prism 10 Δ in front of left eye.
   - The prism is rotated until the red line traverses the white spot light.

✱ Double Maddox rods :
- Is done for the diagnosis of cyclotropia or torsional squint.
- Two Maddox rods, one red and the other white, are placed in front of the two eyes with the axes vertically.
- A 4D base-down prism is placed in front of one of the rods to displace one of the lines upwards. A patient without any cyclotropia will see two parallel lines one above the other.
- Patient with cyclotropia will see one horizontal line and one tilted line. He is then instructed to rotate the Maddox rod corresponding to the tilted line such that the two lines become parallel to each-other.
- The axis of this rod gives the degree of cyclo-deviation.



Optics of the Human Eye

- The thin lens formula is inadequate to deal with the refracting system of the eye,
  - ➪ Because the thin lens formula ignores lens thickness and considers refraction only at the two lens surfaces while the eye is composed of a number of refracting surfaces separated by relatively long distances.

- The Thick lens formula (refraction by thick lenses) can be directly applied to the eye.

✱ <u>Thick Lens Theory</u> (Gauss and Listing theory)

- It suggested the theoretical construction of the cardinal points and planes to permit the use of ray tracing procedures in thick lenses
  - At first, Gauss suggested the presence of two pairs of cardinal points (two principal points and two focal points).
  - Listing added another pair of cardinal points (two nodal points).

Cardinal Points

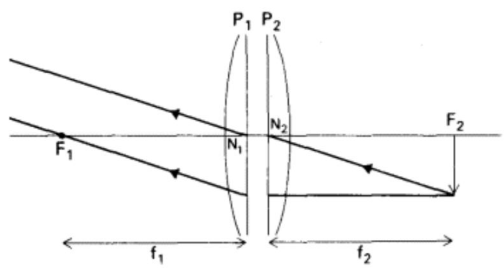
- The full mathematical analysis of refraction by a thick lens is very complex. It has been simplified by the introduction of the concept of principal points and principal planes.

Two principal points (first principal point P_1 and second principal point P_2):

- Both P1 and P2 correspond to conjugate foci of a simple lens and are such that an incident ray passing through the first principal plane of P_1 will pass through the second principal plane of P_2 at the same vertical distance from the optic axis (but the incident and emergent rays are not necessarily parallel).

Two principal planes through P_1 and P_2:

- <u>First principal plane:</u> Is a perpendicular plane on the optic axis at P_1.
- <u>Second principal plane:</u> Is a perpendicular plane on the optic axis at P_2.



- ➪ The exact position of the principal point is calculated from
    - o the curvatures of the lens surfaces,
    - o the lens thickness and
    - o The refractive index of the lens material.

- There are two further points, the nodal points, N1 and N2, which correspond to the centre of a thin lens.

    - ➪ Any ray directed towards the first nodal point, N1, leaves the lens as if from the second nodal point, N2, and parallel with its original direction, i.e. undeviated.

    - ➪ When the medium on both sides of the thick lens is the same, the nodal points coincide with the principal points. When the media on opposite sides of the lens are different, the nodal points do not coincide with the principal points.

- The principal foci, F1 and F2, have the same meaning as for a thin lens, the focal lengths, f1 and f2, being measured from the principal points.

⟲ Applications of Gauss and Listing theory:

1. *A thick lens:* With greater separation of the two refracting surfaces by the lens substance.
2. *A compound homocentric system of lenses:* With relatively long distances between the lenses.
3. *The dioptric system of the eye:* With a number of coaxial spherical refracting surfaces separated by relatively long distances.

The compound homocentric system of lenses

1. Cardinal points of the system:

    1. *Two principal foci F_1 and F_2:*
        - Anterior principal focus F1: Is the meeting of parallel rays emerging from the system
        - Posterior principal focus F2: Is the meeting of parallel rays entering the system.

    2. *Two principal points (first principal point P_1 and second principal point P_2):*
        - See above

    3. *Two nodal points (first nodal paint N_1 and second nodal point N_2):*
        - See above.

2. Planes of the system:

    1. *Two focal planes through F_1 and F_2:*
        - Anterior focal plane: Is a perpendicular plane on the optic axis at F_1.
        - Posterior focal plane: Is a perpendicular plane on the optic axis at F_2.
    2. *Two principal planes through P_1 and P_2:*
        - See above.

3. Focal distances of the system:
    - *See above.*

4. Conjugate distances of the system:

- *Correlation between conjugate distances l1 and l2 and focal distances f1 and f2:*

  $l_1 l_2 = f_1 f_2$ (Newton law).

- *Correlation between conjugate distances (P_1 & P_2) and focal distances (f_1 & f_2):*

  $f_1 / p_1 + f_2 / p_2 = 1$

Refraction by the Eye

- There are three major refracting interfaces to be considered in the eye, the anterior corneal surface and the two surfaces of the lens.
  - The effect of the posterior corneal surface is very small compared with these three as the difference in refractive index between corneal stroma and aqueous is not large

Table 9.1 Refractive indices of the transparent media of the eye (Gullstrand).

Air	1.000
Cornea	1.376
Aqueous humour	1.336
Lens (cortex-core)	1.386–1.406
Vitreous humour	1.336

- In order to calculate the cardinal points, the radii of curvature, and distances separating the refracting surfaces must also be known.
  - These have been determined experimentally by several observers..
  - The results of Gullstrand are given here (Tables 9.1, 9.2, 9.3) (the schematic and reduced eye is based on the given calculations).

The optical constants of the eye are the ➔ indices of refraction, the radii of curvature and the distances between the refractive surfaces of the eye.

Table 9.2 Position of refracting surfaces of the eye (in mm behind anterior corneal surface) (Gullstrand).

Cornea, anterior surface	0
Cornea, posterior surface	0.5
Lens, anterior surface	3.6
Lens, posterior surface	7.2
Lens core, anterior surface	4.146*
Lens core, posterior surface	6.565*

Table 9.3 Radii of curvature of refracting surfaces of the eye (in mm) (Gullstrand).

Cornea, anterior surface	7.7
Cornea, posterior surface	6.8
Lens, anterior surface	10.0
Lens, posterior surface	–6.0
Lens core, anterior surface	7.911*
Lens core, posterior surface	–5.76*

✱ Refractive power of the eye:

- Total refractive power of the phakic eye 58.6 D
- Total refractive power of the aphakic eye 43D this is caused by
    - ➜ Anterior corneal surface 48.8D
    - ➜ Posterior corneal surface – 5.8 D.
        - ➪ This account for 70% of refractive power of the eye.

- The crystalline lens thus has an effective power in situ of +19.11 D
- The relatively greater power of the cornea is due to the greater difference in refractive index between air (1.000) and cornea (1.376), as compared with aqueous and vitreous humour (1.336) and lens (1.406).
    - ➪ A dramatic example of the importance of the air/cornea interface occurs when a swimmer opens his eyes under water. He finds his vision is blurred. The difference in refractive index between water and cornea is only 0.040 (i.e. cornea 1.376 – water 1.336). This problem is eliminated by the swimmer keeping air in front of the cornea by wearing goggles.

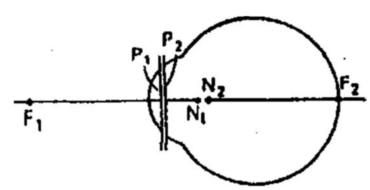
- Centers of curvatures of cornea, ant. And post. Surfaces lens are all in the same line and form the optical axis, image on retina involve.

✪ The Schematic Eye

o Definition:

- A schematic eye is a mathematical construct including the cardinal points of the dioptric system of the eye in which the dimensions and optical properties approximate those of the living human eye.

- The values of the cardinal points of the schematic eye:
    - The cardinal points as described by Gullstrand for the schematic eye (measured in mm behind the anterior corneal surface) are:

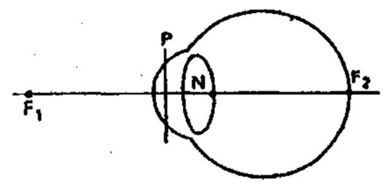


	Accommodation Relaxed	Maximum Accommodation
Corneal system = Aphakic eye		
Refracting power	43.05	43.05
First focal length	–23.227	–23.227
Second focal length	31.031	31.031
Lens system		
Refracting power	19.11	33.06
Focal length	69.908	40.416
Complete optical system of eye		
Refracting power	58.64	70.57
Position of first principal point, *H*	1.348	1.772
Position of second principal point, *H'*	1.602	2.086
Position of first focal point, *F*	–15.707	–12.397
Position of second focal point, *F'*	24.387	21.016
First focal length	–17.055	–14.169
Second focal length	22.785	18.930
Position of first nodal point, *N*	7.078	
Position of second nodal point, *N'*	7.332	
Position of fovea centralis	24.0	24.0
Axial refraction	–1.0	–9.6
Position of near point		–102.3

- Note that the nodal points, via which rays of light pass undeviated (p. 54), are removed from the principal points, which lie at the intersection of the principal planes with the principal axis (Fig. 9.3). This is because the refracting media on each side of the refracting system of the eye are different, namely air (n = 1) and vitreous (n = 1.336).
- The nodal points straddle the posterior pole of the crystalline lens.
- The pupil of the eye allows only a relatively small paraxial pencil of light to enter the eye. Such paraxial rays are refracted and concentrated through the nodal points and adjacent posterior lens substance. Therefore even a small posterior polar cataract produces gross impairment of vision when the pupil is small.

✪ *THE REDUCED EYE:*

- Definition:
  - reduced eye is a mathematical construct in which the eye is treated as a single ideal curved refracting surface having:
    - One nodal point, one principal point and two focal points.
    - An air medium in front (refractive index 1) and a water medium (aqueous humour with refractive index 1.336) behind.



- Ophthalmoptic properties:

A. *Gullustrand reduced eye:*

- The values of the cardinal points of the Gullustrand reduced eye (measured in mm behind the anterior corneal surface):

Principal point P	1.35
Nodal point N	7.08
First focal point F1	–15.7
Second focal point F2	24.13

- Radius of curvature of ideal spherical surface r: 5.73 mm (7.08—1.35).
- The focal lengths (measured from the principal points) are:
  - ➜ First focal length f1 = -17.05 mm. [-15.70 + (-1.35)].
  - ➜ Second focal length f2 = 22.75 mm [24.10 + (-1.35)].
- The dioptric power of the reduced eye (D): is 58.6 D.
- The nodal point N lies:
  - ➜ 5.65 mm (7.00 - 1.35) from the ideal spherical surface.
  - ➜ 17.1 mm (24.1 - 7.0) from f2.

✱ Aphakic eye:

- The cornea is the only refracting element remaining in the aphakic eye.
- The anterior focal length of the aphakic eye was found experimentally to be –23.23 mm (the first focal point lying 21.88 mm in front of the cornea). This gives a calculated power of +43 D for the aphakic eye.

Reduced Eye – Construction of Retinal Image:

- *Construction of the retinal images:* (Fig. 7.7)

  (1) The reduced eye itself is represented by two parallel lines which indicate the principal point P and the retina R:

  a. These two parallel lines intersect principal axis (optical axis) at right angles.
  b. The nodal point (N) is indicated by a point behind the line P.
  c. The anterior principal focus F_1 is indicated by a point in front of the line P.
  d. The posterior principal focus F_2 falls on line R (retina in emmetropic eye).

  (2) Two rays construct the image formed by parallel light incident upon eye:

  ✓ A ray passing through F_1 which after refraction at P, continues parallel to the principal axis.
  ✓ A ray passing through N, undeviated.

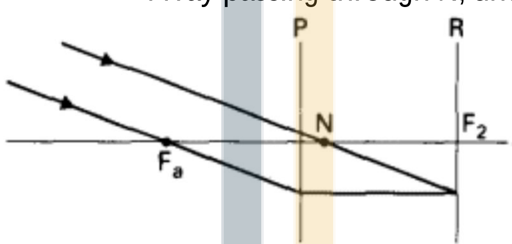


Fig.7.7: Retinal image formation.

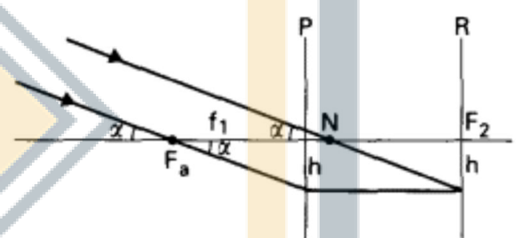


Fig.7.8: Calculation of size of retinal image: 1st method.

- *Calculation of the size of the retinal image:*
  - The size of the retinal image can be calculated from construction of the retinal image by two rays of light incident upon the eye, by one of the following methods:

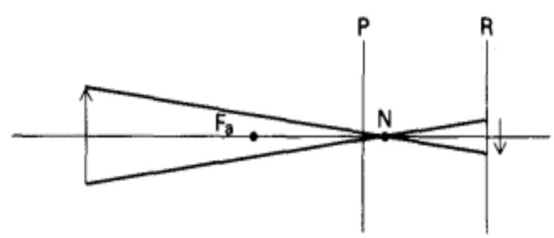
1. First method:

With one ray passing through F_1 and the other, ray passing through N (Fig.7.8):

1- The parallel light subtends angle α at the nodal point N as well as at the anterior principal focus F_1.
2- Therefore, the image size is directly related to the angle subtended by an object at the nodal point which is called the visual angle.

$$\tan \alpha = \frac{I}{f1} \quad \text{so, } I = \tan \alpha \times f1$$

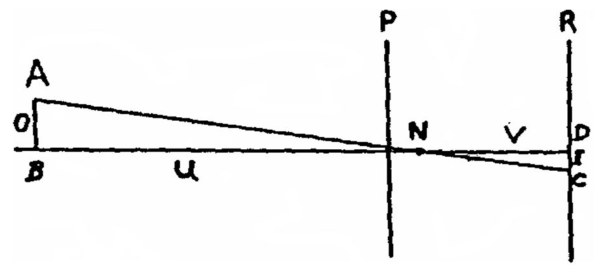
Where: I = the retinal image size.
α = the visual angle.
f1 = the first focal point.



3- As an object of a given size approaches the eye, it subtends a greater visual angle and thus appears larger (Fig. 7.9).

2. Second method:

With both rays passing though N (Fig. 7.10):



1. ABN and CDN are similar:

   As $\frac{I}{O} = \frac{V}{U}$ So, I = O X V / U

   Where: I = the retinal image size.

   O = the known size of the object.

   U =the measurable distance of the object from the eye.

   V = the distance between N and F2 from the reduced eye.

2. The calculation of the retinal image size is important to measure the size of the diseased area of the retina I: Which corresponds to the scotoma O in the field of vision.

➪ <u>*Real and apparent position of iris and size of pupil:*</u>

- Apparent position and size:

  When the iris and the pupil are seen from a less dense medium (air) while they are situated in a denser medium (cornea and aqueous humour) we see:

  a. The apparent position of the iris which appears nearer to the cornea with a shallower anterior chamber.
  b. The apparent size of the pupil which appears larger.

- Iris relation to cornea:

  (1) The iris is placed (between P and F_2): As an object placed behind a lens between its principal point P and its second focal point F_2.
  (2) Therefore, by turning a thin lens into a simple magnifying glass, it produces a pupil image which is virtual, Erect, Magnified and on the same side between the second focal point F2 and the cornea.

- Construction of pupil image (Fig.7.11):

  1) A ray from F2 joining O1 and emerges from cornea parallel to optical axis.
  2) A ray from O1 parallel to the optical axis and comes to a focus at F1.
  3) The two rays are extended backwards to meet at I1 which is the image of O1.
  4) A similar construction for O2 to get I2
  5) Therefore, I1 I2 is the image of the pupil O1 O2 that is between the pupil and the cornea and is larger.

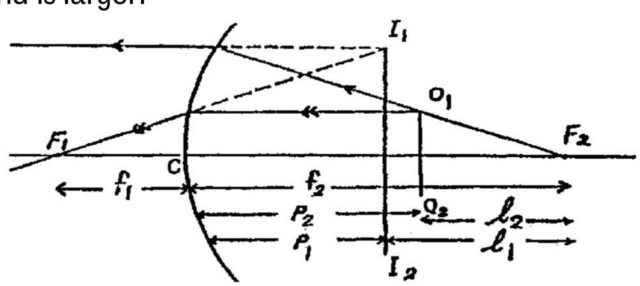


Fig. 7.11 real and apparent position of the iris and size of the pupil.

- Calculation of the position of the iris and the size of the pupil (Fig. 7.11):

A. *The position of the iris (the pupil):*

1- f1 = $\frac{n1r}{n2-n1}$ $and\ f2=\frac{n2r}{n2-n1}$ (chapter 4)
Where: n1 (air) = 1, n2 (aqueous) = 1.336
And r (of anterior surface of cornea) = 7.7
So, f1 = 1 x 7.7 / 1.336 – 1 = 22.91 mm
f2 = 1.33 x 7.7 / 1.336 – 1 = 30.61 = mm
So, f1 of the cornea = 22.91 mm
f2 of the cornea = 30.61 mm

2- $\frac{f1}{p1}+\frac{f2}{p2}=1$ so, $\frac{22.91}{p1}+\frac{30.61}{p2}=1$

3- p2 = real distance of the iris from the anterior corneal surface = 3.5 mm and
So, $\frac{22.91}{p1}+\frac{30.61}{3.5}=1$ and so, p1 =3 and p2 – p1 = 3.5 – 3 = 0.5 m
Therefore, the apparent position of the iris is 0.5 mm nearer to the cornea.

B. *The size of the pupil:*

1. I1 I2 = f1 f2 and M = $\frac{I}{O}=\frac{f2}{I2}=\frac{I1}{f1}$
2. O = real size of the pupil and equals 4 mm, f2= 30.61 mm and I2 = f2 - P2 = 30.61-3.50 =27.11mm.
So, $\frac{I}{4}=\frac{30.61}{27.11}$ so, I = 4.5 mm and I- O = 4.5 – 4 = 0.5 mm
Therefore, the apparent size of the pupil is larger by 0.5 mm

Definitions of terms of refracting system of eye

- The optic axis:
  It is the line upon which the various refracting surfaces of the eye are centred (ANB.)

- The visual line:
  6) Line joining the fovea, nodal point and object of regard (ONM in Fig. 7.14).
  7) It is 5° nasal to and 4° above the optic axis at the cornea.

- The nodal point (N in Fig.7.14):
  1- It lies upon the optic axis and is placed 7 mm behind the apex of the cornea.
  2- It is the point of intersection of the optic axis and the visual line.
  3- So all light rays entering the eye pass through it.
  4- It corresponds to the centre of a thin lens and lies near the posterior pole of the crystalline lens.
  5- A small paraxial pencil of light enters the pupil and is refracted through the nodal point (so a small posterior cortical cataract produces gross impairment of vision when the pupil is small).

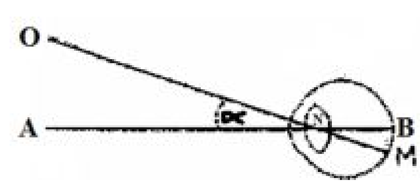
- The fixation axis:
  It the line joining the centre of rotation of the eye and the object of regard (OC in Fig.7.15).

- The centre of rotation of the eye:
  ✓ It is the point along which the eye rotates.
  ✓ It lies on the optic axis and is 12-13 mm behind the apex of the cornea in an emmetropic eye (C in Fig. 7.15).
  ✓ It coincides with geometrical centre of curvature of posterior part of globe.

- The central pupillary line:
  1. A normal to Cornea passing through centre of pupil (APNB in Fig. 7.16).
  2. It cuts the optic axis at the centre of curvature of the cornea i.e. 8 mm behind the apex of the cornea.
  3. It cuts the cornea slightly to the nasal side of the optic axis.

- Angle alpha (Fig. 7.14):
  i. <u>*Definition:*</u> it is the angle between optic axis and visual line at the nodal point.
     - The visual angle is the angle of the two extremities of the object at the nodal point: so visual angle differs from angle alpha (Chapter13).
     - Distance between the fovea and the optic axis=1.25 mm in an emmetropic eye.

  ii. <u>*Measurement of angle alpha*</u> (Fig. 7.17):
  MN= Distance between the retina and nodal point = 15 mm from reduced eye.



SO, Sin angle alpha = $\frac{MB}{MN} = \frac{1.25}{15}$ = Sin 5° (from tables).

Therefore, angle alpha = 5° in an emmetropic eye.

iii. *Importance of angle alpha:*

I. *Abnormal angle alpha occurs in ametropia and leads to pseudo-strabismus:*

a. Angle alpha of more than 5°: in hypermetropia and leads to pseudo-exotropia.

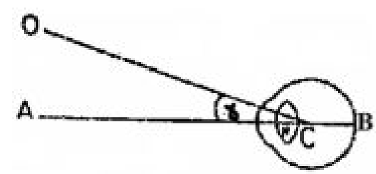
b. Angle alpha of less than 5° or even -ve angle: in myopia and leads to pssudo-esotropia.

II. *In positive angle alpha:* Visual axis cuts cornea on nasal side of optic axis.

III. *In negative angle alpha:* The visual axis cuts the cornea on the temporal side of the optic axis because the posterior pole of the eye becomes on the temporal side of the macula due to changes in the posterior portion of the ocular coats in high myopia.

- Angle gamma:

➪ Angle between the optic axis and the fixation axis (In Fig. 7.15 with the optic axis ANB, fixation axis OC, centre of rotation C and nodal point N).

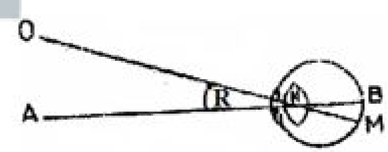


- Angle kappa:

A. Definition:

➪ Angle between the central pupillary line and visual line (In Fig. 7.16 with the central pupillary line APNB, centre of the pupil P, visual line APNB and nodal point N).

B. Measurement of angle kappa:



(1) *By the synoptophore (Fig.7.18):*

1) A slide with a row of numbers and letters at one degree intervals (e.g. E D C B A O 1 2 3 4 5) is placed in front of the patient's eye who looks to O:

   - If the corneal reflex is seen nasal to the pupil, the angle kappa is +ve.
   - If the corneal reflex is seen temporal to the pupil, the angle kappa is -vet.

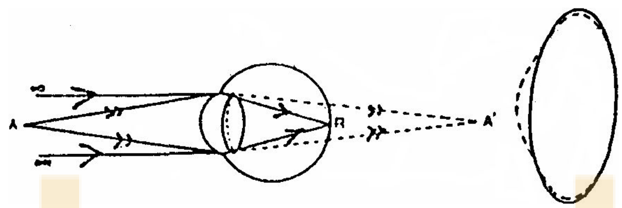
2) So, the angle as ACP which is a little greater than angle kappa, ANP,

(2) *By the perimeter Obsolete nowadays.*

ACCOMMODATION

✱ *Definition:*

- *It is the ability of the eye to change (increase) its dioptric power to see clearly at different distances.*



(a)Principle. (b)Lens form change.

In an emmetropic eye rays from infinity are focused upon retina R.
When a near object A is looked at, a focus is formed behind the retina.
In order to bring this focus forwards to R, the lens increases its convexity with an increase in its dioptric power as illustrated by accommodation.

✱ *Types of accommodation:*

- *Physical accommodation:*
    - It is accommodation related to a physical change of the curvature of the lens
    - it is measured in dioptres (an increase in the converging power of the eye by 1 D leads to exertion of 1 D accommodation).
- *Physiological accommodation:*
    - It is accommodation related to the contractile power of the ciliary muscle
    - It is measured in myodioptres.

✱ *Mechanism of accommodation*

1. *Relaxation theory (Young-Helmholtsz theory):*
    1. The lens is held suspended under tension by the suspensory ligament which attaches it to the ring of the ciliary muscle.
    2. When the ciliary muscle contraction ➔ reduction of the tension on the suspensory ligament and the lens, ➔ allowing the lens to assume a more globular shape ➔ the dioptric power is increased.
    3. Most of the changes in the curvature occur at the anterior lens surface, which moves forwards slightly towards the cornea.
2. *Tschering theory:*
3. *Schachar's theory:*
4. *Cotenary theory:*

✱ Far point of distinct vision (punctum remotum, r) = (Far point of accommodation):

- It is farthest point from eye where objects are clearly seen with accommodation at rest.
- Conjugate focus with retina with accommodation at rest.
    - It is at infinity in emmetropic eye theoretically (but at 6 metres practically).

✱ Near point of distinct vision (Punctum proximum, p) = (Near point of accommodation):

- It is nearest point from eye where objects are clearly seen with maximum accommodation.
- Conjugate focus with retina with accommodation at maximum.

✪ It is variable with age as follows :

- Until 10 years age =7 cm.
- At 35 years = 14 cm.
- At 45 years = 25 cm.
- At 60 years = 100 cm.

☛ It doesn't become symptomatic until near point recedes to a point beyond comfortable reading distance.

✪ *Measurement of the near point of accommodation:*

- *The eye is emmetropic or rendered E (with correcting lenses) at first:*

1. Dynamic retinoscopy: Chapter 14.
2. The card test:
   - The patient approximate the card to his eyes until the letters appear blurred (but not doubled).
3. The strongest concave lens test:
   - The focal length (in cm) of the strongest concave lens that the eye overcome its effect by accommodation and still see clearly (6/6).
4. The Scheiner's experiment:
   - Look at a pin's head through two small holes in a card (with a distance between these two holes less than the pupil diameter), until ➔ a single blurred image of the pin's head is seen which is the near point of accommodation.

✱ Range of accommodation:

- It is the distance between the far point and the near point of distinct vision, over which accommodation is effective.

✱ Amplitude of accommodation, A:

- *Is the difference between the dioptric power of*
  - *the fully accommodated eye (at near point) and*
  - *the eye at rest (at far point)*

❑ Dioptric power of resting eye (with atropine) is called ➔ *static refraction*.
❑ Dioptric power of accommodated eye (without atropine) is ➔ *dynamic refraction*.

✪ *The formula of the amplitude of accommodation:*

$$A = P - R$$

Where A is the amplitude of accommodation in dioptres
P is the dioptric value of the near point distance; and
R is the dioptric value of the far point distance.

P = is the reciprocal of the near point distance-p-in-metres: P=1/p.
R = is the reciprocal of the far point distance-r-in metres: R=l/r.

- To calculate the accommodative power required to focus an intermediate point within the range of accommodation the formula is amended to

$$A = V - R$$

Where A is, the accommodative power required, in dioptres;
V is the dioptric value of the intermediate point;
R is the dioptric value of the far point (the far point distance in hypermetropia, being behind the eye, carries a negative sign).

- Thus, to focus an object at 1 m, the emmetropic eye must exert one dioptre of accommodative power (A = one – 0).

- *Measurement of amplitude of accommodation (A):*
  - I. Objective:
    1. Retinocopy
       - Dynamic: ➔ the dioptric power of the fully accommodated eye (at near point)
       - Static: ➔ the dioptric power of the eye at rest (at far point)
         ➔ The difference is the amplitude of accommodation.
    2. Refractometer
    3. 3rd and 4th Purkinjie Sanson image
  - II. Subjective
    1. Determine the PP
       1. Card test
       2. Concave lens test
       3. The Scheiner's experiment
       4. Accommodation (Prince's) rule: This combines a reading card with a ruler calibrated in cm and D.
    2. Determine the PR
       - A = !00/PP – 100/PR

• Method of spheres: Summation of the number of strongest concave and convex lens tests for p and r.

- *Measurement of fatigue of accommodation by Ergograph of Berens:*
  - Repeatedly approximating a target to the eye until it becomes blurred.
  - The excursion of the target being recorded automatically on a drum.

- *Amplitude of accommodation in different refraction:*
  1. In emmetropia:
     - *His PR is at infinity*

$$R = \frac{1}{\text{infinity}} = \text{Zero}$$

Thus ➔ A= P - O

So, for emmetropia ➔ A = P for emmetropia.

2. In hypermetropia:
   - *To see far objects:* He exerts an amount of accommodation(R) equal to his hypermetropic error.
   - *To see near objects:* He must add the further amount needed.

p is measured (to get P) and r (to get R) = $\frac{1}{\textit{amount} \text{ of refractive error}}$

3. The amplitude of accommodation in myopia:
   - The myope has his PR in front of his eye.
   - R is equal to the amount of the myopic error.

4. The amplitude of accommodation in astigmatism:
   - Accommodation in the two eyes are equal and simultaneous and so never becomes dissociated (cannot act unequally) in astigmatism →so, astigmatism could not be corrected by accommodation.
     - Accommodation in astigmatism will:
       - Correct the least hypermetropic meridian.
       - Change the emmetropic to a myopic meridian.
       - Change the myopic to a more myopic meridian.
   - Therefore no clear image could be obtained by accommodation in astigmatism → so, eyestrain develops

5. The amplitude of accommodation in anisometropia:
   - Accommodation in the two eyes are equal and simultaneous and so never becomes dissociated as in astigmatism → so, anisometropia could not be corrected with accommodation.

✪ *Variation of the amplitude of accommodation with age:*

- *It declines steadily with age:*
  - Until 10 years of age = 14 D (i.e. near point = 7 cm).
  - At 35 years =7 D (i.e. near point = 14 cm).
  - At 45 years = 4 D (i.e. near point = 25 cm).
  - At 60 years = 1 D (i.e. near point = 100 cm).

✱ *Relative accommodation:*

❖ Definition:

- Is the amount of accommodation that can be exerted or relaxed for a given constant amount of convergence.

❖ Types of relative accommodation:

a. *Positive relative accommodation:*
   - It is the amount of accommodation exerted with a given constant amount of convergence.
   - *The strongest minus lens:* (Placed in front of both eyes) which can be tolerated without blurring of vision.

b. *Negative part of relative accommodation:*

- ➜ It is the amount of accommodation relaxed with a given constant amount of convergence.
- ➜ *The strongest Plus lens:* (Placed in front of both eyes) which can be tolerated without blurring of vision.

❖ Relative range of accommodation:

- It is the distance between the near and the far point of relative accommodation.

❖ Measurement of relative accommodation:

- <u>In emmetropic eye:</u> By the reading test types in front of the eyes at the reading distance of 33 cm (with a constant amount of convergence of 3 m.a.):
  - ✓ *The strongest minus lens:*
    (Placed in front of both eyes) which can be tolerated without blurring of vision ➔ -ve Accommodation
  - ✓ *The strongest Plus lens:*
    (Placed in front of both eyes) which can be tolerated without blurring of vision ➔ +ve Accommodation
- <u>In ametropia:</u> The patient is rendered emmetropic first by glasses.

❖ Relative accommodation in the emmetropic eye:

- ★ *When looking at infinity:* All the relative accommodation is➔ positive.
- ★ *As the eye looks nearer:*
  - ➪ Positive part decreases and
  - ➪ negative part increases.
- ★ *As the near point is reached:* All relative accommodation is➔ negative.

✱ *<u>Reserve accommodation:</u>*

✪ Definition:

- It is the Part of available accommodation that is reserved to avoid straining of the ciliary muscle
- It is usually one third of the available accommodation.

✪ importance:

- ➜ The positive part of relative accommodation should be as large as possible and at least greater than the negative part for comfort of the ciliary muscle and so we must keep one third of the correcting glasses of presbyopia.

✱ *<u>Binocular accommodation:</u>*

✪ When both eyes are used, the accommodation increases due to the Stimulus of act of convergence (this accommodation excess is usually 0.5 D).

✱ *<u>Accommodative Convergence/Accommodation Ratio:</u>*

✪ (AC/A ratio):

- It is the number of prism dioptres of convergence which accompanies each dioptre of accommodation.
- The normal range: for the AC/A ratio is 3:1 to 5:1.

📖 Methods of measurement of AC/A:

1. ***Heterophoria method:*** the more accurate method.
   - This measures the ocular deviation for distance and near with full spectacle correction:

$$AC/A = IPD + (D_d - D_n)/D$$

Where IPD is the interpupillary distance in cm,
D*n* is the ocular deviation for near,
D*d* is the ocular deviation for distance and
D is the near fixation distance in dioptres.
(By convention a positive (+) value denotes an esodeviation and a negative (–) value an exodeviation).

2. ***The gradient method:***
   - which uses a minus lens rather than a near object to stimulate accommodation.

$$AC/A = (D_d - D_n)/D$$

Where D is the power of the minus lens used to induce accommodation.

3. Prsim cover test: at 6 meters and 33 cm
   AC/A = Difference in the convergence power at these 2 distance/ 3

📖 The conditions associated with an abnormally high AC/A ratio:

i. *Convergence excess esotropia:*
   - the eyes are straight for distance but esotropia for near
   - i.e. A larger angle of esotropia for near than for distance.
   - *Convergence excess esotropia may be controlled with:*
     - *Bifocal spectacles*.
     - *If surgery is, appropriate:* recession of both medial recti is effective.

📖 Practical application:

i. Uncorrected 1 D hypermetrope accommodates 1 D for distance but with no convergence effort.
ii. Uncorrected myope converges without accommodative effort to see clearly at the eye far point.

(3) PRESBYOPIA:

✱ *Definition:*

➜ It is a physiological recession of the near point of distinct vision beyond the normal reading or working distance with accommodation fully exerted.

✱ *Aetiology:* Recent theories are:

(1) The lens:

- Becomes more rigid due to sclerosis of the lens fibres in old age with decreased physical accommodation.
- Loses elasticity.
- Reduction in optical properties.

(2) The ciliary muscle:

a. Weakness of ciliary muscle with decreased physiological accommodation (decreased tension due to atrophic changes).
b. Decreased muscle innervation.
c. Changes in the neuromuscular junction.

(3) The zonule: Loses elasticity.

✱ *Onset:*

- To focus on an object at a reading distance of 25 cm, the emmetropic eye must accommodate by 4 D.
- For a comfortable near vision, one third of available accommodation must be kept in reserve.
- Therefore, the patient will begin to experience difficulty or discomfort for near vision at 25 cm, when his accommodation has decayed to 6 D.

Onset of presbyopia depends on :

1. Age: Presbyopia usually occurs between 40 and 45 years of age in emmetropia.
2. Amplitude of accommodation.
3. Refractive error:
   - It occurs earlier in a hypermetrope (accommodates more for near vision) and later in myopia.
   - In myopia of 4D, presbyopia never occurs and the patient can always read without glasses.
4. Size of pupil: small pupil has a pin hole effect.

✱ *Symptoms:*

1. At first, ➔ eye strain, headache and indistinct small prints on reading at night.
2. Then, ➔ the reading becomes impossible in day light also.

✱ *Correction:*

A. Optical correction:

1. *Reading glasses: by prescribing A convex lens for near work as follows:*
   1. *Correction of The error of refraction* for distance (if present).

Thus patient is emmetrope

A = P

2. *Determine the Patient's PP:*
   - Card test
   - Concave lens test
   - The Scheiner's experiment
   - Accommodation (Prince's) rule

3. *Determine the Patient's amplitude of accommodation,*

   A = P = 1/pp

4. *Determine the amount of accommodation to be reserved:*
   - 1/3 accommodation is kept in reserve ➔ to give the presbyope a range for reading (by the ciliary muscle action).

5. *Determine the working distance needed:*
   - ✓ 33 cm is the accepted distance for reading a textbook.

     100/reading distance

6. *Calculate the reading add:*
   - It is the difference between the accommodation at the working distance and the allowed accommodation.

7. The interpupillary distance for reading: is measured.

✱ *Decentration of lenses in old presbyopes:*

- This is indicated because convergence is necessary in spite of weak accommodation.
- Decentration of lenses occurs nasally on both sides.
- *Prismatic power gained by decentring a spherical lens is given by the formula:*

P = D x h Where,

P = Prismatic power in prism dioptres.

D = the lens power in dioptres.

h = the decentration in centimetres.

Correction Example: A presbyope aged 50 years with +2D for distance:

1. +2D
2. Say 40 cm.
3. $\frac{100}{40}$ = 2.50 D
4. 2.5 X $\frac{1}{3}$ =0.75D approximately.
5. 2.50 - 0.75 =1.75D.
6. Say 33 cm which needs 100/33= 3D accommodation.
7. 3-1.75=1.25D.
8. 2+1.25=3.25D.
9. Average 2.4 mm.
10. Average 64 mm.

2 . *Bifocal contact lenses: Chapter (l8).*

B. <u>Surgical correction:</u> to achieve monovision:

1) Bifocal or accommodative intraocular lenses: Chapter (19).
2) Conductive keratoplasty: Chapter (32).
3) Photorefractive surgery:
   - ★ <u>PRK:</u> Chapter (32).
   - ★ <u>LASIK:</u> Chapter (32).
4) Scleral surgery: chapter (32).

<u>Clinical notes:</u>

- Maximum near correction that should be prescribed is probably about 3 – 3.5 D, this would allow for a reading distance of about 33cm.
- Correction above this is generally not well tolerated.
- It's generally better to under correct than over correct.
- If high correction is prescribed, a prism should be considered to help with deficiency in convergence.
- In practice, the refractionist learns by experience to anticipate the approximate presbyopic correction from the patient's age.
- In ametropia, the presbyopic correction is added to the patient's distance correction.
- The presbyopic correction must be adjusted for different working distances. A patient may require middistance glasses, e.g. for reading music, as well as for reading text.

Catoptric (Purkinje-Sanson) images

- Definition:

Catoptric images are images formed by reflections from the surfaces of the refracting media of the eye (these images were described by Purkinje and were used for diagnostic purposes by Sanson).

- Principles:

Each refracting interface in the eye acts also as a spherical mirror (convex or concave) reflecting a small portion of light incident upon it:

A. *Practically four catoptric images are formed by reflection at the following four surfaces:*
   1- *Image I:* Is formed by reflection at the anterior corneal surface.
   2- *Image II:* Is formed by reflection at the posterior corneal surface.
   3- *Image III:* Is formed by reflection at the anterior lens surface.
   4- *Image IV:* Is formed by reflection at the posterior lens surface.

B. *Other refracting surfaces in the eye form more Images such as:*
   ★ The anterior surface of the lens nucleus.
   ★ The posterior surface of the lens nucleus.
   ★ The anterior surface of the vitreous.

Fig.l0.2: Purkinje-Sanson images.

- Characters of catoptric images:

The characters of catoptric images are presented in Table 10.1 and Fig. 10.2:

✓ *Images I, II and III:* Are erect and virtual because they are formed by convex reflecting surfaces.

✓ *The image IV:* Is inverted and real because it is formed by a concave reflecting surface

- When using images II, III and IV, the refraction of the reflected light as it emerges from the eye must be considered (i.e. the apparent position of the images as that of the iris when viewed by the observer must be considered).
- Changes in lens during accommodation is recorded by slit lamp photography.

Table 10.1: Characters of catoptric images.

Characters	image I	image II	image III	image IV
(1) Formation:	By reflection at ant. Corn surface.	By reflection at post.Corn.surface	By reflection at ant. lens surface.	By reflection at post.lens surface.
(2) Position:	Erect.	Erect.	Erect.	Inverted.
(3) Nature:	Virtual.	Virtual.	Virtual.	Real.
(4) Brightness:	Bright.	Very faint.	Faint.	Faint.
(5) Size:	Large	Smallest.	Largest;	Small.

(6) Actual site:	Just behind ant. lens capsule.	Close behind image I.	In the vitreous.	In the anterior lens surface.
(7) During accommodation:	No change in size and site.	No change in size And site.	Smaller in size and approaches image I.	Smaller in size but no change in site.

- Uses of catoptric images:
  - *Use of image I:*
    2) *Study the anterior corneal curvature by:*
       a. The placido disc which examines the regularity of the corneal curvature.
       b. The keratometer which measures the radius of curvature of the cornea.
    3) *Diagnosis and measurement of the angle of squint*.

  - *Use of images III and IV :*
    Study the changes in the lens position and curvature during accommodation (by indirect measurements like the optical constants of the eye).

  - *Use of images I & II & III :* for pachymeter.

CONVERGENCE

✱ *Definition:*

- Is the process by which the visual axes are turned inwards (directed upon the object of attention).

✱ *Types of convergence:*

- *Voluntary convergence:* It is initiated in the frontal lobe (can be acquired by training).
- *Involuntary (reflex) convergence:* It is a psycho-optical reflex centred in the peristriate area of the occipital cortex.

✱ *Definitions of certain terms:*

✪ The far point of convergence:

- It is the relative position of the eyes when they are completely at rest with a slight divergence (therefore, it is beyond infinity). OR
- The point to which the visual axes are directed when convergence is relaxed

✪ The near point of convergence:

- It is the nearest point for which the eyes can be converged without producing diplopia (it is 7-8 cm normally.) OR
- The point to which the visual axes are directed when the maximum convergence is exerted

▪ Near point of convergence is always closer than near point of accommodation.

NB: Near point of vision is when the object is seen clearly, of accommodation is when the object is blurred and of convergence is when the object is doubled.

✪ The range of convergence:

- It is the distance between the far and the near point of convergence.

The amplitude of convergence:

- *It is the difference in the converging power required to maintain the eyes in convergence at the near point and in divergence at the far point of convergence:*
  - ❑ Positive convergence: It is the part of convergence between the eyes and infinity.
  - ❑ Negative convergence: part of convergence beyond infinity i.e. behind eye.

✱ *Measurement of the amplitude of convergence:*

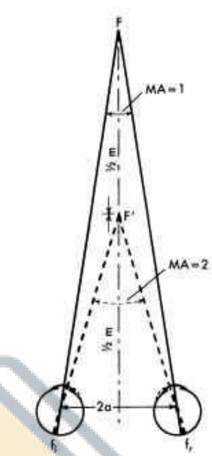
1. *By angular displacement of the visual angle in metre angles (m.a):*
   - The meter angle: The MA is defined as
     - The amount of convergence required for each eye to fixate at an object located at 1 m from the eyes in the median plane.

> ➪ Thus if the fixation distance is 1 m, an emmetropic subject must converge 1 MA and accommodate 1D; if the fixation distance is 1/2 m, the MA equals 2 and the accommodation required is 2D; and so on.

↳ *The angular displacement varies with the distance between the two eyes:*

➔ <u>With an interpupillary distance of 64 mm</u>:

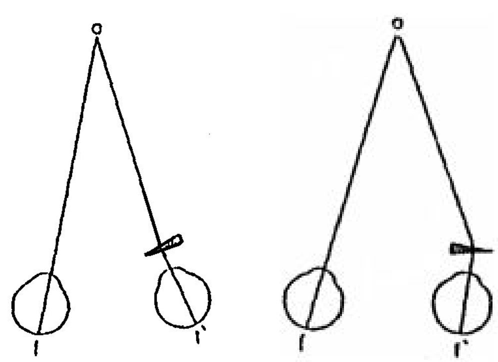
- The convergence at 2 metres is 0.5 m.a.
- The convergence at 1 metre is 1 m.a.
- The convergence at 0.5 metre is 2 m.a.
- The convergence at 0.33 metre is 3 m.a.

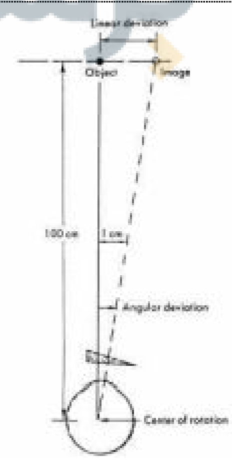


(a)In metre angles (m.a.)

2. *By prism in prism dioptres (Δ):*
   1. Positive convergence:
      - ➪ It is measured by ➔ <u>the strongest prism base-out</u> placed in front of one eye and is tolerated without diplopia
        - ☛ Which equals 30 Δ , and may reach 60 Δ by training.
   2. Negative convergence:
      - ➪ It is measured by ➔ <u>the strongest prism base-in</u> placed in Front of one eye and is tolerated without diplopia
        - ☛ Which equals 4-8 Δ.

> NB: normal amplitude of convergence is 10.5 m.a or 34-38 Δ (9.5 m.a. or 30 Δ +ve convergence and 1 m.a. or 4-8 Δ -ve convergence)





a) Positive convergence. b) Negative convergence.

prism is defined as having the power of 1 prism diopter (delta symbol (prism)) when it displaces the visual axis, referred to the center of rotation, by 1 cm at a distance of 1 m (Fig. 5-4), and 1 delta symbol (prism) is equivalent to 0.57 of arc.

- ***Measurement of fatigue of convergence by the ophthalmic Ergograph of Berens:***
    - A target is repeatedly approximated towards the eyes until → a fine line appears double.

✱ *Relative convergence:*

- Definition:
    - is the amount of convergence which can be exerted or relaxed with a given constant amount of accommodation.
- Types of relative convergence:
    - *Positive part:*
        - It is the amount of convergence exerted with given constant amount of accommodation.
    - *Negative part:*
        - It is the amount of convergence relaxed with a given constant amount of accommodation.
- Measurement of relative convergence:
    - *The same as for relative accommodation by accommodating for a fixed object at 33 cm and varying convergence by:*
        - Prisms base-out: To get the positive part.
        - Prisms base-in: To get the negative part of relative convergence as usual.

✱ *Reserve convergence:*

- It is the part of the available convergence that is reserved to avoid straining of ocular muscle.
    - There must be excess positive convergence in reserve for comfort to the ocular muscles.
    - Patients are able to exercise only the middle third of convergence without fatigue and so if their work has to go outside this area (either in the positive or the negative part of relative convergence), prisms or exercise courses should be given.

RELATION BETWEEN ACCOMMODATION & CONVERGENCE:

- ***Association of accommodation and convergence:***
    - Accommodation and convergence are associated movements (accommodation in D is numerically equal to convergence in m.a and so 3D= 3m.a at 33cm).

- ***Dissociation of accommodation and convergence:***
    1. *Accommodation in excess of convergence:*
        1. In hypermetropia leading to convergent squint.
        2. Use of concave lenses in front of the eye to exert accommodation without convergence.
    2. *Convergence in excess of accommodation:*
        1. In myopia leading to divergent squint.
        2. In old age as accommodation is diminished but convergence is retained.

3. Atropine instillation as accommodation is paralyzed but convergence is retained.
4. Use of prisms in front of each eye to exert convergence without accommodation.

Orthophoria is the condition in which the balanced action of the extraocular muscles allows fusion without effort.

(1) DIRECT OPHTHALMOSCOPY:

✱ *Definition:*

↳ The method by which we see an erect magnified image of fundus by the direct method.

✱ *Principle:*

⇨ If patient and observer are both emmetropic, rays emerging from a point in the patient's fundus will emerge as a parallel beam and will be focused on the observer's retina. However, there is a problem with this method: Sufficient light for visualization of the fundus emerges only if the patient's fundus is properly illuminated.

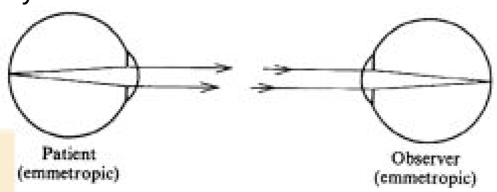
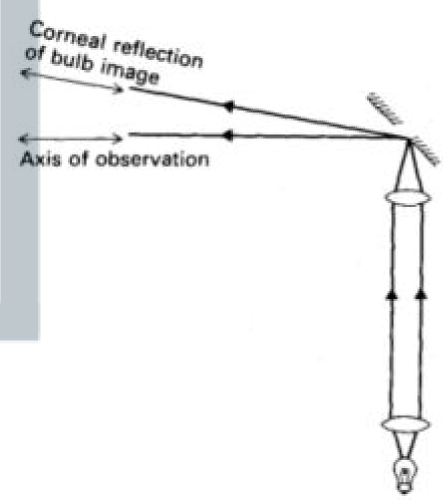


Fig. 15.1: Direct ophthalmoscopy.

✱ *Components of the direct ophthalmoscope:*

- The direct ophthalmoscope consists of:
  1. *Electric bulb:* Halogen bulbs are used now as a source of light due to their advantages:
     1) Intense brightness and whiteness (higher luminance).
     2) Greater blue portion of the spectrum to get ➔ a greater scattering and fluorescence of transparent media.
     3) A bright red-free light (red-free filters) which is useful for:
        - Observation of the NFL for defects as in early glaucoma.
        - Enhancement of the contrast of the blood vessels against the retinal background.



  2. *A system of lenses:* Which focus the light source onto a plane mirror.
  3. *A plane mirror:*
     - ✓ The mirror reflects the emitted light in a diverging beam to illuminate the retina of the patient's eye.
     - ✓ The mirror contains a hole through which the observer can view the illuminated retina of the patient's eye.
     - ✓ Light reflected from illuminated retina of patient's eye passes back through hole in the mirror then into the observer's eye.

> ✓ The image of the bulb is formed just below the mirror hole, so its corneal reflection does not lie in the visual axis of the observer to avoid dazzling.

- Accessories of the direct ophthalmoscope:

1. *A line figure:* As an astigmatic dial for accurate focusing.
2. *Fixation star:* A dot or a star shaped figure to determine eccentric fixation.
3. *Slit diaphragm:* For observation of elevated retinal lesions.
4. *Pinhole or half-circle diaphragm: To* reduce reflections by limiting the illumination beam.
5. *Red free filter (green filter):* For a green light to detect certain retinal conditions (in NFL or BVs).
6. *Blue filter:* To enhance the visibility of fluorescein staining of the cornea.
7. *Polarized filters:* To reduce reflections from the cornea and retina

- NB: The direct ophthalmoscope contains no prism.

✱ *The field of view (field of vision):*

- Definition:
  - It is the part of the observed fundus that can be seen at any one time.
- Construction of the field of view:
  - *The projected image of sight-hole (AB) on the retina (or observer's pupil, whichever is smaller) is constructed using two rays (Fig. 15.2):*
    - A ray through the nodal point N.
    - A ray parallel to the visual axis, is refracted by the eye to pass through its posterior focal point.

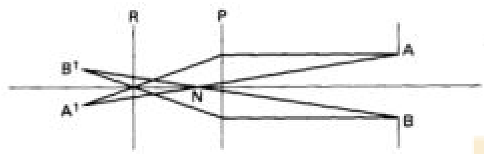
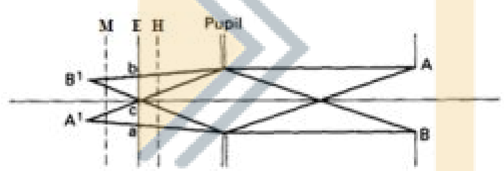


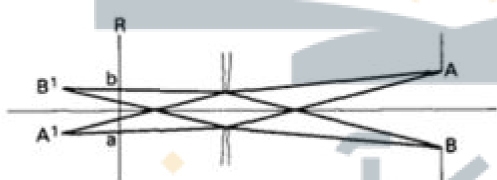
Fig: 15.2: the field of view

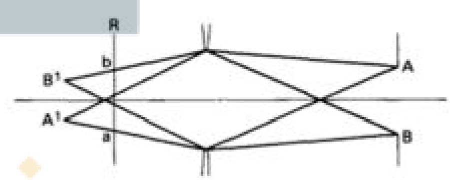
- Factors affecting the field of view:

I. *The state of refraction (axial length of the eye):*
   - The field of view is largest in H, intermediate in E, and smallest in M (Fig. 15.3).



II. *The size of the pupil of the observed eye:*
   - Increase size of pupil of observed eye ➔ increase the field of view.

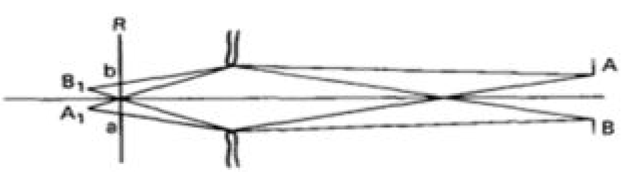


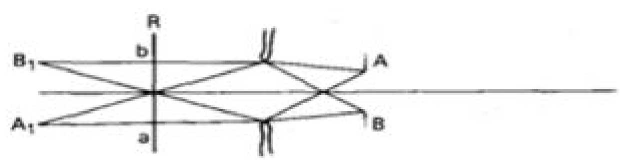


- Constricted pupil (b) dilated pupil

III. *the size of the observer's pupil or The size of the sight-hole in the mirror of the ophthalmoscope:*
   - Whichever is small limits the size of the field of view.

IV. *The distance between the observed eye and the observer:*
   - Increase distance ➔ decrease the field of view.





- Larger distance→ smaller field of view. (b) Smaller distance → larger field of view

V. *Total internal reflection of light at the periphery of the crystalline lens:*
   - This leads to a dark shadow which is seen when the peripheral parts of the retina are examined.

✱ *The field of illumination:*

- *Definition:*
  - It is the part of the observed fundus that is covered by the image of light source.
- *Extent:*
  - Always greater than the field of view in direct ophthalmoscopy because the size of illumination of the observed fundus is greater than the size of the observer's pupil.
- *Factors affecting the field of illumination:*
  1. *The refractive state of the eye*: As described above.
  2. *The position of the light source*: As described above.
  3. *The intensity of illumination of the fundus:* Varies inversely with the size of field of illumination.
  4. *The type of the mirror used:*
     - ❑ Plane mirror:
       - ✪ The reflected rays by the plane mirror are ➔ divergent and so come to a focus behind the retina (even in the myope) (Fig. 15.6) and so,
         - ☛ The field of illumination is largest in H, intermediate in E, and smallest in M.

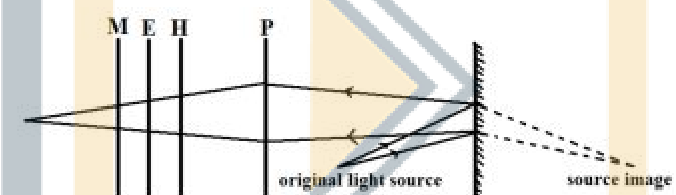


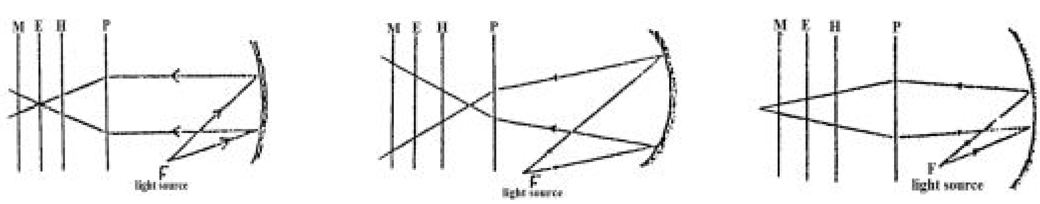
Fig: 15.6 effect of plane mirror on the field of illumination

     - ❑ Concave mirror:
       - ✪ The resulted field of illumination depends on the position of the source of light in relation to the concave mirror (with a focal length of 20 cm usually) as follows:

         A. *With the light source at the principal focus F of the concave mirror:*
            - ➔ The reflected rays by the concave mirror are parallel and so come to a focus on the retina of E (Fig. 15.7a) and so the field of illumination is largest in H and M and smallest in E.

         B. *With the light source far from the principal focus F of the concave mirror:*
            - ➔ The reflected rays by the concave mirror are convergent and so come to a focus in front of even the retina of the H (Fig.15.7b) and so the field of illumination is smallest in H, intermediate in E, and largest in M (this is the position commonly used).

         C. *With the light source nearer than the principal focus F of the concave mirror:*
            - ➔ The reflected rays by the concave mirror are divergent (as with the plane mirror) and come to focus behind even the retina of M (Fig. 15.7c) and so the field of illumination is largest in H, intermediate in E, and smallest in M.

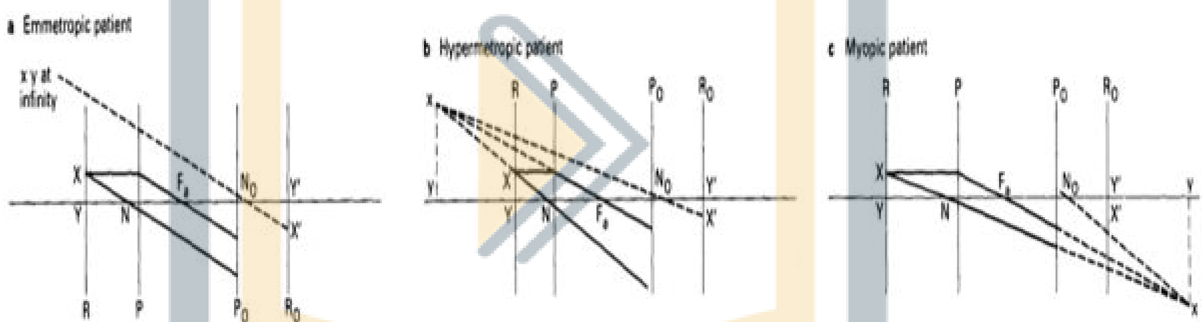


✱ Position and size of image of the observed retina:

- Construction of the position and size of image of the observed retina formed in the emmetropic observer's eye:
    1. *The image xy of illuminated retina XY of observed eye (is formed at far point of observed eye) is constructed first by two rays (Fig. 15.8):*
        - A ray from X parallel to the optic axis passes through anterior focal point F of observed eye.
        - A ray from X passes through nodal point N of observed eye undeviated.

    .

    2. *The image X'Y' is then constructed (assuming that the anterior focal point of the obsewed eye F coincides with the anterior focal point of the observer's eye Fo) by the following two rays:*
        - A ray from the top of image xy passing through observer's nodal point No.
        - Extension of the ray xF to meet the ray xNo at X'.

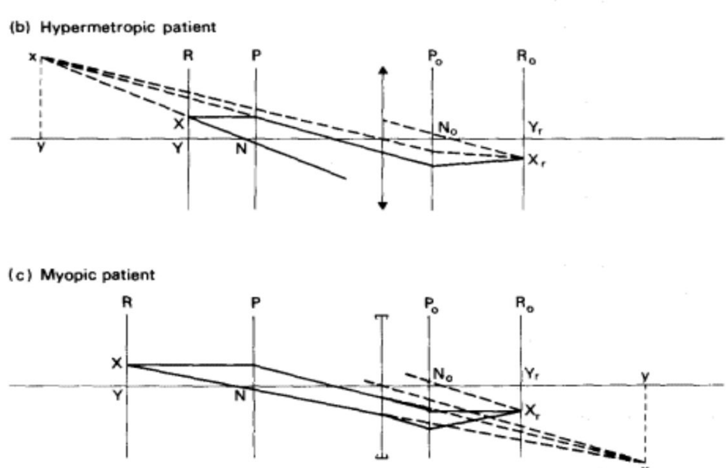


(a)Emmetropic observed eye. (b)Hypermetropic observed eye. (c)Myopic observed eye.
Fig. 15.8: Construction of image of the observed retina in the observer's eye:

☛ Character of the resulted image X'Y' formed in observer's retina:

- ❑ *Orientation of the image:*
    - ➜ *The image X'Y' on the observer's retina of the illuminated retina XY of the observed eye is inverted:* So seen as erect whether the observed eye is E, H or M.
- ❑ *The size of the image:*
    - ➜ Is smallest in H, intermediate in E and largest in M observed eye.
- ❑ *The position of the image in relation to the observer's retina:*
    - ➜ Is behind in H, on in E and in front of the observer's eye in M observed eye (so the view of an emmetropic observer is clear when the observed eye is E and blurred when the observed eye is H or M).

(A) Construction of image in observer's eye when a correcting lens is used :

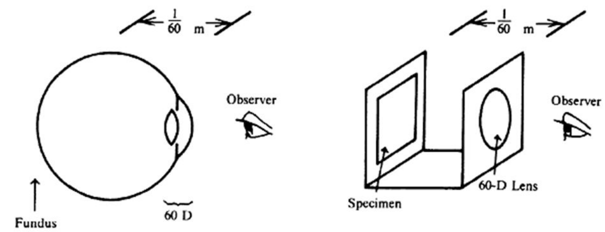


✱ *Magnification:*

A. In H, E and M observed eyes:

↳ M of image of the observed retina can be calculated as follows:

1. *From the loupe formula (Chapter 6):*
   - The observer is using the dioptric power of the observed eye as a loupe and is thus able to inspect the observed retina well within his near point of distinct vision and he sees it clearly.
   - The formula for magnification achieved by a loupe is: M= $\frac{F}{4}$



Where F = the dioptric power of the loupe.

   - So M will be
     - 15X in E eye with a power of +60D,
     - less than 15 X in H eye with less than +60D and
     - more than 15 X in M eye with more than 60D.

2. *From the reduced eye:*
   1. *When the anterior focal point F of the observed eye coincides with the anterior focal point Fo of the observer's eye:*
      - *In E observed eye:*
        - Formula: M= $\frac{I}{O} = \frac{V}{U}$

          Where V = Near point = 250 mm.
          U = 15mm from the reduced eye.

        - Construction (Fig. 15.10):
          - xy is the projected virtual image of XY by the observer at the nearest point of distinct vision i.e. at 25 cm (250 mm).
          - X'Y' = XY.

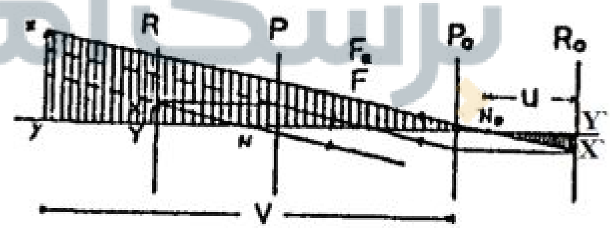


Fig.15.10: Magnification of image.

        - Calculation: M= $\frac{xy}{XY} = \frac{V}{U} = \frac{250mm}{15mm} =$ 16.5.
      - *In H observed eye:*
        - M is less than in E (narrower X'NoY' angle) and the image xy is virtual.
      - *In M observed eye:*
        - M is greater than in E (wider X'NoY' angle) and the image x is real.

➜ Therefore, the wider the angle subtended by the observed retina XY at the nodal point of the observer's eye, the greater the magnification.

2. *When of the observer is within F of the observed eye:*
   - M is greatest in H, intermediate in E, and least in M.
3. *When correcting lens is used:*
   - *Practically, correcting lens is slightly far from F of observed eye:*
     - M is the same as when F of observed eye coincides with Fo of observer's eye.

B. In astigmatic observed eye:
   - There are two different principal meridians (with two different anterior principal foci) and so M is greater in the meridian of the greatest refraction and vice versa.

- NB: Therefore, in regular astigmatism with the rule the optic disc is oval vertically in direct ophthalmoscopy.

✱ Location of a vitreous opacity by direct ophthalmoscopy:

(A) By Newton's formula:

- *Newton's formula:*
  - It states that I1 I2 = f1 f2 in any system as the eye.
- *Construction (Fig. 15.11):*
  - I2 = the distance between the object (vitreous opacity O) and the second focal point F2.
  - I1 = the distance between the image I (of the vitreous opacity O) and the first focal point F1.
  - f1 = the anterior focal length.
  - f2 = the posterior focal length.
  - XY = the strongest convex lens in the sight-hole of the direct ophthalmoscope which is placed at F1 (to give a sharp image of the vitreous opacity O).

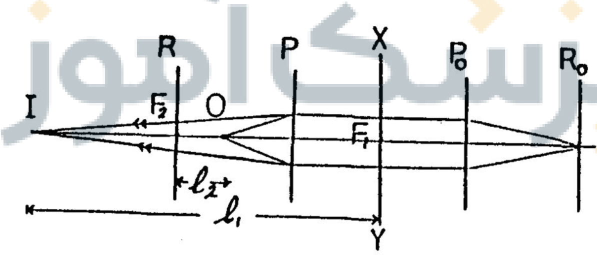


Fig. 15.11: Location of a vitreous opacity,

- *Calculations:*
  - ✓ *Calculations for an E observed eye:*
    - f1 = 15 mm and f2 = 20 mm (from the reduced eye).
    - So, I1 I2= 15 x 20
    - I1 =the focal length of the strongest convex lens placed at F1 which gives the sharp image of O and will have F1 I for its focal length.
    - So I1 = $\frac{1}{\text{power of the convex lens}}$ in metres.
    - Example: If the power of the convex lens is +10 D:

- $I1 = \frac{1000}{10}$ = 100 mm and so $I2 = \frac{300}{100}$ = 3 mm.
- Therefore, the distance between the retina and vitreous opacity will be 3 mm in E observed eye.

✓ *Calculations for H or M observed eye:* By either:

(1) Using the calculations for an ametropic observed eye:

a. When the observed eye is H: The retina will be nearer to the opacity than in E eye and so for each 3 D H we deduce 1 mm from the calculation for E observed eye.

b. When the observed eye is M: The retina will be farther from the opacity than in E eye and so for each 3 D M we add 1 mm to the calculation for an E observed eye.

(2) Using the amount of refractive error and numerical value of the focusing lens in D:

(a) *When the observed eye is H:* From the amount of H in D deduced from the numerical value of correcting lens we can get I1 in mm.

→ Example: If an opacity in the vitreous of H eye of +2 D is focused by +12D lens: I1 I2 = f1f2 = 15 X 20 and $I1 = \frac{1000}{12-2} = \frac{1000}{10} = 100$ mm so, $I2 = \frac{300}{100} = 3$ mm

(b) *When the observed eye is M:*

- From the amount of M in D added to the numerical value of the correcting lens, we can get I1 in mm.

(B) By parallactic displacement:

- To differentiate between the level of two opacities in the fundus (one is in front of the other) with slight movement of the observer's head and ophthalmoscope:
  - → A nearer opacity moves in the same direction of the observer's head movement.
  - → A farther opacity moves in the opposite direction of the observer's head movement.

(C) Measurement of fundus lesions in standard units:

- *Lateral measurements:* 1 Disc diameter = 1.5 mm.
- *Depth measurements:*
  - → 3 D = 1 mm in emmetropic eye.
  - → 3 D= 2 mm in aphakic eye.

✱ Fallacies in the refractive state of the observed eye by direct ophthalmoscopy:

1. *Equal H and M in numerical value in the observed eye and observer's eye (and vice versa) do not have their far points coincide :*
   - → +4D observed eye is seen by -3.50 D observer's eye.
   - → -4D observed eye is seen by +4.50D observers eye.
2. *The distance between the observed eye and the observer's eye is practically more than 30 mm:*
   - So the anterior focal point of the observed eye and of the observer's eye are separated.
3. *The observed eye and the observer's eye are using their accommodation:*
   - Causes a more separation of the anterior focal point of the observed eye and of the observer's eye.
4. *The lens in the ophthalmoscope is not in contact with the cornea of the observed eye (but at least 1.5 cm in front of it):*
   - So the lens correcting H is lower than H error and lens-correcting M is higher than the M error).
5. *Higher refractive error:*
   - Leads to a greater faulty difference of the power of the correcting lens.
6. *High minus lenses:*
   - Lead to a greater magnification (as in the eyepiece of the Galilean telescope).
7. *Greater magnification with reduced field of vision:* Disadvantage in high M.
8. *The degree of astigmatism is not absolutely correct:*
   - Because it is estimated by taking the difference in the readings between the two principal meridians.

✱ Difficulties of direct ophthalmoscopy with constricted pupil of observed eye:

i. Reflexes from the cornea:
   - ✰ Are due to corneal image of light source which will prevent viewing the macula clearly.
   - ✰ Avoided by looking obliquely through the pupil to focus the optic disc then moving the observer's head and ophthalmoscope outwards (equal to 1.5 disc diameter) to see the macula (as the axis of the observer must not lie in line with the corneal reflex of the bulb image).

ii. Reflexes from the lens: These reflexes also prevent seeing the macula clearly.

iii. Constriction of the pupil of the observed eye on exposure to light of the direct ophthalmoscope: This makes viewing the macula more difficult.

(2) INDIRECT OPHTHALMOSCOPY:

Table 15.1 Summary of the optical properties of the direct and indirect ophthalmoscope.

	Direct ophthalmoscope	Indirect ophthalmoscope
Image:	Not inverted	Vertically and horizontally inverted
Field of view:	Small (6°)	Large (25°)
Magnification:	Large (× 15)	Small (× 3 [+20D]) (× 5 [+13D])
Binocularity:	Not available	Stereoscopic view
Influence of patient's refractive error:	Large	Small
Teaching facility:	None	Teaching mirror

A. BINOCULAR INDIRECT OPHTHALMOSCOPY (BIO):

Definition:

- It is the method by which we render the observed eye artificially highly myopic by a high convex lens which forms➔ a real inverted image of the fundus of the observed eye at a distance in front of the observed eye (between the convex lens and the observer, Fig. 15.12).

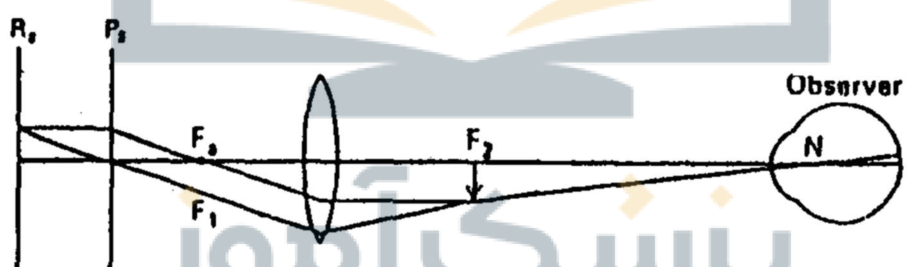


Fig. 15.12: Indirect ophthalmoscopy.

Methods of binocular indirect ophthalmoscopy:

- Binocular indirect ophthalmoscope (BIO):
  - *Components of BIO:*
    1. The Condensing lens (powerful convex lens) is held in front of the observed eye:
       - Distance:
         - The observer holds the condensing lens at arm's length.
       - Power:
         - The usual powers used are: +13 D, +20 D and +28 D.
       - Design of lenses:
         - Aspheric design: With the surface of the steeper curvature facing the examiner➔ to decrease the distortion of image.
         - Doublet lens: May further reduce distortion but increases the reflections.
         - Antireflective coating: To minimize reflections.
         - Coloured lenses:

- Yellow-tinted volk lenses reduce unwanted infrared radiation on the patient's retina and eliminate blue light to reduce scattering.
  - <u>A scale on the lens surface</u>: for fundus measurements.

Table 15.2: optical characteristics of condensing lenses used in BIO.

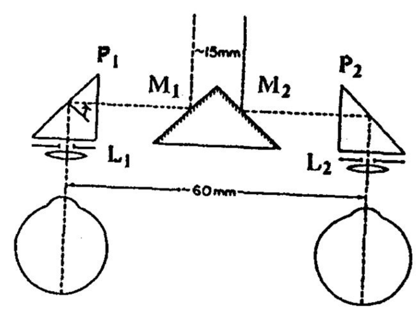
Optical Characteristics	The power of the condensing lens		
	+13 D	+20 D	+28 D
(a) Magnification:	5	3	2
(b) Estimated field of view:	30°	50°	60°
(c) Approximate stereopsis:	as normal	3/4 normal	1/2 normal

2. *<u>The illumination:</u>*
   - *The illumination is provided by ➔ an electric lamp mounted on the observer's head*
   - *<u>The light</u>:* Passes through the condensing lens into the observed eye.
   - *<u>The light reflected from the observed eye</u>:* Is refracted by the condensing lens to form a real inverted image between the condensing lens and the observer (Fig. 15.12).
   - *<u>The observer views this real image of the observed retina</u> which is:*
     - ⇨ Both vertically and laterally inverted.
     - ⇨ Situated at or near the second principal focus of the condensing lens (Fig. 15.12).
     - *I.e. approximately 8 cm in front of+13 D lens (so the observer views the image from a distance of 40-50 cm because he holds the condensing lens at arm's length).*
   - <u>The level of the observer's eye</u>: Is the same as that of the observed eye.

3. *<u>Binocular viewing system:</u>*

   Is mounted on the observer's head and consists of :

   1 .Two convex lenses L1 and L 2:
   - The power of each convex lens is +2 D to help the observer to view the fundus:
     - Without using his accommodation (especially if the patient is aphakic or highly H).
     - If he was presbyopic.
   - However, the observer must wear his spectacle correction if:
     - His near correction is more than +2 D because of underlying presbyopia or Hypermetropia.
     - He has any significant refractive error.



   2 .two reflecting prisms P1 and P2:
   - ❑ Provide light to the observer's eye by total internal reflection as the angle of incidence (45°) is greater than the critical glass/air angle (41°).

   3 .Reflecting mirrors M1 and M2.
   - ❑ To achieve binocularity by reducing the observer's pupillary distance from 60 mm to 15 mm with the aid of reflecting mirrors M1 and M2.

✱ *Field of illumination:*

- Construction of the field of illumination:

P = the principal plane of the observed eye and S = the pupil of the observed eye:

1. The illumination: Is provided by an electric lamp mounted on the observer's head.
2. The illuminating light beam is rendered convergent: By the condensing lens.
3. These convergent rays become more convergent: By the refracting system of the observed eye and so, they meet at a point in the vitreous (Fig, 15.Ha).
4. The light then diverges again: To strike the retina.

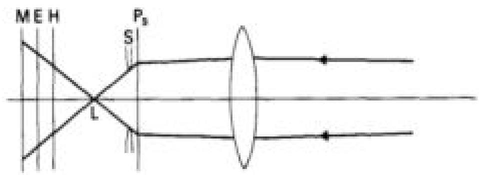
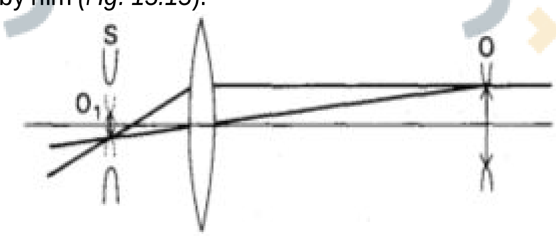


Fig. 15.14: Field of illumination in indirect ophthalmoscopy.

- Factors affecting the field of illumination:
  1- The refractive state of the eye: It is smallest in H, intermediate in E and largest in M.
  2- The pupil size of the observed eye: It is enlarged when the pupil of the observed eye is dilated.
  3- The intensity of illumination of fundus: It is smaller with high intensity of fundus illumination.

✱ *Field of view (field of vision):*

- *Construction of the field of view:*
  - The condensing lens is held in front of the observed eye at such a distance that the observed pupil and the observer's pupil are conjugate foci:
    - ➜ This means that light arising from a point in the subject's papillary plane is brought to a focus by the condensing lens in the observer's pupillary plane, and vice versa. Therefore ➔A reduced image of the observer's pupil is formed in the subject's pupillary plane (the image of a 4 mm pupil is approximately 0.7 mm)
    - ➜ Only those rays of light which leave the observed eye via the area of image O1 of the observer's pupil O can, after refraction by the condensing lens, enter the observer's pupil and seen by him *(Fig. 15.15*).

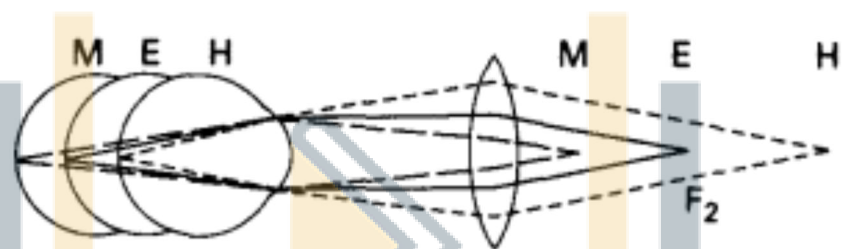


- *Factors affecting the field of view:*

1. *The refractive state of the eye:* it is smallest in H, intermediate in E and largest in M.
2. *The size of the observer's pupil:* it is limited by small size of observer's pupil.
3. *The condensing lens:* The field of view increased by:
   - ➔ A larger size (aperture) of the condensing lens: (Fig. 15.16).
   - ➔ Increased power of the condensing lens:
     - +13 D lens: Leads to 30° field of view.
     - +20 D lens: Leads to 50° field of view.
     - +28 D lens: Leads to 60° field of view.

✱ *__Position and size of image of observed retina:__*

- *__The position of image__ of the observed retina depends on the state of refraction of observed eye:*
  - in E observed eye:
    - The image of the retina of an emmetropic eye is always located at the second principal focus of the condensing lens, regardless of the position of the lens relative to the eye. This is because all rays emerging from the emmetropic eye are parallel
  - in H observed eye:
    - The image of the observed retina lies outside the second principal focus F2 of the lens ,this is because rays emerging from the hypermetropic eye are divergent.
  - in M observed eye:
    - The image of the observed retina lies inside the second principal focus F2 of the lens this is because rays emerging from the myopic eye are convergent.



Relative positions of the image in hypermetropia H, emmetropia, E, and myopia, M

- *__The size of the image__ of the observed retina* depend on :

1. The distance between the condensing lens and the observed eye (Fig. 15.20):

A. __If the principal focus F1 of the lens coincides with the anterior focal point Fa of the observed eye:__
   - ➪ In Fig. 15.20a, a ray parallel to the optic axis passes through F1 of the lens and is refracted through the lens parallel to the optic axis and so the image size of the observed retina is the same irrespective of the refractive state of the observed eye.

B. __If the principal focus F1 of the lens is outside the anterior focal point Fa of the observed eye:__
   - ➪ In Fig. l5.20b, a ray parallel to the optic axis passes through Fa of the observed eye (which is outside F1 of the lens) and is refracted through the lens convergent to the optic axis and so the image size of the observed eye is smallest in H, intermediate in E and largest in M.

C. __If the principal focus F1 of the lens is inside the anterior focal point Fa of the observed eye:__
   - ➪ In Fig. l5.20c, a ray parallel to the optic axis passes through Fa of the observed eye (which is inside F1 of the lens) and is refracted through the lens divergent to the optic axis and so the image size of the observed retina is largest in H, intermediate in E and smallest in M.

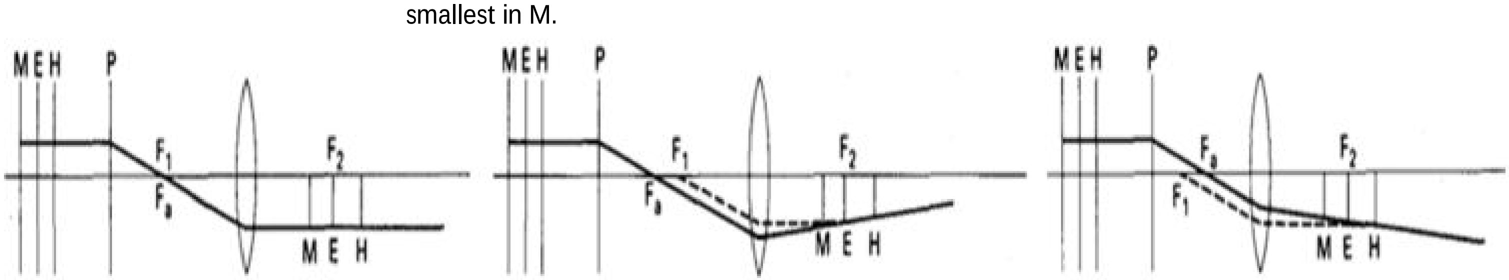


Fig. 15.20: Effect of the distance between the condensing lens find the observed eye:
(a)Fa of lens coincides with F1 of observed eye; (b) Fa of lens is outside f1 of observed eye; (c) Fa of lens is inside F1 of observed eye.

2. *The refractive state of the observed eye (Fig. 15.20):*
   - In E observed eye:
     - The image size is constant irrespective to the position of the lens in relation to the observed eye.
   - In H observed eye:
     - The image becomes smaller when the principal focus of the lens is outside fa of the eye and becomes larger when the principal focus of the lens is inside fa of the eye.
   - In M observed eye:
     - The reverse of what occurs for H observed eye.
   - In astigmatic observed eye:
     - There is unequal magnification in the two principal meridians and so the optic disc appears oval in astigmatism.

- *Magnification:*
  - Calculation of the image size:
    - *__The magnification for E observed eye:__*
      - *Linear magnification:*

$$M = \frac{\text{size of image } ab}{\text{size of object } AB} = \frac{cb}{NB}$$

Where, M = the linear magnification.
cb = the focal length of the condensing lens (1000/20=50 mm for +20 D lens).
NB = the distance between the nodal point and the emmetropic observed retina (15 mm from the reduced eye).

$$\text{So, } M = \frac{50}{15} = 3.3$$

So, M of + 20D lens is 3x for E observed eye.
Therefore, M of +13 D is 5x
Therefore, M o f+28D is 2x.

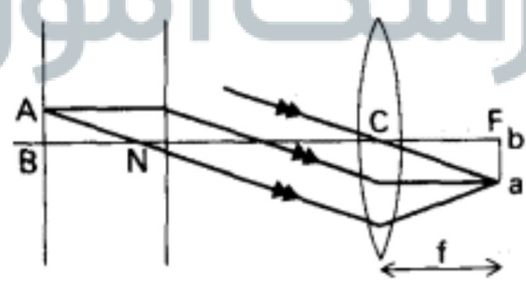


Fig. 15.18: Magnification of image.

- *Angular magnification:*
  - The angular magnification can also be calculated and its value is the same as that of linear magnification.

- Axial Magnification:

(1) ***Magnification of an ametropic observed eye:***

- ☆ *In H observed eye:* It is more (due to shorter NY distance) than in E observed eye.
- ☆ *In M observed eye:* It is less (due to longer NY distance) than in E observed eye.

I. The power of the condensing lens used (Table15.1):

The image becomes smaller in size if the power of the lens is increased:

- ✓ +13 D lens: Leads to 5X, magnification.
- ✓ +20 D lens: Leads to 3 X, magnification
- ✓ +28 D lens: Leads to 2 X, magnification.

- Troublesome reflexes on doing BIO:

★ *Optical principles:*

Three troublesome reflexes are produced by source of light:

1- The patient's cornea acts as a convex mirror: Thus, it produces a virtual erect diminished image of the light source which may cover the pupil and prevent anything behind to be seen.

2- The anterior surface of the condensing lens (towards the examiner) acts as a convex mirror: Thus, it produces a virtual erect diminished image of the light source behind the condensing lens (i.e. between the condensing lens and the patient).

3- The posterior surface of the condensing lens (towards the patient) acts as a concave mirror: Thus, it produces a real inverted image of the light source in front of the condensing lens (between the lens and the examiner).

★ *Prevention of the reflexes:*

A. The reflex from the patient's cornea can be avoided by either:

1. *A sideways movement of the condensing lens while the light source is stationary:* The image of the patient's fundus moves in the same direction as the lens which is greater than the lens movement (because the image is formed nearer to the principal focus of the lens), or
2. *Movement of the examiner's head and keeping the lens stationary:* The image of the patient's fundus moves in the opposite direction of the movement of the examiner's head.

B. The two reflexes from the anterior and posterior surfaces of the condensing lens can be avoided by slight tilting of the condensing lens towards or away from the patient:

This will move the two images of the light source (the two reflexes) in opposite directions and so the fundus could be seen in the clear space between the two images.

- Parallactic displacement with binocular indirect ophthalmoscopy:

❑ *Value:*

To differentiate between levels of two opacities near each other in fundus.

❑ *Principle:*

i. A and B are two opacities in the fundus for example A on the edge of the optic disc and B at the bottom of optic glaucomatous cup (Fig. 15.19).

ii. When condensing lens is shifted slightly so that its optical centre moves from O1 to O2 image of A and B will move from A1 to A2 and B1 to B2.

RETINOSCOPY (SKIASCOPY)

- ***Definition:***
  - It is an Objective method of measurement of refractive state of eye using retinoscope.

- ***Methods of retinoscopy:***

A. <u>The simple method of illumination</u> (old method):

➔ *A plane or concave mirror reflects an external source of light*

- A light source is located beside the patient's head.
- The light is reflected from a plane or concave mirror, held by the observer into the observed eye.
- The observer views the observed eye through a small hole in the mirror:
  - <u>Light is reflected from a plane mirror:</u> ➔ the image is
    - o erect,
    - o virtual,
    - o same size and
    - o At same distance behind the mirror, Fig.l4.1a) or.
  - <u>Light is reflected from a concave mirror :</u>➔the image is
    - o inverted,
    - o real and
    - o Is between the observer and the observed eye, Fig. 14.1 b).

Fig. 14.1: Simple method of illumination in retinoscopy.

B. <u>The self luminous retinoscope</u> (handheld electric retinoscopes):

- *Components:*
  1. *A light source.*
  2. *A strong convex lens (the condensing lens).*
  3. *A mirror at 45°:*
     - ➲ To give both systems of illumination (plane and concave mirror effects).

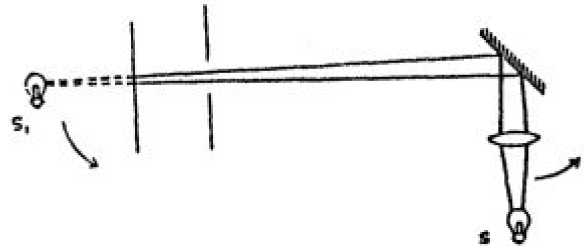


Fig. 14.2: Electric retinoscope

- *Plane and concave mirror effect:*
  - *Both can be provided by altering the distance between the light and the condensing lens by moving this lens within the shaft of the instrument to vary the angularity of the light leaving the mirror:*

❑ *At one extreme within the shaft of the instrument at its lowest position:*

➔ A plane mirror effect (the rays are parallel) is obtained.

❑ *At the other extreme within the shaft of the instrument at its highest position*:

➔ A concave mirror effect is obtained (the rays converge at a point close to the instrument).

❑ *At an intermediate position:*

➔ The retinoscope acts as a concave mirror of focal length equal to the distance between the observer and the observed eye

- Thus a focused image of the retinoscope bulb filament falls on the patient's eye
- It is of NO value in retinoscopy. (As the image of the light source is coincident with the observed eye).

❑ *Just below the intermediate position:*

➔ The retinoscope acts as a concave mirror of focal length slightly exceeding the distance between the observer and the observed eye; but with a plane mirror effect

- (as a virtual image S1 of the light source is formed just behind the observed eye , Fig. 14.2)

➔ It is useful in clinical practice for *two reasons:*

- A brighter illumination (than that produced by the plane mirror effect with the shaft at its lowest position) which makes retinoscopy easier when the pupil is small and when there are opacities in the media of the eye.
- The plane mirror effect is retained (which most observers prefer).

- *The types of self luminous retinoscopes:*
  1. The spot retinoscope: The source of light used produces a circular image.
  2. The streak retinoscope: The source of light used produces a linear image.
  3. The dynamic retinoscope: Which is used for dynamic retinoscopy.

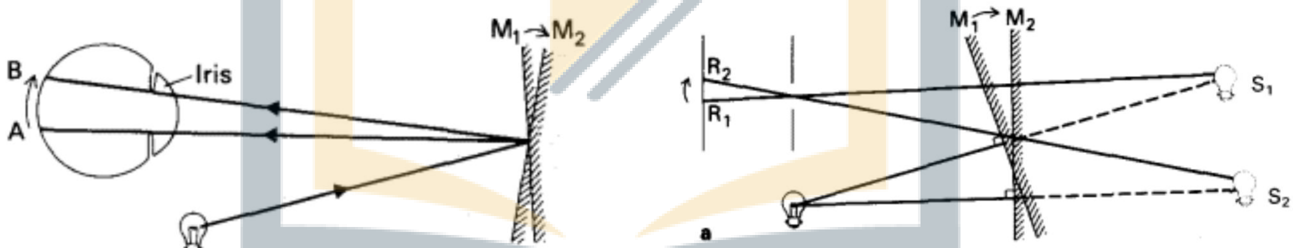
✱ ***Stages of retinoscopy:***

1. The illumination stage:

- *Definition:*
  - It is the stage in which light is directed into the observed eye to illuminate the retina.

- *The source of illumination:*
  - A. ***When the plane mirror effect is used:***
    - ➲ Movement of light across the observed fundus is➔ with the movement of the plane mirror.
  - B. ***When the concave mirror effect is used:***
    - ➲ Movement of light across the observed fundus is➔ against the movement of the concave mirror.

Conclusion:
The illuminated fundus area moves with the movement of the plane mirror and against the movement of the concave mirror, irrespective the refractive state of the observed eye.



(a) Movement of light is with as that of plane mirror,

(b) Movement of illumination at retina R1R2. is with that of mirror M1 to M2.

Fig.l4.3: Illumination stage of retinoscopy: Plane mirror or plane mirror effect.

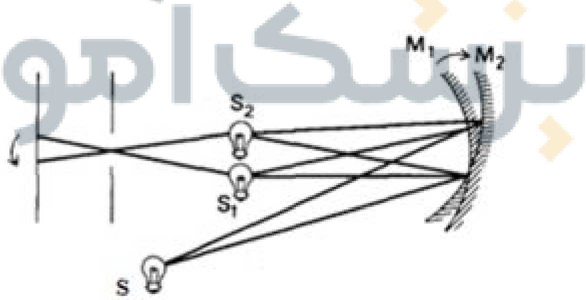


Fig.14.4: illumination stage of retinoscopy: concave mirror or concave mirror effect.

2. The luminous reflex (the red reflex) stage:

- *Definition:*
  - The formation of the image of the illuminated retina of the observed eye at its far point

  ⌦ I.e. E at infinity, H behind the eye and M in front of the eye).

- *Construction of the image of the illuminated retina of the observed eye at its far point:*

✱ *An image A1B1 of the illuminated retina of the observed eye is formed at its far point and can be constructed by two rays:*

- A ray from point A of the retina R on the principal axis of the eye, which leaves the eye along the principal axis.
- A ray from a retinal point B, off the principal axis, which travels parallel to the principal axis as far as the principal plane, P, of the eye, where it is refracted to pass onward through the anterior principal focus, Fa, of the eye.
- A ray from retinal point B which passes undeviated through the nodal point, N (Fig14.5).

> • NB When drawing these diagrams from memory, construct the image at the far point for each refractive condition and Fa will look after itself. Do not put Fa at a random position and then try to make the diagram 'work'.

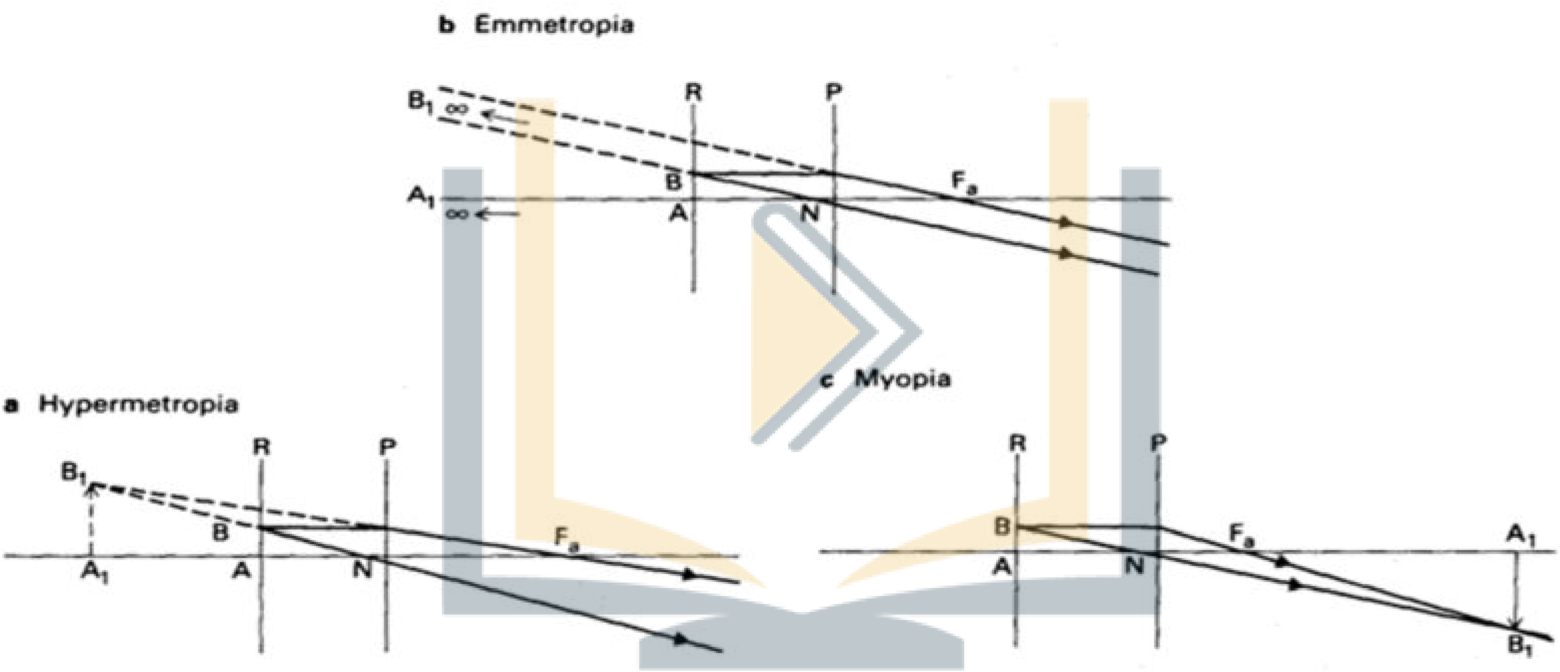


Fig.14.5: Reflex stage of retinoscopy (plane mirror effect).

3. The projection stage:

- *Definition:*
  - It is the stage in which the image at the far point of the observed eye (the reflex stage) is located by ➔ moving the illumination across the fundus and noting the behavior.

❑ *Construction of the projected image by observer in the pupil of observed eye:*

- o Image A1B1 of illuminated retina of observed eye at its far point is constructed first (Fig.14.5).
- o Then the projected image by the observer in the pupil of the observed eye is constructed by drawing an additional hypothetical ray from B1 passing through the nodal point No of observer to observer's retina RO (Fig. 14.6).
- o This ray locates the point Bo, the image of Bo on the observer's retina.

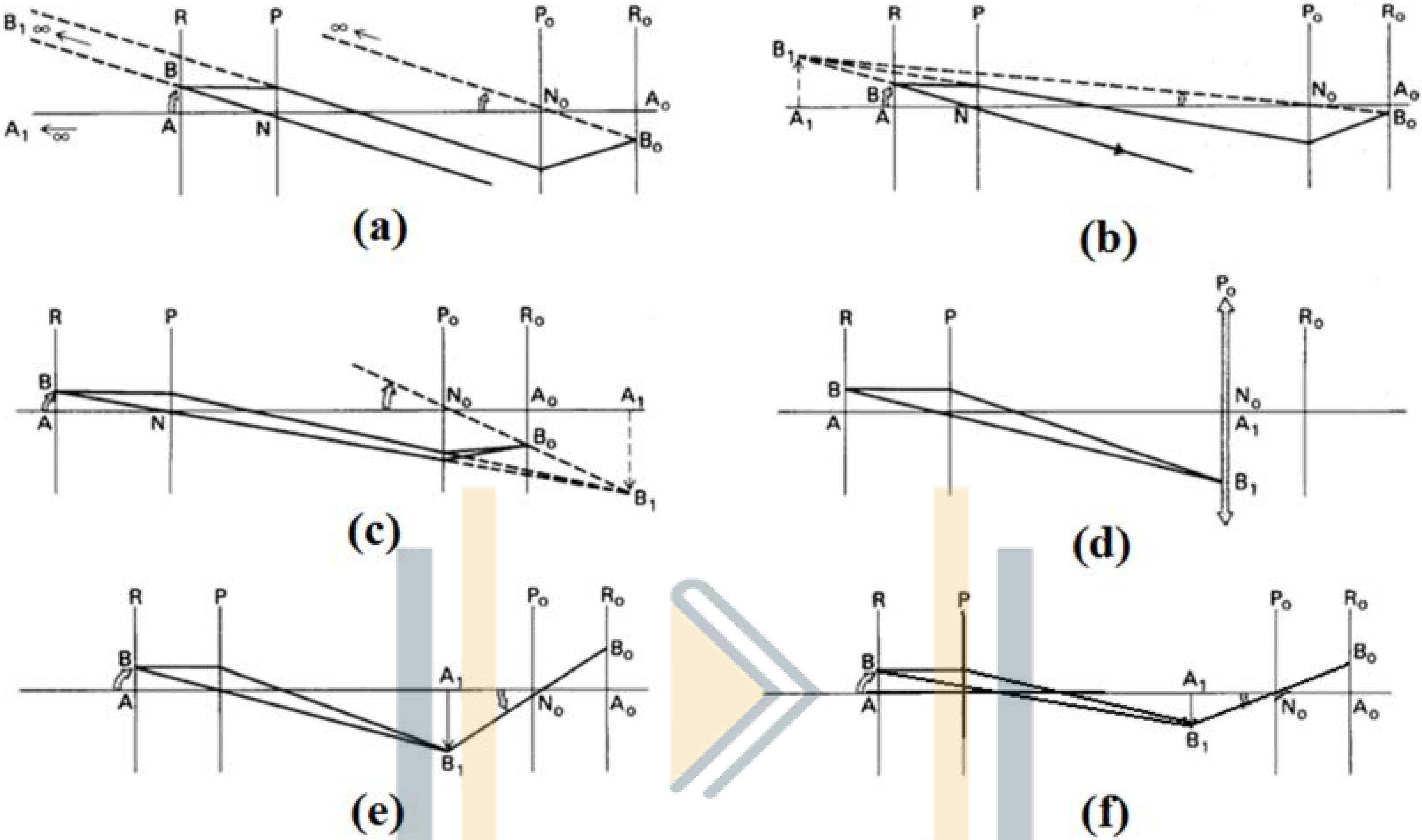


Fig. 14.6: Projection stage of retinoscopy:
(a) Emmetropia; (b) Hypermetropia; (c) Myopia less than -1 D for working distance of 1 metre; (d) Myopia of-1 D for working distance of 1 metre (neutral point); (e) Myopia of more than –1 D for working distance of 1 metre; (f) Myopia of a higher degree than in (e).

- *Viewing of the projected image by the observer:*
  - The observer views the image A1B1 of the illuminated retina AB from a convenient distance usually 2/3 or 1 m.
  - The observer does not see actual image A1B1 but rays from A1B1 are seen as ➔ illuminated area or reflex which is projected in pupil of observed eye.

- *Behavior of the luminous red reflex (projected in the pupil of the observed eye) in relation to the movement of the illuminated fundus area of the observed eye using a plane mirror:*

A. *The direction of the red reflex movement:*

- *In an emmetropic (E) observed eye:*
  - The luminous red reflex moves in the same direction as the illuminated fundus area of the observed eye and so in the same direction of the movement of the plane mirror (with movement) (Fig. 14.6a).
- *In a hypermetropic (H) observed eye:*
  - The same as in an emmetropic observed eye (with movement) (Fig. 14.6b).
- *In a myopic (M) observed eye:*
  - The movement of the luminous red reflex varies with the position of the observer in relation to the far point (conjugate focus) of the myopic observed eye

1. <u>If far point of the myopic observed eye is behind the observer</u>:
   - The red reflex moves in the same direction as in E or H observed eye (with movement, Fig. 14.6c)

2. <u>if the far point of M observed eye coincides with the observer's nodal point</u>:
   - *No image B1 can be formed on observer's retina (Fig. 14.6d):*
     - The red reflex is diffuse bright with no movement because movement of red reflex is infinitely rapid.
   - *This point is called the neutral point (The point of reversal):*
     - Which is the principle of retinoscopy test in which all conditions of refraction are made myopic equal to the dioptric value of the observer's working distance (myopic value of working distance).

3. <u>If the far point of M observed eye is in front of the observer</u>:
   - The red reflex moves in the opposite direction of the movement of the plane mirror (against movement) (Fig. 14.6e and 14.6f).

B. <u>The rapidity of the red reflex movement:</u>

- The red reflex appears to move more rapidly as the neutral point is approached (at this point no movement is seen because it is very rapid.

✱ *<u>The field of illumination:</u>*

- Definition:
  - The part of the observed fundus covered by the image of the source of light (which is the image of the original source of light, of 25 mm diameter and at 25 cm behind the observed eye).

✱ *<u>The field of view (field of vsion):</u>*

- *Definition:*
  - The part of the observed fundus covered by the image of the observer's pupil (assuming that the observed eye is myopic 1 D with 1 metre Observer's working distance).
- *Characters:*
  - The field of view (0.06 mm) (which is the portion of the observed fundus seen by the observer) is ➔ much smaller than the field of illumination (0.15 mm).
  - *This small field of view is surrounded by darkness and so we must notice that:*
    - ➔ If the plane mirror (i.e. the immediate source of light) is moved, the illuminated area of the fundus will be followed by a dark area called the shadow.
    - ➔ In retinoscopy, it is more accurate to observe the movement of the central part of the red reflex (the red reflex movement) than to observe the junction between the illuminated area i.e. the red reflex and the nonilluminated area i.e. the shadow (the shadow movement).

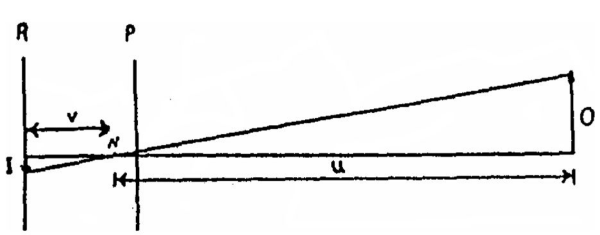
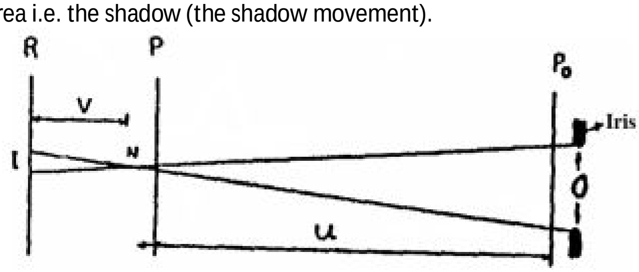


Fig. 14.7: Field of illumination in retinoscopy.



Fie. 14.8: Field of view in retinoscopy.

✱ *<u>The optical properties of the red reflex:</u>*

1. *The brightness of the red reflex:*
   The brightness of the red reflex (the intensity of the illuminated fundus area of the observed eye) is affected by the following factors:
   1) <u>The intensity of the source of light:</u>
      - Increase in the intensity of the source of light,➔ increases the brightness of the red reflex and vice versa.
   2) <u>The type of mirror or mirror effect used:</u>
      - A concave mirror or a concave mirror effect of the retinoscope gives ➔ a brighter red reflex.
   3) <u>The distance between the source of light and the observed eye</u>:
      - Increase in the distance will ➔ diminish the brightness of the red reflex and vice versa.
   4) <u>The refractive state of the observed eye:</u>
      - The lower the error of refraction ➔ the brighter the red reflex and vice versa (Fig. 14.9):
        - ✪ The red reflex is brighter in M observed eye of 1 D because the illuminated fundus area R1 is small with a great amount of light per unit area.
        - ✪ The red reflex is dim in M observed eye of 10 D because the illuminated fundus area R2 is large with a very small amount of light per unit area.

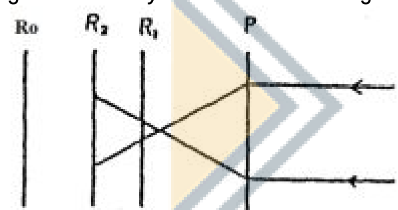


Fig.14.9: A smaller illuminated fundus area on R1 of -1 D than on R2 of -10 D myopia.

2. *The movement of the red reflex:*
   A. The rapidity of movement of red reflex: This depends on the following:
      1. *<u>The rapidity of movement of the mirror or retinoscope:</u>*
         ➔ The more rapid is the movement of the mirror or retinoscope, the more rapid is the movement of the red reflex and vice versa.

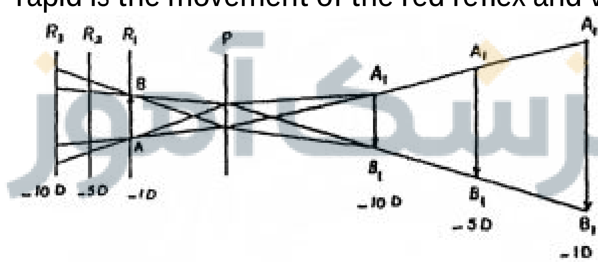


Fig.14:10: Effect of refractive state of observed eye on rapidity of red reflex movement.

      2. *<u>The refractive state of the eye:</u>*
         a. In a low refractive error of the observed eye, the movement of the red reflex is rapid.
         b. In a higher refractive error of the observed eye the movement of the red reflex is slow
         c. In emmetropic observed eye (R1 in Fig. 14.10), there is no movement of the red reflex because it is infinitely rapid (as the distance A1B1 is very long).
      3. *<u>The distance between the observer and the observed eye.</u>*
      4. *<u>The distance of the original source of light and the mirror</u>: When the mirror method is used.*

   B. The direction of movement of the red reflex:
      ★ See above

3. *The shapes of the red reflex*:

(1) Rounded red reflex: If the observed eye is E, H or M (Fig. 14.11a).

(2) Oval red reflex: If there is regular astigmatism of the observed eye because magnification differs in the two principal meridians:

- ✓ Oval red reflex with curved sides: If both meridians are ametropic (Fig. 14.11b).
- ✓ Oval red reflex with straight sides (banded red reflex): If one meridian is E which appears as a straight line along which is the axis of the cylinder (Fig 14.11c).

(3) Scissors red reflex:

- ✓ If there is ➔ irregular astigmatism (corneal opacities or posterior staphyloma (Fig14.11d).

(4) Spinning red reflex:

- ✓ If there is ➔ keratoconus of the observed eye (Fig. 14.11e).

(5) Bright red reflex with paracentral shadow:

- ✓ If the pupil is dilated (due to spherical aberration produced by the lens) (Fig. 14.11f).

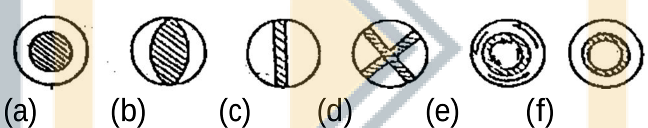


Fig.14.11: The shapes of the red reflex
(a)Rounded RR ;(b) Oval RR with curved sides ;(c) Oval RR with straight sides (banded red reflex): (d) Scissors RR: (e) Spinning RR; (f) Bright RR with paracentral shadow.

4. *Aberrations in the red reflex*:

A. Negative aberration:

- *Cause :*
  - ❖ Keratoconus of the observed eye with more curved central part of the cornea.
- *Principle (Fig. 14.12):*
  - ☆ *The central rays:*
    - ⌖ pass through the more curved (highly myopic) central part of the cornea and so➔ the central part of the red reflex moves slowly against the movement of the plane mirror.
  - ☆ *The paracentral rays:*
    - ⌖ Do not enter the pupil of the observer(Eo) and so there is a➔ paracentral shadow in the red reflex.
  - ☆ *The peripheral rays:*
    - ⌖ Pass through the less curved (less myopic) peripheral part of the cornea but are refracted more than the paracentral rays and enter the pupil of the observer and so➔ the peripheral part of the red reflex moves rapidly against the movement of the plane mirror.
- *Effect:*
  - ☆ The red reflex movement is ➔ rapid peripherally which appears to spins round the central part of the red reflex which moves slowly.

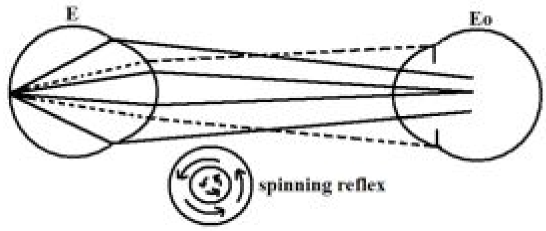


Fig.14.12: - ve aberration (keratoconus).

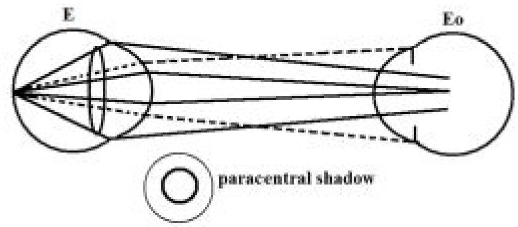


Fig.14.13: + ve aberration (spherical aberration).

B. Positive aberration:

- *Cause:*
  - o Spherical aberration produced by the lens when the pupil is dilated.
- *Principle (Fig. 14.13):*
  - ☑ *The central rays:*
    - Enter the pupil of the observer's Eo and so the red reflex is bright centrally.
  - ☑ *The paracentral rays:*
    - Do not enter pupil of the observer and so there is a paracentral shadow in the red reflex.
  - ☑ *The peripheral rays:*
    - Pass through the periphery of the lens and are more refracted than the paracentral rays (due to spherical aberration) and enter the pupil of the observer and so the red reflex is bright peripherally.
- *Effect:*
  - ☆ A paracentral shadow is seen in the red reflex which can be avoided if we look to the central part of the red reflex.

✱ *The neutral point (point of reversal):*

✪ Definition:

- It is the principle of retinoscopy test in which all conditions of refraction are made myopic of a value equal to the dioptric value of the observer's working distance (i.e. 1D at 1m or 1.5D at 3/4m).

✪ The optical condition at the neutral point:

- *No movement of the red reflex* :
  - This is because the observed eye is rendered myopic of a value equal to the observer's working distance i.e. with the observer at the far point (conjugate focus) of the observed eye.

- *Brightness of the red reflex:*
  - *Brightest red reflex:* At the point of reversal , with no movement of the red reflex (Fig.14.14):
    - ⇨ AB :➔ this is the field of view).
    - ⇨ X Y :➔this is the field of illumination which is larger than the field of view).
    - ⇨ A1B1: ➔ is the image of the pupil of the observed eye on the observer's retina Ro.
    - ⇨ Therefore, AB and A1 B1 are conjugate foci at the point of reversal.
    - ⇨ when AB is inside XY ➔ the red reflex is brightest (Fig. 14.14 and 14.l5a).

- *Dull (dim) red reflex:*
  - A dull red reflex occurs if the mirror is changed slightly (Fig. 14.15b Shows that XY has moved with slight change in the position of the mirror so one edge of the image AB of the observer's pupil is in darkness while the other edge is in light).

- *Dark red reflex:*
  - A black red reflex occurs with further movement of the mirror (Fig. 14.15c shows that the mirror has moved more and XY has completely left AB and now the image AB of the observer's pupil is completely dark).

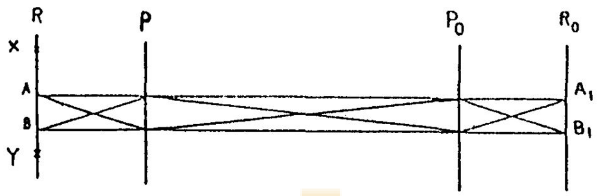
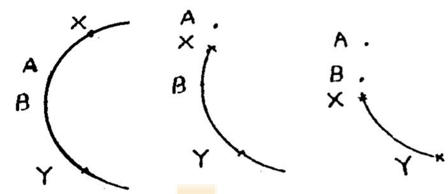


Fig.14.14: Brightest RR at neutral point.



(a) Brightest (b) Dull (dim). (c)Dark.

Fig.14.15: 3 Changes in brightness of RR. at NP.

- <u>Methods of detection of the neutral point:</u>
  - *Positioning and Alignment*
    - Position yourself at the same level as the patient at approximately arm length (75cm)
    - Uses the right eye to perform retinoscopy on the patient's right eye, and the left eye for the patient's left eye.

  - *Fixation and Fogging*
    - Retinoscopy should be performed with the patient's accommodation relaxed.
      - Patient should fixate at a distance on a non- accommodative target (Children typically require cycloplegia)
    - Place your head so that it almost obscure the patient view of the distant light source
  - *Test in the dark room*

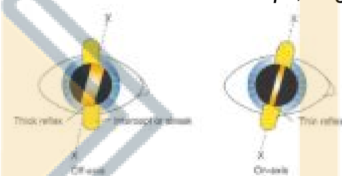
A. *<u>With the plane mirror method or with the focusing spot retinoscope:</u>*
   i. *If there is a spherical error only:*
      - ✓ Neutralize by adding spherical lenses (convex or concave) until the red reflex movement is abolished and its brightness is at maximum and followed by a complete darkness.

   ii. *If there is a regular astigmatism:*
      - ★ Neutralize the lower meridian first.
      - ★ *Then we correct the other meridian by either:*
        - Higher spherical lenses.
        - Cylindrical lenses with the axis along the band reached.

B. *<u>With the streak retinoscope:</u>*
   - *Principles:*
     - *<u>Finding the cylinder axis</u>*
       - *Before the powers in each of the principal meridians are determined, the axes of the meridians must be determined.*
       - *Four characteristics of the streak reflex aid in this determination:*
         1. *Break:*
            If the intercept (streak) is not oriented parallel to one of the principal meridians ➔ The retinal(pupillary) reflex will be not aligned with the intercept, and the line appears broken.

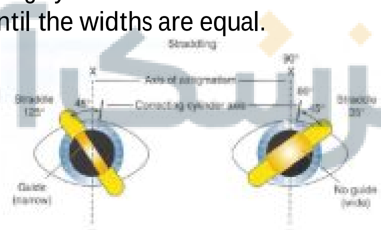
2. *Skew: (oblique motion of the retinal reflex): may be used to refine the axis in➔ <u>small cylinders</u>.*
   - *If the intercept (streak) is not oriented parallel to one of the principal meridians,➔ it will move in a slightly different direction from the pupillary reflex (Fig 4-12). The reflex and streak move in the same direction when the streak is aligned with one of the principal meridians*

3. *Width:*
   The width of the pupillary reflex in the pupil varies as it is rotated around the correct axis. The reflex appears narrowest when the intercept, aligns with the axis.



4. *Intensity:*
   The intensity of the line is brighter when the streak is on the correct axis.

- This axis can be confirmed through a technique known as <u>straddling</u>,
  - ⇨ With the correcting cylinder in place ➔ the retinoscope streak is turned 45° off-axis in both directions,
    - If the axis is correct, the width of the reflex should be equal in both off-axis positions.
    - If the axis is not correct, the widths will be unequal in these 2 positions.
  - ⇨ The axis of the correcting cylinder should be moved toward the narrower reflex and the straddling repeated until the widths are equal.



<u>Finding the cylinder power</u>

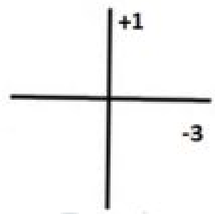
After the 2 principal meridians are identified, Neutralization as follow;

- <u>With 2 spheres:</u>
  - Neutralize 1 axis with a spherical lens; then neutralize the axis 90' away. The difference between these readings is the cylinder power.
  - For example, if the 90' axis is neutralized with a + 1.50 sphere and the 180' axis is neutralized with a +2.25 sphere, the gross retinoscopy is + 1.50 +0.75 x 180. The examiner's working d istance (ie, + 1.50) is subtracted from the sphere to obtain the final refractive correction, plano +0.75 x 180.

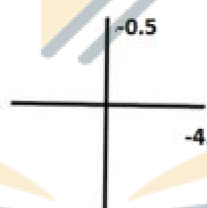
- <u>With a sphere and cylinder:</u>
  - Neutralize 1 axis with a spherical lens.
    - To enable the use of with reflexes, neutralize the less plus axis first.
  - Then, with this spherical lens in place,➔Neutralize the axis 90° away by adding a plus cylindrical lens.

- The spherocylindrical gross retinoscopy is read directly from the trial lens apparatus.

- ***<u>The recording of the retinoscopic results:</u>***
  - This is usually done in the form of a cross (power cross) which indicates the neutralization point of the two main meridians and also their orientation Fig. 14.17).
  - The right eye is recorded on the left half of the page and the left eye on the right half.
  - As we sweep the retinoscope back and forth, we are really measuring the power along only a single axis. If we move the retinoscope from side to side (with the streak oriented at 90°), we are measuring the optical power in the l80° meridian. Power in this meridian n is provided by a cylinder at axis 90°.
    - For example: if neutralization occurred with -3D while sweeping in the 180 meridian (i.e. slit was vertical) and with +1D while sweeping in the 90 meridian. What is the power cross?



- ***<u>The calculation of the final refraction</u>***: This is obtained by deducing:
  a. The dioptric value at the observer's working distance: 1 D for 1m or 1.5 D for 2/3m.
  b. The effect of ciliary muscle if paralyzed with a mydriatic cycloplegic during retinoscopy: 0.5-1D.



Corrected for Working distance (1.5D)

- <u>Spectacle prescription:</u>
  - <u>Convert the power cross as usual</u>: -0.5/-4.00 × 90

OR

  - <u>From the trial frame directly without the power cross (standard method):</u>

> *Neutralization:* The point at which the streak disappears and the pupil becomes completely filled with light (Fig. 14.16d) or completely dark
>
> *We work on the central part of the red reflex :* As it corresponds to the macula to avoid:
> a. Negative and positive aberrations.
> b. The shadow.

- Difficulties in detection of the neutral point:
  - <u>If there is irregular astigmatism with scissors red reflex:</u> It is eliminated by either:
    - The lens which causes the two bands of light to move (meat) in the centre of the pupil.
    - Altering the gaze of the observed eye.

- ☆ <u>If there is keratoconus with spinning red reflex:</u>
  - ➪ We work at the central part of the red reflex.
  - ➪ *The stenopaeic slit may be used:*
    - ☛ It is placed in the trial frame and rotated until the patient sees best.
    - ☛ This meridian is corrected first with spherical lenses.
    - ☛ Then the meridian at right angle is also corrected.
- ☆ <u>If there is a spherical aberration by the crystalline lens with a dilated pupil</u>: We work at the central part of the red reflex.

Checking of the neutral point:

- o *After detection of the neutral point it <u>can be checked by</u>:*
  1. <u>If the power of the lens in the trial frame is Increased by 0.5D:</u> The movement of the red reflex will be reversed.
  2. <u>If the observer moves his head backwards:</u> The red reflex moves against the movement of the mirror.
  3. <u>If the observer moves his head forwards:</u> The red reflex moves with the movement of the mirror.

- NB: The name "neutral point" is better than the name point of reversal because if reversal of the movement of the red reflex is taken this would mean overcorrection.

<u>Summary of Retinoscopy</u>

The performance of streak retinoscopy using a plus-cylinder phoropter is summarized in the following steps:

1. Set the phoropter to 0 D sphere and 0 D cylinder. Use cycloplegia if necessary. Otherwise, fog the eyes or use a nonaccommodative target.
2. Hold the sleeve of the retinoscope in the position that produces a divergent beam of light. (If the examiner can focus the linear filament of the retinoscope on a wall. the sleeve is in the wrong position.)
3. Sweep the streak of light (the intercept) across the pupil perpendicular to the long axis of the streak. Observe the pupillary light reflex. Sweep in several different meridians.
4. Add minus sphere until the ret inoscopic reflex shows with motion in all meridians. Add a li ttle extra minus sphere if uncertain. If the reflexes are dim or in distinct. consider high refractive errors and make large changes in sphere (-3 D.-6 D. -9 D. and so on).
5. Continue examining multiple meridians while adding plus sphere until the re tinoscopic reflex neutralizes in 1 meridian. (If all meridians neutralize simultaneously, the patient's refractive error is spherical; subtract the working distance to obtain the net retinoscopy).
6. Rotate the streak 90° and position the axis of the correcting plus cylinder parallel to the streak. A sweep across th is meridian reveals additional with motion. Add plus cylinder power until neutrality is achieved.
7. Refine the correcting cylinder axis by sweeping 45° to either side of it. Rotate the axis of the correcting plus cylinder a few degrees toward the "guide" line. The brighter and narrower reflex. Repeat until both reflexes are equal.
8. 8-Refine the cylinder power by moving in closer to the patient to pick up with motion in all directions. Back away slowly, observing how the reflexes neutralize.
9. Change sphere or cylinder power as appropriate to make all meridians neutralize simultaneously.
10. Subtract the working distance (measured in diopters). For example, if the working distance is 67 cm, subtract 1.5 D (1.00/0.67).
11. Record the streak retinoscopy findings and, when possible, check the patient's visual acuity with the new prescription

✱ ***Dynamic retinoscopy:***

- Definition:
  - It is an objective measurement of the refractive state of the eye with the patient's eyes fixed at a near distance while he is actively accommodating and converging (unlike static retinoscopy with the patient's eyes fixed at infinity or with a cycloplegic drug to relax the accommodation).

- Uses and methods:

  A. *Determination of the near point of accommodation:*
  - A self-luminous retinoscope is used for dynamic retinoscopy while the patient is wearing the correcting lenses for distance as has been determined by the static retinoscopy.
  - The patient fixes and accommodates binocularly upon a target in front of the retinoscope (as the patient's Finger held by the examiner).
  - The target is brought nearer and nearer to his eyes until the band of light and shadow in his pupil is reversed despite his strongest effort of accommodation for the distance of the target.
  - The surgeon then moves closer to the patient until the reversal movement stops which measures the near point of accommodation (if it occurs at 33. cm from the eye, the total accommodation is 3D).

  B. *Objective measurement of refraction when eye is focused for near vision:*
  - The patient wears the correcting lenses for distance and he is asked to fix binocularly and focus the target placed at his working distance (say 33 cm).
  - With a plane mirror effect and a patient with full accommodative power, a with movement is obtained.
  - This is neutralized with the addition of convex lenses (+0.50D or +0.75 D) to the trial frame to give the low neutral point.
  - Further convex lenses are then added with gradual relaxation of accommodation until the shadow is reversed marking the high neutral point (unlike in static retinoscopy where a rapid reversal of the shadow is obtained).
  - This high neutral point represents an objective measurement of refraction when the eye is focused for near vision which is an objective finding of the negative relative accommodation.

- Static and dynamic retinoscopy findings:
  a. Dynamic retinoscopy findings are taken if both static and dynamic retinoscopy findings are similar.
  b. Postcycloplegic test is essential if the static and dynamic retinoscopy findings are not similar.

TELESCOPES

✱ Definition:

↳ An optical device used to magnify distant objects

✱ Principle:

↳ Any telescope is characterized by

- Composed of 2 lenses (except 2 concave)
- No vergence = Power is Zero = Afocal
  - ➜ Rays enter // and Emerge //
  - ➜ Angular magnification occurs
- Distance between the 2 lenses:
  - ➜ Sum of their focal lenses (Astronomical)
  - ➜ Difference between their focal lenses (Galilean telescope)

- Power: $F = F_1 + F_2 - S F_1F_2$

  F= Power of the system
  F1= power of objective lens
  F2= Power of the eyepiece lens
  S= Distance between the 2 lenses.

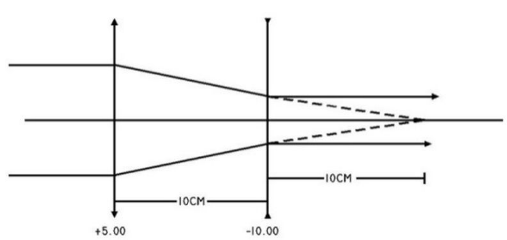
(1) GALILEAN TELESCOPE:

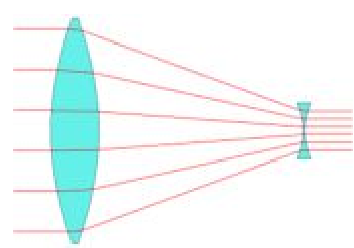
✱ *<u>Principles of Galilean telescope lenses (Fig.21.1) :</u>*

- Composition:
  a) A convex objective lens.
  b) A concave eyepiece lens.

- The distance between the objective and eyepiece lenses:
  ↳ Equal to the difference between their focal lengths.

- The incident and the emergent rays:
  1. The image of an object at infinity is formed by the convex lens at its f2.
     - ➜ This image now becomes ➔ an erect virtual object for the concave eyepiece lens lying at its F1.
  2. Thus rays from the virtual object are rendered ➔ parallel by the concave lens.
     - ➜ Therefore, the incident and emergent rays are parallel.





- The eyepiece intercepts the converging rays coming from the objective, rendering them parallel and thus forming, to the infinite (afocal position), a virtual image, magnified and erect.

✱ *Advantages:*

(1) Erect magnified image.
(2) The system is compact and so can be mounted in a spectacle frame.
(3) It can be adopted for viewing near or distant objects.

✱ *Disadvantages:*

i. Reduced field of view of 17° or less due to ➔ high magnification.
ii. Reduced depth of focus due to Magnification. Thus, the object–lens distance is critical.
iii. The object to be seen➔ is held closer to the eye.

✱ *Magnification:*

1. *Magnification occur through➔ increasing the angle subtended by the object at the eye:*

- Angular magnification: $M = \frac{ae}{ai}$

  Where, ae = Angle of emergence.
  ai = Angle of incidence.

  ☛ Angular M of telescope for distant vision ➔ range 1.5x to 8x.

- Mathematically: $M= \frac{Fe}{Fo}$

  Where, Fe = the power of the eyepiece lens in D.
  Fo = the power of the objective lens in D.

✱ *Convertion into a microscope for near vision (as in the surgical loupe:*

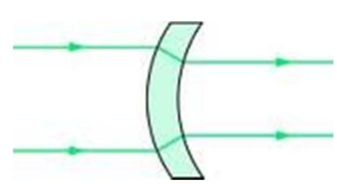
- By putting a magnifying lens M2 over the convex objective lens M1.
- The effective M = telescopic M x M of the magnifying lens.
- Galilean telescopic spectacles are preferred when the maximum reading distance needed by the patient is attained with the least reading addition.

✱ *Power:*

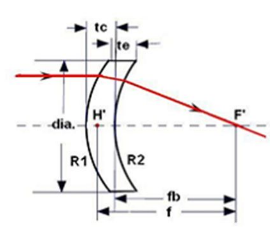
☆ *Objective lens:* Usually +20 DS (with spherical or aspherical curvature).
☆ *Eyepiece lens:* Usually -20 DS to -40 DS (In addition to the refractive error):

✱ Applications:

1. Low vision aid: e.g. Telescopic spectacle
2. Insturments:
   - Slit lamp
   - Operating microscope,
3. Afocal lenses:
   - The concave and convex surface cancels each other
     ↳ No refraction ➔ only magnification
   - Used in treatment of ansiokonia



4. Aphakia with correction
   - Eye regarded as high minus
   - Corrected with high plus
5. High myopia with correction



- Eye regarded as high plus
- Corrected with high minus

6. Thick lens (Meniscus type) act as a gallelian telescope

(2) ASTRONOMICAL TELESCOPE:
(Kepterian telescope)

✱ *Principles:*

- Composition:
  - A convex objective lens of long F2.
  - A convex eyepiece lens of short F1.
- The distance between the objective and eyepiece lenses:
  - ↳ Equal to the sum of their focal lengths.
- The incident and the emergent rays:
  1. The image of an object at infinity is formed by the convex lens at its f2.
     - ➜ This image now becomes ➔ an inverted real object for the convex eyepiece lens lying at its F1.
     - ➜ Thus rays from the real object are rendered ➔ parallel by the convex eyepiece lens.
     - ➜ Therefore, the incident and emergent rays are parallel.

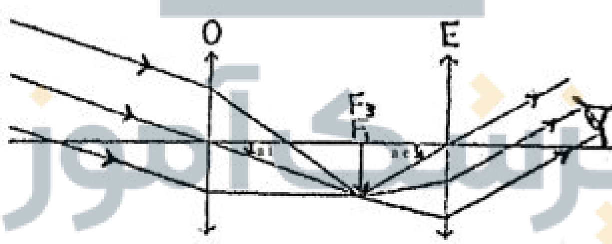


Fig.21.2: Astromical telescope.

✱ *Magnification:*

1. Angnlar magnification: $M = \frac{ae}{ai}$
2. Mathematically $M = \frac{Fo}{Fe}$

✱ *Advantage:*

↳ Large field and better image than Galilean telescope.

✱ *Disadvantage:*

- Inverted image.
- Bigger size that gallilean telescope

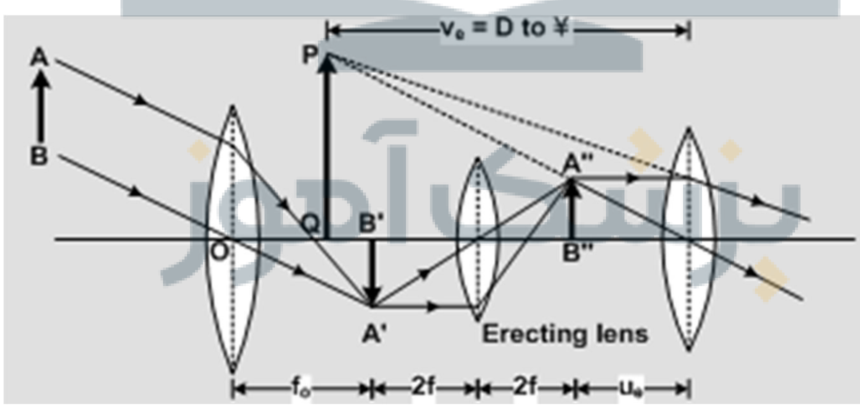
Terrestrial telescope
(Spyglass)

- The astronomical telescope forms inverted final images of distant objects (like moon and stars) which are acceptable.
    - But when terrestrial objects are to be viewed, ➔ it is necessary to have an erect final image. this can be made by
        - Introducing a third lens between objective and eye-piece of telescope.

- The incident and the emergent rays:
    - The image of an object at infinity is formed by the convex lens at its f2.
        - This image now becomes ➔ an inverted real object for the convex Extra lens lying at its 2F
        - Consequently The image now becomes ➔ An Erect real Object for the convex eyepiece lens lying at its F1.
        - Thus rays from the real object are rendered ➔ parallel by the convex eyepiece lens.
    - Therefore, the incident and emergent rays are parallel
- Magnification: ➔ As Astronomical

- Disadvantage: ➔ Long telescope

- Length of the telescope: ➔ FL of Objective + FL of eyepiece + 4 times the FL of extra lens



AFOCAL SYSTEMS IN OPHTHALMIC PRACTICE

➢ *Definition:*

- These are optical systems which
  1. Do not form real images at finite distances but form➔ virtual images and
  2. Depends on the angular magnification of the beams which pass through and not on the vergence of light.

➢ *Principle:*

- Two separate optical elements of such a power and in such position that ➔ each cancels the vergence change produced by the other.

➢ *Types:*

1. *Telescopes:*
   - Galilean (non inverting).
   - Astronomic (inverting).
2. *Meniscus type of thick lenses.*
3. *Compound microscope alone and in instruments.*

ASPHERIC LENSES IN OPTICAL APPLIANCES

Definition:

- Aspheric lenses are spectacle lenses, contact lenses or IOLs ➔ with nonspherical surfaces.

Types:

1- Toric lenses (with a toric surface): For correction of astigmatism.
2- Varifocal (progressive addition) lenses: For correction of presbyopia.
3- Aspheric lenses: For correction of:
   - Aphakia.
   - Subnormal vision.
   - Prismatic effect (spherical aberrations).

MICROSCOPES

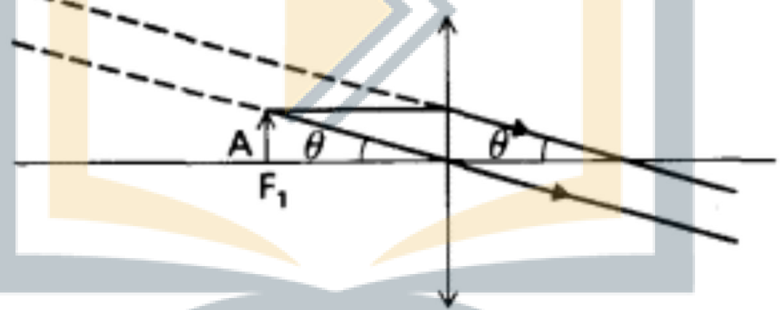
Definition:

An optical device used to magnify near objects (unlike a telescope, usually magnifies distant objects).

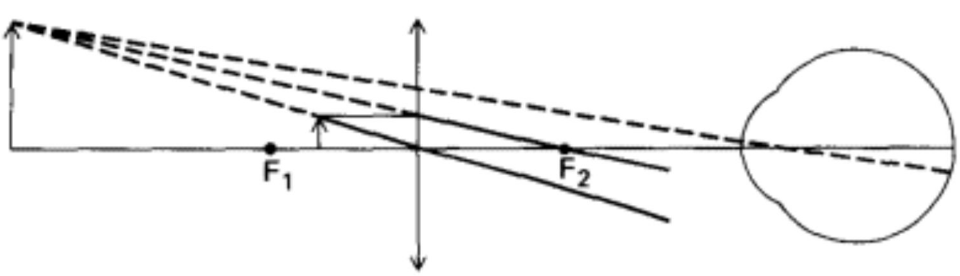
(1) THE SIMPLE MICROSCOPE:

- *Principles:*
  - *A single biconvex lens in which the object is placed at either;*

A. If the object is at F of the lens:
   - M=F/4 only (less by 20% than if the object is placed inside F).



B. If the object is inside F of the lens (Practically the object is inside F of the lens) as in a corneal loupe or magnifying lens.
   - A magnified erect image of the object is seen at the minimum distance of distinct vision (25 cm) of the observer with his eye very close to the lens.
   - *Magnification:*
     - Angle subtended by image (by microscope)/Angle subtended by object situated at S (by eye)
     - Also M=Apparent size of image/apparent size of object= Distance of image/Distance of object) = 1 + S / F.



(2) THE COMPOUND MICROSCOPE:
(LIGHT MICROSCOPE OR BRIGHT-FIELD MICROSCOPE)

✱ *Components:*

A. The observation system:
   1. Two convex lenses:
      - The objective lens of 100 - 300D.
      - The eyepiece lens of 20-50D.
   2. A stage: ➔On which the specimen is placed.

B. The illumination system: By a light source.

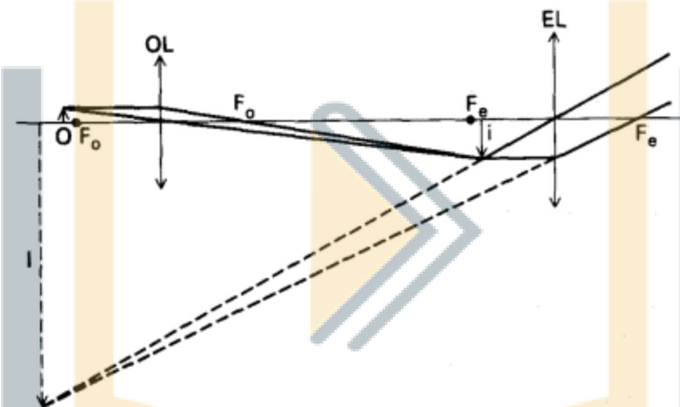


Fig. 22.1: optical principles of the compound microscope.

✱ *Optical principles (Fig.22.1):*

1. Object (O): ➔at a distance S just outside f1 (between F & 2F) of objective lens OL.
   ➔ Real inverted magnified image I some distance behind objective lens.

2. Eyepiece lens:
   ➔ The image formed by the objective lens falls at (or close to) its f1 and so ➔acts as a loupe and further magnifies the image ➔ virtual ,still inverted (horizontally and vertically) and magnified image.

3. Porro prisms:
   - To get an erect image.
   - To shorten the physical length of the microscope.

4. Magnification:
   - The maximum magnification is more than 1500 x:
     Magnification of eyepiece × Magnification of objective

     $M = (F/4 + 1)(V1 / U1)$

     Where, V1=Distance of image from objective.
     U1=Distance of object from objective.
   - The maximum resolving power: Is about 200 nm (2000 A°),

✱ *Uses in ophthalmic practice:*

(a) In ophthalmic instruments to provide magnified view of the eye as in:
1- The keratometer.
2- The operating microscope.
3- The slit lamp microscope.
4- The fundus camera.

(b) Histopathological studies: Of ocular specimens.

(1) OPERATING MICROSCOPE:

- See later

(2) THE SPECULAR MICROSCOPE:

✱ *Definition:*

- Microscopic examination of endothelial cells Using specular reflection from the interface between the endothelial cells and aqueous.

✱ *Equipment:*

- *Contact:* ➔ decrease eye movements
- *Noncontact:* ➔ wider field

✱ *Types :*

I. The conventional specular microscope: (Stationary slit)

- *Optical principles:*
  - *A slit beam is projected onto the corneal surface at an angle near the normal:*
    - *More than 99% Of light is transmitted through the aqueous due to:*
      - ✓ Corneal transparency.
      - ✓ Similar refractive indices of cornea and aqueous.
    - *Less than 1% of light is reflected and scattered from:*
      - corneal epithelium, stroma, endothelium and Aqueous interface (0.02%).
    - *A portion of the reflected and scattered light is collected:*
      - By the objective lens and an image is produced on a film plane.

II. The wide field specular microscope: (Moving slit)

- It records a large field of endothelium.
- Increasing the angle of incidence of the illuminating source allows for a wider slit and thus a wider field. However;
  - Image quality suffers due to increased illumination and scattering from the corneal stroma and epithelium. ➔

- Decreased contrast and loss of cellular definition results.
- endothelial cells will appear shortened in one direction

- Modern solution:
  - Small slits/spot- improve image quality & it can be scanned over the tissue for a larger field of view.

Uses of the specular microscope:

1. Examination and photography of the corneal endothelium for:
   a) Studying its response to trauma (as in phacoemulsification).
   b) for documentation.
2. Measurement of endothelial Cells count:
   - By superimposing a transparent grid on the endothelial cell image.
   - By computer analysis of number, density, distribution of ➔ form and size of cells.
3. Examination and photography of corneal epithelium and stroma.
4. Study of the anterior segment of the eye including lens, iris and anterior vitreous face.

Measurement of the thickness of the cornea and the depth of AC by an attached pachometer.

- NB: normal cell count in youngs exceeds 3000 cells/mm →gradually decreases with age.

SLIT-LAMP BIOMICROSCOPE

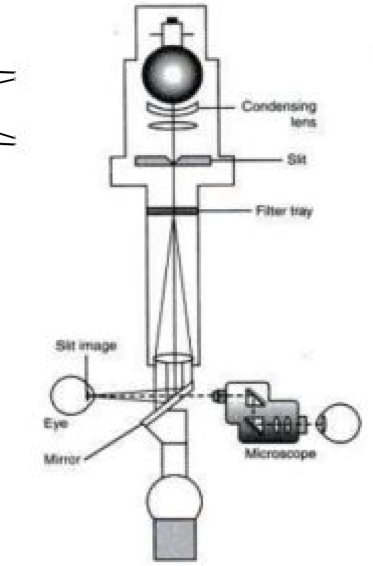


Fig. 12.2. A cross section of the observation system of a modern slit lamp.

- *Component of the slit-lamp biomicroscopy:*
    - An illumination system
    - Binocular stereoscopic compound microscope
    - Mechanical System

1. Binocular stereoscopic compound microscope:

- *A relatively low-powered two compound microscopes mounted at an angle of about 14° to each other (to give the observer a binocular stereoscopic view)*

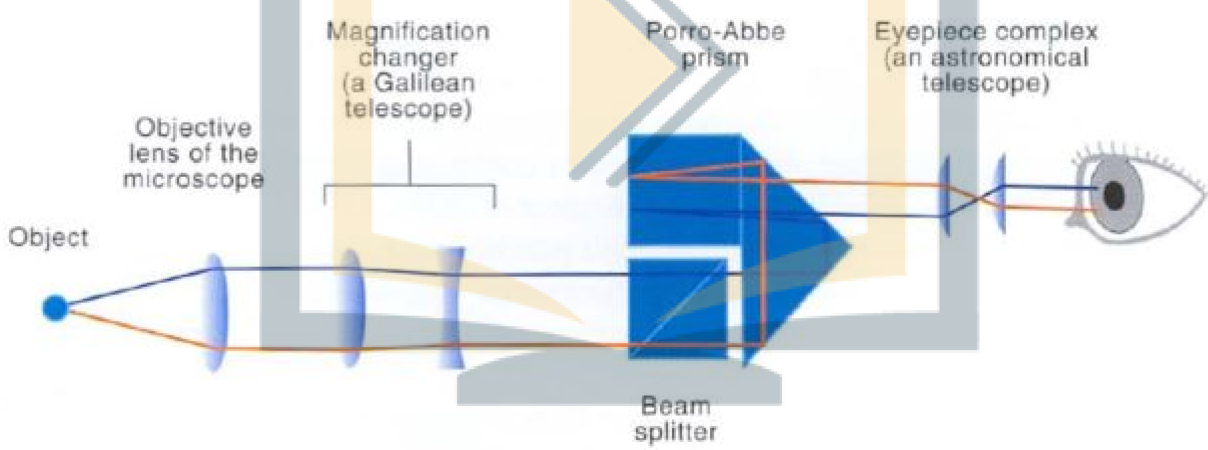


Fig.23.1: Binocular stereomicroscope.

1. *Eyepiece* (An astronomical telescope):
    - Consists of 2 convex lenses.
    - The image produced is magnified and inverted.

2. Inverting Prisms: (porro-Abbe Prism)
    - They are 2 triangular prisms arranged to reflect light (by TIR) several times, resulting in
        - An Optically sharp, inverted image with no magnification and little loss of light.
    - They compensate for the inverted image produced by eyepiece

3. *Telescopic or zoom lens system:* to
    - vary magnification and
    - to increase the working distance of the compound microscope from few mm to 20cm:

A. Galilean telescopic system:
- Consists of a single convex lens and a single concave lens, (separated by the difference of their focal lengths).
  - The image produced is erect and magnified, so no additional inverting prism is necessary.

- NB: If the telescope is reversed (with the object now closer to the concave lens), the image is minified. Many microscope designs use this optical "trick" to allow variable magnification. A knob or lever rotates the lenses to reverse their positions. This turns the system into a "reverse" Galilean telescope.

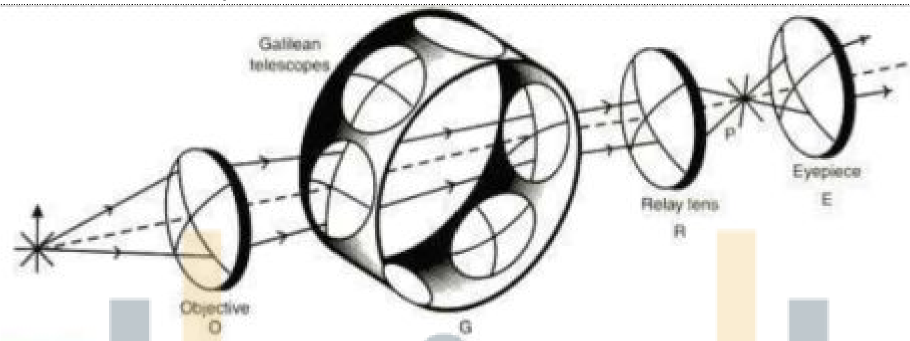


Fig. 12.3. Galilean magnification changer (G) is placed between the slit-lamp objective (O) and the relay lens (R) which focuses the light through a prism erector (P) into the eyepiece (E).

B. Zoom lens system (G):
- o The simplest zoom effect can be obtained by placing a single movable concave lens between the microscope lenses (Fig. 23.2).

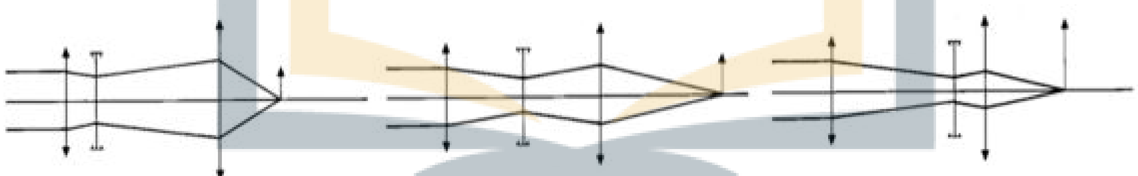


Fig. 23.2 Simple uncompensated zoom lens system.

C. Change the eyepiece lens
D. Change the objective lens

4. *Objective lens*
- The object is placed at F of the objective lens
- This provide // rays to the Gallelian telescope and thus the objective lens ➔ move the working distance from infinity to approximately 10 cm in front of the microscope.

✱ *Magnification:*
- ★ M=5x -50x (better 10, 16 and 25X,) as resolution is limited with greater M.
- ★ M is changed by lenses of different powers or by zoom lens system.

2. Slit-lamp illumination system:

1. *illumination:*
   - <u>*Halogen lamps:*</u>
     - Higher luminance (i.e. intense brightness and whiteness).
     - Higher colour temperature (greater blue end of spectrum) → greater scattering and fluorescence of transparent media.

2. *Condenser systems:*
   - <u>*Value:*</u>
     - To gather and project light into the objective lens to ➔ achieve maximum image brightness.
   - <u>*Principle:*</u>
     - Consists of a couple of planoconvex lenses with their convex surfaces in apposition.

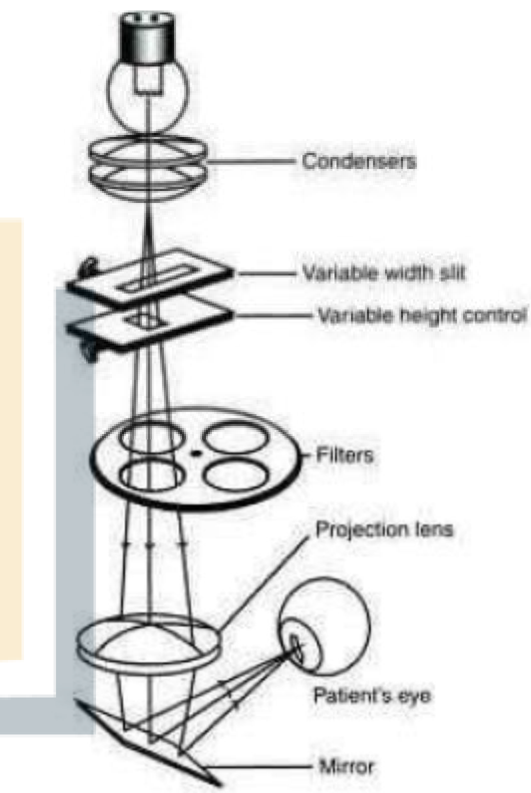


Fig. 12.4. Typical slit-lamp illumination system.

3. Slit & other diaphragm:
     - slit height and width can be varied using two knobs

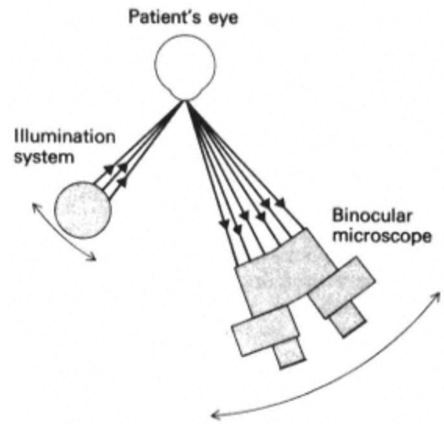
4. *filters:*
   - <u>Absorption filters:</u> ➔ To change the composition of the light for certain examinations:
     - Blue cobalt filter: Is used during applanation tonometry.
     - Green (red free) filter: For examination of the vitreous because:
       i. The scattering of light is greatest when the incident light is of short wavelength.
   - <u>Neutral density filters:</u> ➔ To control the intensity of light.

5. Projection Lens:
   - It forms an Image of the slit at the eye.
   - The diameter of the projection lens is usually fairly small. This has two advantages
     1) It keeps the aberrations of the lens down which results in a ➔ belter quality Image;
     2) It increases the depth of focus of the silt and thereby produce➔ a better optical section of the eye.

6. Reflecting mirror or prism:
   - Forms the final component of the illumination system.
   - It reflects light along the horizontal axis into the eye.

3. Special mechanical system:

- It combines both ➔ microscope and illumination system.
- It make both of them have
    - ➜ A common focal plane and
    - ➜ A common axis of rotation for the microscope and the light system.



✱ ***Methods of Illumination:***

1. Direct Focal Illumination
    - ⇨ The slit beam is accurately focused upon that part of the eye under inspection.

2. Diffuse Illumination
    - ⇨ The beam of light is thrown slightly out of focus across the structure being examined so that ➔ a large area is diffusely illuminated.
    - ⇨ This can be a particularly helpful way of looking at the anterior capsule of the lens.

3. Lateral Illumination
    - ⇨ This technique involves illuminating the structure being examined by light which is reflected from tissue just to one side of it.
        - ➜ For instance, if a beam of medium width is directed upon the margin of the pupil, the outer rim of the sphincter muscle becomes apparent.

4. Retro-Illumination
    - ⇨ This technique involves illuminating the structure being examined by light reflected from a structure behind it.
    - ⇨ The structure behind is used as a mirror to illuminate the part of the eye in question.
        - ➜ A good example of retro-illumination is when areas of iris atrophy are identified by light which is reflected from the choroid. The illuminating column of the slit lamp should be brought to lie between the objective lenses of the microscope so that the illuminating and viewing systems are co-axial.

5. Specular Reflection
    - ⇨ This is a method of examining the surface by examining the rays of light reflected from it.
    - ⇨ The corneal surfaces and the anterior lens capsule can be examined in this way.
    - ⇨ Bearing in mind the laws of reflection the patient's gaze is directed to bisect the angle between the axis of illumination and that of the microscope.

6. Sclerotic Scatter

- When the slit beam is directed on to the limbus at, for example, the 9 o'clock position, ➔ the whole limbal area glows. The maximum glow will be at the 3 o'clock position.
- The light from the slit beam is reflected backwards and forwards between the two internal limiting surfaces of the cornea and it is scattered centrifugally all around the cornea.

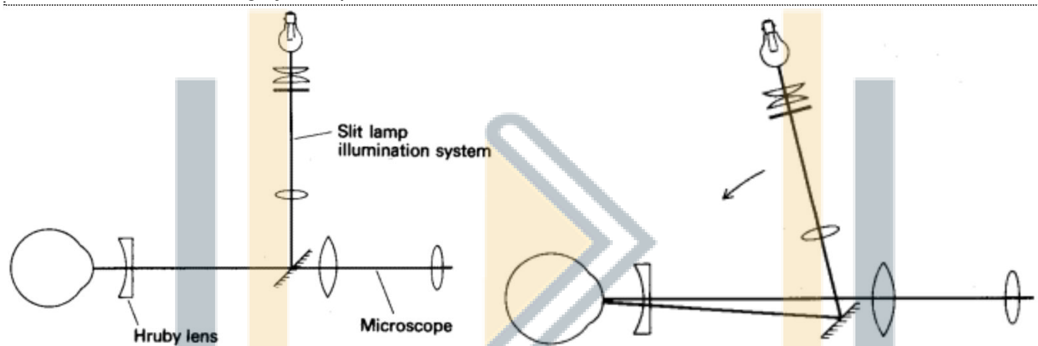
7. Slit illumination: To make and examine sections in clear ocular structures.

AUXILIARY (ACCESSORY) LENSES FOR EXAMINATION OF FUNDUS AND VITREOUS

✱ *Basic principles:*

- *With the basic slit lamp it is not possible to see further back into the eye than the anterior third of the vitreous*:
  - The auxiliary lens abolishes the corneal refraction. So ➔ the rays coming from the fundus are brought within the focusing range of the microscope.

- *The illumination column of most slit lamps can be tilted (Fig. 23.5):* So that the axis of the illumination system can be thrown below that of the viewing system (this tilting of the illumination system avoids its overlap with the viewing system and so light reflected from the cornea does not enter the viewing system).



(a) Before tilting of illumination column. (b)After tilting of illumination column.

Fig.23.5: Tilting of the illumination system of the slit lamp.

✱ *Types of auxiliary lenses:*

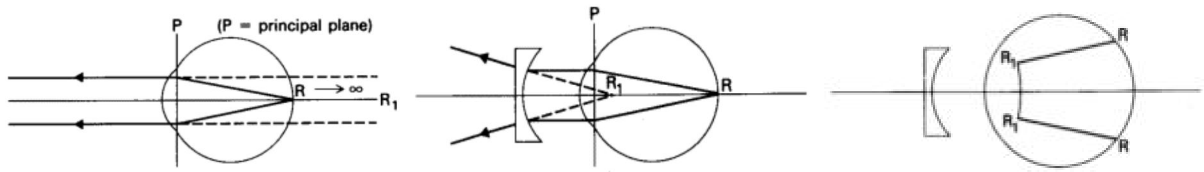
I. Planoconcave lenses:

- *General principles:*

The lens forms ➔ an erect virtual intermediate image of the fundus within the focusing range of the microscope.

- Types of planoconcave lenses:

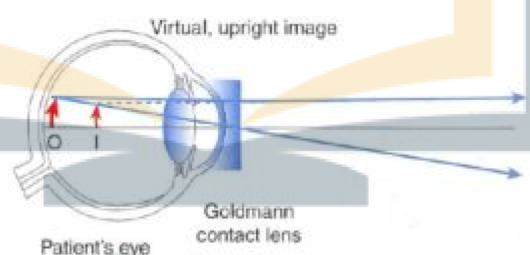
1. Hruby lens:
   - Type:
     - Non-contact planoconcave lens of ➔ -58.6 D ➔ placed with its concave surface immediately towards the cornea (Fig. 23.6a).
   - Principle:
     - It forms ➔ a virtual erect and intermediate image of fundus, anterior to retina and within the focusing range of the microscope:



(a) (b) (c) (d)

- <u>Working distance of the lens:</u>
  - The lens held at a distance of 15 mm from the patient's cornea i.e. at F1 of the eye (and so an object located at F2 of the eye appears with a magnification of 1:1).
- <u>Uses:</u>
  - Examination of the axial parts of the fundus and vitreous (up to 30° vertically and 60° laterally).

2. Goldman posterior fundus contact lens:
   - Type:
     - It is a planoconcave contact lens of ➔ -64 D, of a higher refractive index than the cornea ➔ placed with its concave surface in contact to the cornea.
   - <u>Principle:</u>
     - It forms ➔ <u>a virtual erect and diminished image</u> of fundus, anterior to retina and within the focusing range of the microscope:



- <u>Working Distance:</u> ➔ in contact with the cornea
- <u>Uses :</u>
  - Examination of the axial parts of the fundus and vitreous (up to 30° from the axis of the eye).

> - <u>The advantages of Goldmann fundus contact lens over Hruby lens:</u>
>   a. Lateral and axial magnification is independant on the refractive error.
>   b. The monocular and binocular field of view are wider.
> - <u>The advantages of Hruby lens over Goldmann fundus contact lens:</u>
>   - ❑ Examination of medium lateral periphery of fundus up to 60°.
>   - ❑ Examination of the sensitive patients and shortly after surgery.

1. Goldmann one-mirror contact lens:
   - <u>Principle:</u>
   - It is a planoconcave contact lens with:
     - *Mirror tilted at 62° with anterior surface of lens:* For angle of AC.
       - The image is ➔ erect and magnified but laterally reversed.

2. Goldmann 3-mirror contact lens:

- *A planoconcave contact lens with 3 mirrors with different inclinations:*
    i. *Central part:* ➔ For axial parts of the fundus and vitreous (the central 30°).
    ii. *Mirror tilted at 73°(largest mirror):* ➔ For medium lateral periphery of the fundus (30°-60°).
    iii. *Mirror tilted at 67°(longest mirror):* ➔For the peripheral parts of the fundus and ora serrata.
    iv. *Mirror tilted at 59°(smallest mirror):* ➔For the retrociliary part of fundus and angle of AC.

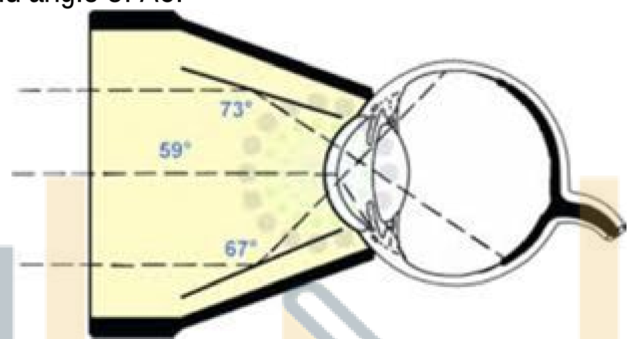


Fig. 23.7: Goldmann 3-mirror contact lens:

<u>Planoconvex lenses:</u>

- Principles:
    - It produces ➔ a real inverted intermediate image of the fundus between the lens and the slitlamp (as in indirect ophthalmoscopy) and so the slit lamp microscope is moved away from the patient.

- Types of planoconvex lenses:
    (1) El-Bayadi lens: Of +58.6 D (Fig. 23.8).
    (2) Schlegel contact lens.

- The advantages of the planoconvex lenses over the planoconcave lenses:
    1. A very large monocular or stereoscopic field of view.
    2. Examination of highly myopic eyes where the displacement of the microscope away from the eye is required (with myopia of-20 D the displacement is 18 mm for the Hruby lens and 7 mm for the Goldmann fundus lens).
    3. Lateral and axial magnification are independent of refractive state of the eye
        - in El-Bayadi planoconvex lens (but not in Schlegel planoconvex lens).
- Disadvantage:
    - Planoconvex lenses are not used to see the vitreous: Due to abnormal field curvatures.

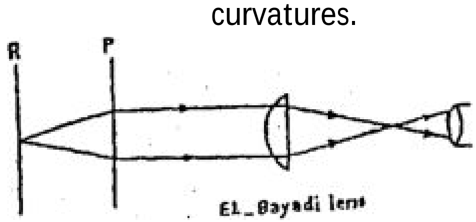


Fig.23.8: El-Bayadi planoconvex lens. Fig.23.9: Volk's + 90 lens.

II. *Volk's double aspheric +60 D,+78 D and +90 D lenses:*

- *Type: Non-contact* double aspheric biconvex +60 D, +78 D or +90 D
- Principle*:*
  - It produces ➔ a real inverted image of the fundus as in indirect ophthalmoscopy (Fig. 23.9).
  - The 90 D lens gives a wider field of view but less magnification than the 78 D lens.

- Working distance of+90D lens:
  - Is 8 mm from the patient's cornea with 4-6mm pupil dilatation (up to 10 mm if widely dilated pupil) with a maximum field of view of 60°.

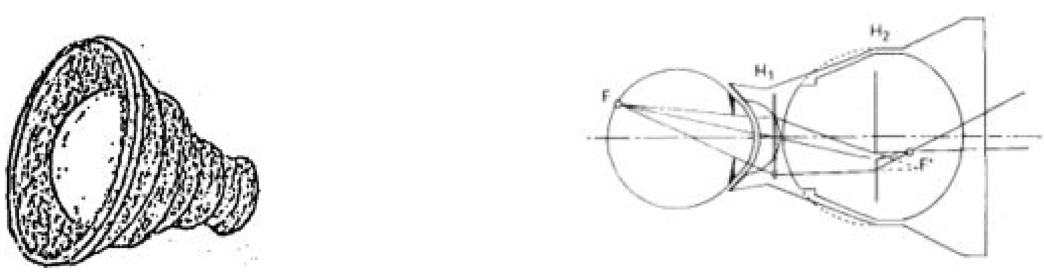
- Uses*:*
  - It allows scanning of the posterior pole, the peripheral retina and vitreous.

- Slit lamp magnification with +90 D lens:
  - Lower M of 5-7X: When learning the Volk+90 D procedure.
  - Moderate M of 15 X for:
    - Full field of view of 60°.
    - Excellent details.
  - Higher M of 30-40 X:
    - For follow-up of extreme details.
    - For photography.

III. *Rodenstock Superfield Panfundoscopic lens:*

- Principle:
  - It consists of
    (1) A meniscus lens applied to the cornea and is coupled with
    (2) a spherical lens (i.e. 2 lens system; Fig. 23.10)
  - it produces ➔ an inverted and reversed, slightly reduced image of the fundus (in a plane within the anterior part of the spherical lens) which is enlarged by the magnification of the slit-lamp.

- Advantage:
  - The whole fundus can be seen In one view without moving the lens.



(a) Side view. (b) 2 lens system (inverted, reversed and sliglitly reduced image).
Fig.23.10: Panfundoscope:

APPLANATION TONOMETER

- ***Definition:***
  - It is used to measure the IOP.

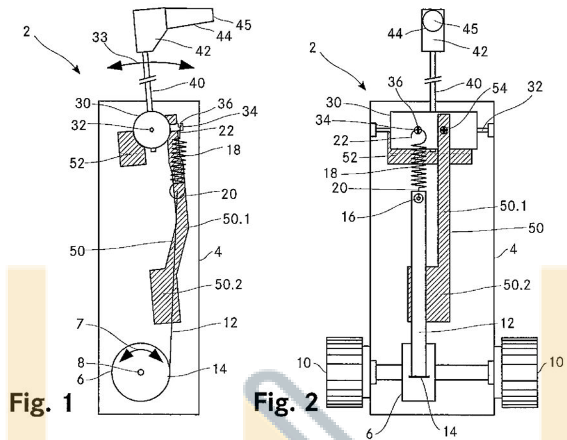
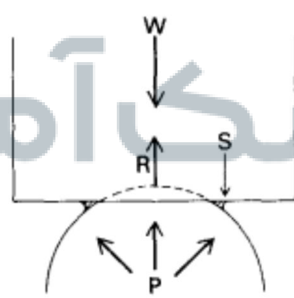


Fig. 1 Fig. 2

- A device (2) for determining an intraocular pressure of an eye comprises a measurement arrangement with a measurement body (44), attached to a measurement arm (40), for applanation of the eye and a rotary knob (10) which is attached to a shaft (6). The measurement arm (40) is attached radially to a pivot axis (32) and the measurement arrangement comprises a mechanical coupling between the rotary knob (10) and the pivot axis (32), with a rotation of the rotary knob (10) being able to generate an applanation force required for applanation of the eye. The mechanical coupling comprises tension transmission means (12) attached to the pivot axis (32) via a first lever arm (34), and to the rotational axis (8) of the shaft (6) via a second lever arm (6).

- ***Optical principles:***
  - Based on Imbert-Fick law:
    - Pressure within a sphere (P) is roughly equal to the external force (W) needed to flatten a portion of that sphere divided by the area (A) of the sphere which is flattened: $P = f / A$



- The standard area of contact: ➔ 3.06 mm at which:
  1. Effect of surface tension (S) and rigidity of the cornea (R)➔ cancel each other out thus
     - The Force (W) applied is ➔ directly proportional to the IOP (P).
  2. The ocular volume change caused by the tonometer is➔ very small and does not significantly alter the intra-ocular pressure

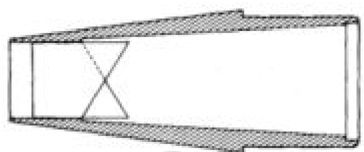
When the area of contact is 3.06 mm in diameter, R = S and W is proportional to P

- The Area of contact:

- o The tonometer head is applied to the cornea with sufficient force to produce the standard area of contact 3.06 mm
  - *More than 3.06 mm:* ➔ Corneal rigidity leads to inaccuracy.
  - *Less than 3.06 mm:* ➔ Surface tension causes error.

- Components:
  1. The applanation head: Spring loaded lever with adjustable tension on the spring.

  2. The doubling unit:
     - ➪ In order to achieve a standard area of corneal contact➔ the applanation head contains two prisms, mounted with their bases in opposite directions to act as a doubling unit which➔ bisects and shifts the image of the applanation area laterally by 3.06 mm.



(b)Doubling prism

     - ➪ When the cornea is applanated, ➔ the tear film-which rims the circular area of applanated cornea-appears as a circle to the observer.
       - ➜ The tear film is often stained with fluorescein dye and viewed under a cobalt blue light to enhance the visibility of the tear film ring.
       - ➜ Higher pressure from the tonometer head causes the circle to have a larger diameter because a larger area of cornea is applanated.
       - ➜ Split prisms- mounted ➔ create 2 images offset by exactly 3.06 mm.
       - ➜ When the half circles just overlap one another ➔ At this point, the circle is exactly 3.06 mm in diameter, and the reading on the tonometer (multiplied by a factor of 10) represents the IOP in mill imeters of mercury

(c)Correct applanation area.

  3. The measuring drum: is connected to a rotatory knob and is calibrated from 0 to 10 (which is multiplied by 10 to get the IOP in mmHg).

➢ *Procedure:*
1. A drop of fluorescein solution into conjunctival sac after surface anaesthaesia.
2. Increase the light source to max intensity with blue filter in place and the slit opened fully.
3. The measuring drum is turned to graduation line 1 to bring the measuring head into its frontal end position.

4. The position of applanation head is adjusted to face the patient's cornea and then slowly approach the whole slit lamp toward the eye, when the tip is within centimeter from the cornea, ➔ use the joystick to gently bring the tip into contact under direct vision, the limbus will light up when you have made contact.

• Stop moving forward when limbus shines with light, best observed with naked eye

5. The examiner looks through the left hand eyepiece of the slit lamp microscope (i.e. through the applanation head) and sees that the green circle of corneal contact is splitted into two green half circles which are laterally displaced in opposite directions by the 2 prisms.

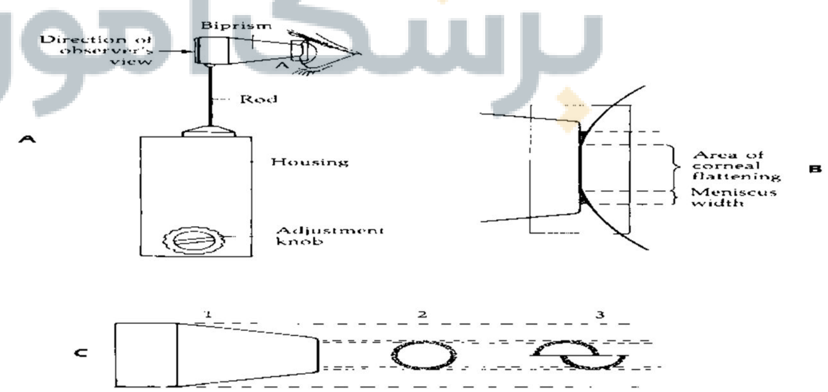
6. Now Adjust the dial to alter the force on the prism until ➔ the half circles just overlap one another (i.e. until the inner boundaries of, the two green half circles are in contact) and thus the applanation surface is 3.06mm (Fig.23.10c).

7. The value read from the measuring drum must be multiplied by 10 to get the intraocular pressure in mm mercury

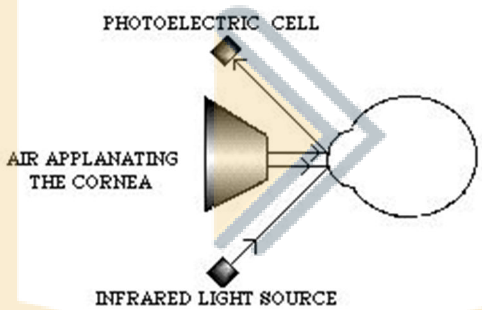
8. If there is a high degree of corneal astigmatism, the area of contact will be elliptical, not circular, and an error of the order of 1 mmHg. Per 4 dioptres of astigmatism will result.

   - ➜ The correct area of contact will be achieved if the measurement is made by applanation at ➔ 43° to the meridian of lower corneal power (43° to the axis of the minus cylinder).
   - ➜ The prism is marked in degrees. If the prism is mounted with the axis of the minus cylinder at the red mark ➔ it is then correctly aligned to take the reading at 43° to the meridian of lower corneal power.

➜ See pitfalls and tricks in Goldmann Applanation Tonometry PPT by Ted Barnett

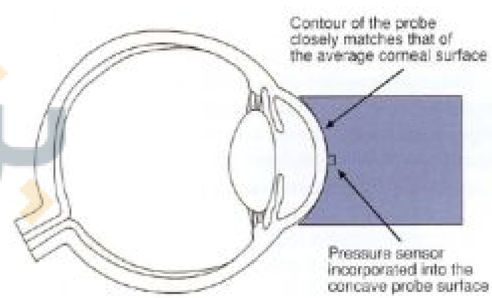


- ***Non-Contact Tonometer:***
  - ☑ Tonometers have been developed which flatten the cornea with a puff of air, avoiding the need for the instrument to touch the eye.
  - ☑ Corneal applanation is measured by collecting light reflected from the central cornea: A parallel beam of light is directed on to the central cornea at an angle of 30° and the reflected light is measured by a photodetector at an angle of reflection of 30°.
    - The reflected beam of light will be strongest at this angle when the cornea is flat and acting as a plane mirror, rather than as a curved mirror.
  - ☑ The instrument records the force of air required to flatten the cornea and displays the intraocular pressure which corresponds to that force.
  - ☑ The air tonometer must be used at a set distance from the cornea, and the instrument incorporates an optical alignment system to facilitate this.



Dynamic Contour Tonometry

- Although Goldmann applanation tonometry is the current gold standard for clinical measurement of IOP,
  - Its accuracy is limited because
    - A. The instrument is required to deform the surface of the cornea in order to take each measurement.
    - B. Many factors, especially central corneal thickness, can substantially affect its accuracy.



- Dynamic contour tonometry attempts to minimize these factors by shaping the surface of the probe to accommodate the shape of the human cornea (Fig 8-25).
  - When the concave probe is placed in contact with the cornea, deformation of the cornea is minimized.
- The IOP is measured by a pressure sensor in the center of the probe surface.
- The device can be mounted on a slit lamp and is advanced toward the patient's eye in a fashion similar to that of a Goldmann tonometer.
- A microprocessor measures IOP continuously, even detecting pulsatile fluctuations.

PACHOMETER

✱ Definition:

- ➜ Pachymeters are instruments used to measure corneal thickness.
- ➜ These values are especially important in
  1. refractive surgery and
  2. In monitoring corneal edema.

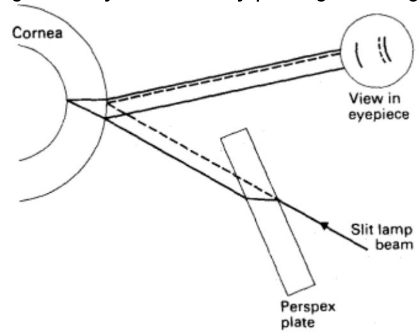
- The 3 main methods for measuring corneal thickness are
  1. optical doubling,
  2. optical focusing, and
  3. Ultrasonography.
  4. Scanning slit topographers

1. Optical doubling,

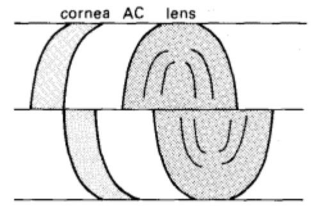
- Principle: ➔ Doubling of Purkinje image

1. Purkinje images:
   - The Purkinje-Sanson images formed by anterior and posterior corneal surfaces (images II and I) ➔ is used to measure the corneal thickness.
   - The Purkinje-Sanson images formed by the posterior corneal surface and anterior lens surface (images II and III) ➔ is used to measure the AC depth.

2. Doubling of Purkinje images:
   - The Doubling Device: is used in conjunction with a slit-lamp biomicroscope.
   - Methods:
     1. *In Maurice and Giardine pachymeter*:
        - ➜ A perspex plate (covered by coloured celluloid) having a cut-out area➔ is placed in the slit lamp beam.
          - Some light proceeding undeviated via the cut-out zone (dotted line) and some being laterally deviated by passage through the perspex plate.

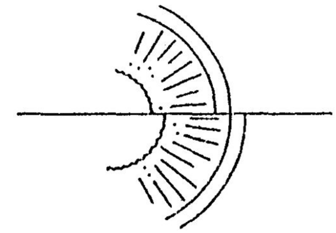


(a) Pachymeter of Maurice and Giardine



2. In Jaeger pachymeter: ➔ Two glass plates
3. An image-doubling prism (similar to that used in keratometers and applanation tonometers)
4. *In Haag Streit 900 slit lamp: ➔ specially adapted eyepiece* (which is substituted for the normal slit lamp eyepiece).

- Alignment :
  - The endpoint is reached when the images are superimposed; a measurement of corneal thickness can then be directly read off a scale (Fig 8-26).



2. Optical focusing

- Principle:
  - In the optical focusing technique,
    - a specular microscope is calibrated so that when the endothelium is in focus, ➔the corneal thickness measurement is automatically displayed.
    - The zero is established by focusing on the interface between the contact element and the epithelial layer.

3. Ultrasound Pachymetery

- Principle:
  - It measure corneal thickness, in the same way ultrasound measure the axial length of the globe.
    - ➔ If the velocity of sound in the cornea is known and if the precise time required for sound waves to pass through the cornea can be measured, ➔ the thickness of the cornea can be calculated.
    - ➔ Multiple measurements allow construction of a 2-dimensional map of corneal thickness

4. Scanning slit topographers

- Orbscan & PentaCam: see later

(1) OPERATING MICROSCOPE:

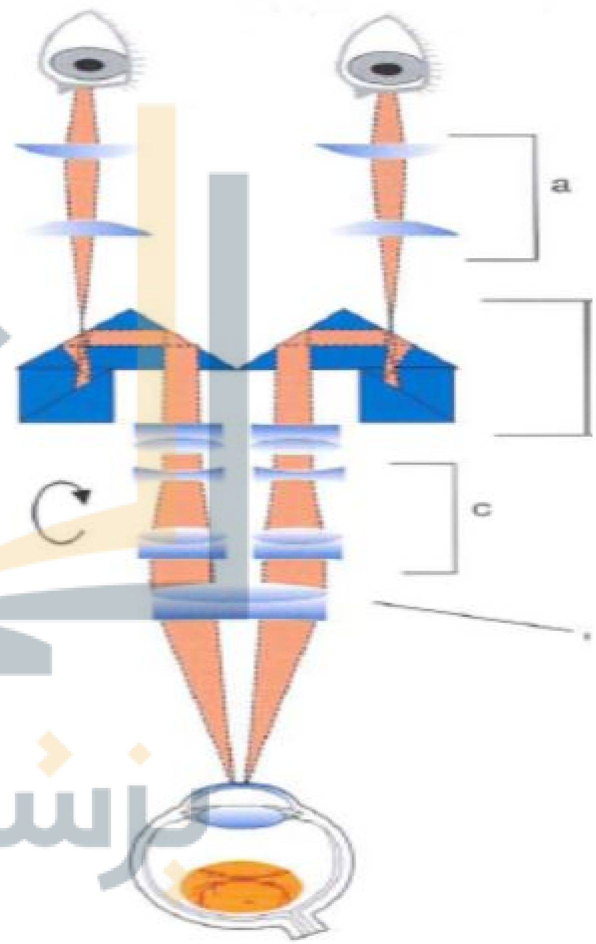
✱ *Definition:*

- Two compound microscopes mounted at an angle of about 14° to each other to➔ give the observer a binocular stereoscopic view.

✱ *The optical principles:*

- Are the same as that of the ➔ Compound microscope
  - Same constituents as slit lamp which consist of
    1) Astronomical telescope (eye piece)
    2) Inverting prism
    3) Galilean telescope
    4) Objective lens
    5) Light source
    6) Binocular viewing system

➔ But Unlike Slit lamp; Microscope has a longer working distance and illumination is not slit shaped



a)An eyepiece, an astronomical telescope, which provides most of the magnification;
b)An inverting prism, such as a Porro-Abbe prism,which compensates for the inverted image produced by the eyepiece;
c)A magnification changer, such as a Galilean telescope system, in which different lenses can be introduced to change the magnification; and
d)An objective lens which adjusts the working distance.

- Two parallel optical systems, each a mirror image of the other, provide a stereoptic view of the patient's eye.

1. The observation system:

A. *The main binocular stereoscopic microscope:*

1. *Two eyepieces:* (Astronomical telescope)
   - Consists of 2 convex lenses.
   - The image produced is magnified and inverted
   - Provide magnification 10 -15x, is connected to
2. Inverting Prisms: (porro-Abbe Prism)
   - They are 2 triangular prisms arranged to reflect light (by TIR) several times, resulting in

- ⇨ An Optically sharp, inverted image with no magnification and little loss of light.
- they compensate for the inverted image produced by the eye piece

➜ The two erect prism boxes are connected to a 45 inclined eyepiece tube.

3. *The microscope body which contains:*
   1. *Telescopic or zoom lens system:* to
      - vary magnification and
      - to increase the working distance of the compound microscope from few mm to 20cm:

      A. Galilean telescopic system:
      - Consists of a single convex lens and a single concave lens, (separated by the difference of their focal lengths).
        - ➜ The image produced is erect and magnified, so no additional inverting prism is necessary.

- NB: If the telescope is reversed (with the object now closer to the concave lens), the image is minified. Many microscope designs use this optical "trick" to allow variable magnification. A knob or lever rotates the lenses to reverse their positions. This turns the system into a "reverse" Galilean telescope.

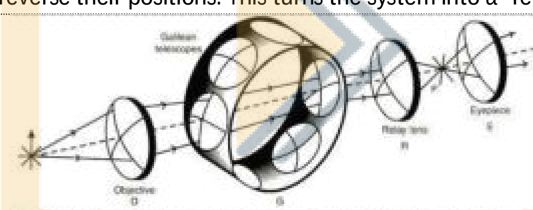


Fig. 12.3. Galilean magnification changer (G) is placed between the slit lamp objective (O) and the relay lens (R) which focuses the light through a prism erector (P) into the eyepiece (E).

      B. Zoom lens system (G):
      - The simplest zoom effect can be obtained by placing a single movable concave lens between the microscope lenses (Fig. 23.2).
   2. A magnification indicator window.
   3. Assistant microscope

4. *The objective lens:*
   - F of the objective lens is 15-20 cm.
   - The object is placed at F of the objective lens
   - This provide // rays to the Gallelian telescope and thus the objective lens ➔ move the working distance from infinity to approximately 15-20 cm in front of the microscope.

⇨ The total M of the operating microscope is 6 x to 40 x.

⇨ The field of view is 5-10 mm in diameter.

- NB: The distance between the patient's eye and surgeon's eye is 35-40 cm.

5. *The beam splitter:*
   - The beam splitter is placed between the eyepiece tube and microscope body and it provides splitting of the light beam through the microscope

objective into two dimensions, one to the photographic attachment and another one to the teaching head.

- *The assistant binocular stereoscopic microscope:* It consists of
  1. two eyepieces and
  2. two erect prism boxes and
  3. One objective.

2. The illumination system:

- *Source of illumination:*
  - *Halogen lamps or fiber optic delivery systems:*
    - ✪ Advantage of halogen:
      1. Higher luminance ➔ intense brightness and whitness
      2. Greater blue end of the spectrum ➔ greater scattering & fluorescence of transparent media
      3. No thermal effect (inert gas)
- Types of illumination:
  1. Coaxial :
     - For visualization of posterior capsule
     - For vitreous surgery
  2. Oblique:
     - Anterior segment surgery (Avoid corneal reflections)
- Hazards of illumination:
  - ⇨ Prolonged exposure of retina to direct light ➔ Retinal burn.

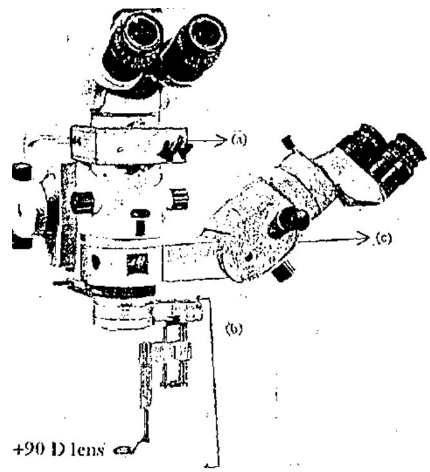
✱ Accessories:

✱ Operating microscope equipped with slit lamp biomicroscopy:

- *Use in posterior segment surgery:*
  - ✪ Adjustment:
    - The proper angle between the slit illumination beam and the axis of observation beam must be between 5-11°, so that both beams focus on the same fundus spot.
  - ✪ Advantages *(over indirect ophthalmoscope):*
    1. *Higher magnification*
    2. *Biomicroscopic observation of the fundus*
  - ✪ Disadvantages:
    1. *Reduced field of observation than indirect ophthalmoscope →overcome by:*
       1. Use low M for entire fundus and high M for retinal tear itself.
       2. Goldmann 3-mirror contact lens (but it interferes with cryo-application)
    2. *Need Training.*

- *Use in anterior segment surgery:*

- Adjustment
    - By changing the angle between the slit beam and axis of observation to an angle of 30°.



- Fig. 26.2: Operating microscope with :(a) Stereoscopic diagonal Inverter (b) Non-contact binocular indirect ophthalmomicroscope (with a front lens of +90D usually), (c) Assistant binocular stereoscopic microscope.

✱ Operating microscope equipped with binocular indirect ophthalmomicroscope (BIOM,):

- *Principle:*
  - Same principle of BIO.
- *Advantages:*
  1) Wide observation angle (up to 120°).
  2) Non-contact to the cornea.
  3) Perfect mobility of the eye to see the far periphery of the fundus easily.

- Stereoscopic diagonal inverter (SDI, Fig.26.2):
    - It consists of 2 right-angled prisms2 Porro prisms, (placed between the 2 eyepieces and objective of the operating microscope).

    - It erects the inverted image of the observation system such as
        - the binocular indirect ophthalmomicroscope or
        - A wide field contact lens.

REFRACTOMETERS

✱ *Definition:*

- Are devices incorporating banks of lenses for measuring the refractive state of the eye.

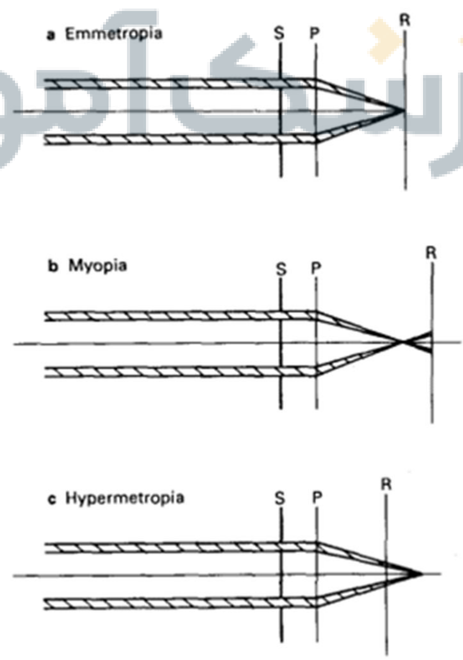
✱ *Basic principles:*

1. Scheiner double pinhole principle (Fig. 27.1):

- *Double pinhole apertures (Scheiner disc):* Placed before pupil to isolate 2 small bundles of light from a distant source of light.
    1. *If the eye is emmetropic:*
        - ➔ *The rays of the 2 bundles form a single focus on the retina*
    2. *If the eye is myopic:*
        - ➔ The rays of the 2 bundles cross each other before reaching the retina and 2 small spots of light are seen.
    3. *If the is hypermetropic:*
        - ➔ The rays of the 2 bundles are intercepted by the retina before they meet and 2 small spots of light are seen.

- *By adjusting the position of the object (mechanically or optically) until one focus of light is seen by the patient*: ➔the far point of the patient's eye and the refractive error can be determined.

• *This is the earliest of a class of 'zonal focus' methods of refraction:* in which the overall refractive condition is determined by examining through small zones of the optical aperture.



- A convex lens: ➔ is placed in front of the eye so that its focus lies in the spectacle plane and
- A movable target ➔ is viewed through the lens (Fig.27.2a).

  - ✪ If the target lies at the first principal focus of the lens,
    - ⇨ Light from the target will be parallel at the spectacle plane, and focused on the retina of the emmetropic eye (Fig. 27.2b).
  - ✪ If the target is within the F1 of the lens,
    - ⇨ light from it will be divergent in the spectacle plane (simulating a concave trial lens) (Fig. 27.2c)
  - ✪ If the target is outside F1 of the lens
    - ⇨ Light from it will be convergent in the spectacle plane (simulating a convex trial lens) (Fig.27.2d).

- The vergence of the light in the spectacle plane ➔ is linearly related to the distance of the target from the first principal focus of the lens.

- The term 'optometer' was first used in 1759 by Porterfield who described an instrument for 'measuring the limits of distinct vision, and determining with great exactness the strength and weakness of sight'.

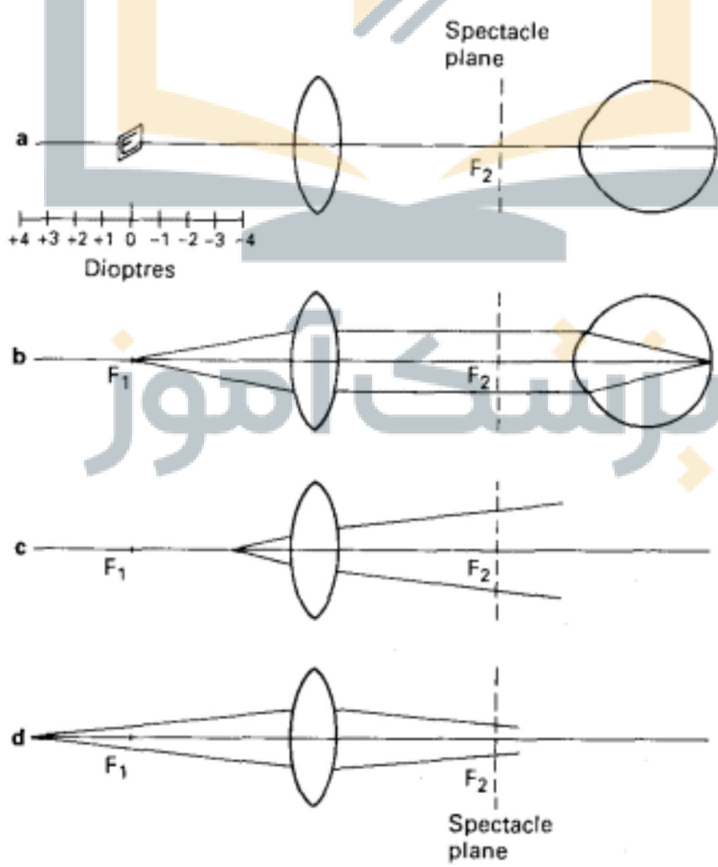


Fig. 27.2: Optometer principle.

3. Meridional Refractometry:

- In the presence of astigmatism,
  - It was realized that if the spherical refraction is measured in at least three arbitrary meridians, ➔the position of the principal axes and their refractive power can be found by mathematical calculation.

4. Grating focus principle:

- *A moving grating of light:* ➔Is projected into the eye (which utilize the whole pupil).
  - ⇨ *The focus of the grating on the retina is then analyzed by a photodetector*.

5. Automated Retinoscopy principle:

- In which neutralization of retinoscopic reflex is not performed but the speed of reflex in each meridian is determined.

6. Continuously variable spherocylindrical power:

- It is based on the fact that any refractive correction can be simulated by the sum of: A variable sphere or two variable cross cylinders.

✱ *Types of Refractometers:*

A. Objective refractometers:

1) Early objective refractometers:
   - Principle*:*
     - ⇨ *It rely on the examiner decision on when the image is clearest or aligned*
     - ⇨ *It was basesd on schiener and optometer principle*
   - Drawbacks*:*
     - *Alignment problem:*
       - *Both pinhole aperature must fit into the patient pupil, if the patient moves ➔ error in reading.*
     - *Irregular astigmatism :*
       - onty 2 small aperature is examined (not the whole pupil)
     - *Accommodation (instrument Myopia)*

2) Automated objective refractometers (Infrared Optometers):

   1. Automated Infrared Refractometer:
      - The patient is refracted using invisible IR light to overcome instrument accommodation
      - A separate distant target must still be provided to relax the accommodation while the IR is used to measure his refraction
      - Disadvantage:

- ☛ The refraction for IR differ from its refraction to visible light
  - ➩ This difference range from 0.75 to 1.5 D more hypermetropic to the IR, because infrared light is not reflected by the same layers of the retina as visible light (it may be reflected from choroid or sclera) however the instrument is calibrated to overcome this error

2. Photorefraction:
   - Depend on photography of patient fundus
3. Electrophysiologic method:
   - Using VEP
   - Advantage: test the whole visual pathway
   - Disadvantage: Doesn't measure astigmatism accurately

B. Subjective automated refractometers:

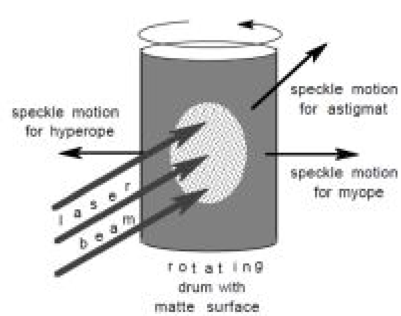
I. Early subjective refractometers:

- These optometer require the patient to adjust the instrument for the best focus or best alignment of parts of the target.
  - ✰ Drawbacks:
    - ▪ Instrument accommodation (so these optometer were unsuccessful)
  - ✰ Example:
    - ▪ Badel optometer
    - ▪ Young optometer

II. Modern subjective Optometers:

1. Laser speckle pattern refraction:

   Principle:
   - ➯ When a laser beam strikes a roughly diffusing surface (matte surface),➔ an observer sees a characteristic speckle pattern.
     - ▪ If the observer is an ametrope, he still sees the pattern sharply and clearly without his glasses.
     - ▪ If the observer is Myopic: ➔ the speckle will move against his head movements,
     - ▪ If the observer is Hypermetropic: ➔ the speckle will move with his head movements,
   - ➯ A patient's refraction may be determined by placing lenses in front of the patient until the pattern stops moving.



2. Computer activated refraction:
    - Principle:
        - A computer system ➔ performs refraction using the conventional refraction techniques.
            - ➜ It is equipped with a full range of trial lenses, cross cylinder, prisms & Maddox rod.
        - Visual acuity slides are➔ presented to the patient by the computer and the patient respond by pressing the button.

3. Multimeridional refractometery: see before.
4. Continous variable spherocylinderical power: see before.

↳ *Comparison of objective and subjective refractometers:*

1. *Operating skill and patient cooperation:*
    - ⇨ Less needed in objective refractors.
2. *Measurement time:*
    - ⇨ 0.2-10 seconds only in objective refractors and
    - ⇨ 2-8 minutes in subjective refractors.
3. *Light use:*
    - ⇨ Subjective refractors use visible light while objective refractors use invisible infrared light, ➔no stimulation of accommodation.

4. *Instrument accommodation:*
    - ⇨ Occurs when the target to be viewed is within an instrument, and therefore near the eye. It has been a major problem in subjective design.

5. *over-refraction*: Is present in subjective refractors but usually not in objective refractors due to:
    A. Reflections from glasses or contact lenses.
    B. Inadequate pupil size with intraocular lenses.
6. *Binocular refraction for distance and for near:*
    - ⇨ With the Humphrey subjective vision analyzer only.
7. *Corrected visual acuity:*
    - ⇨ Is determined in subjective refractors but not in objective refractors except the Humphrey automatic refractor.

8. *Results with ocular disease*.
    - ✪ Macular disease: Objective refractors give better results.
    - ✪ Cloudy media: Subjective refractors give rough refraction with less than 6/18 VA while objective refractors do not function properly.
9. *Optical system:*
    - ⇨ Usually spherocylindrical in subjective refractors, but spherical only in objective refractors.

- The subjective optometers proved unsatisfactory because of alignment problems, irregular astigmatism and instrument accommodation.

FOCIMETER (LENSMETER)

✱ *Definition:*

⇨ Optical device that measures the vertex power of a lens or contact lens

➔ (Trade names: Focimeter, lensmeter, ultimeter, vertometer and refractionometer).

✱ *Uses:*

1. Measurement of the vertex power of a lens accurately and directly.
2. Measurement of the axis of a cylinder.
3. Location of optical centre of lens to detect and calculate the power of a prism.
4. Measurement of the back vertex power of a soft contact lens.
5. Measurement of the posterior central curve (base curve) of a hard contact lens.

✱ *Optical principles:*

A. *Non-Badel lensmeter design:*

✪ Principle:

- An illuminated target is moved back and forth behind the unknown lens
- At the position were the target is at the FL of the unkown lens ➔ the emergent rays become parallel and these parallel rays when viewed through the eyepiece produce a clear image indicating that FL of the unknown lens power is found.
- Taking the inverse of the FL ➔ gives the power of the unknown lens.

✪ Disadvantage:

1. The instrument would have to be too long (0.25D lens need 4 meters)
2. The scale of measuring the power of the lens would be non linear
   ➔ Therefore measurement of more powerful lens would be less accurate.

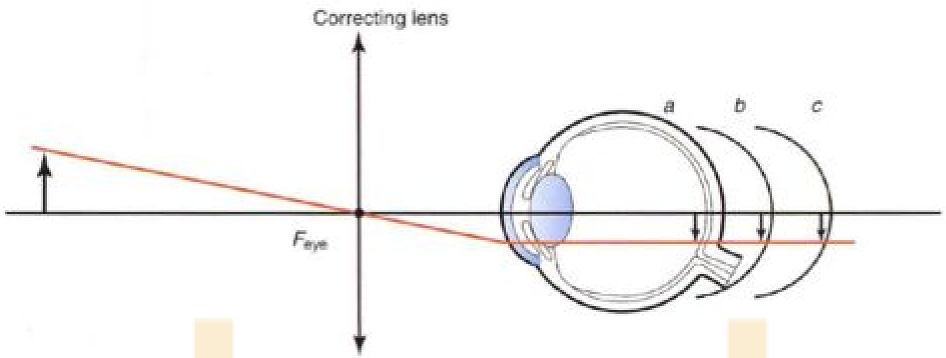
B. *Badel (optometer) lensmeter design:*

☛ Both problems in non badel principle is overcomed by the introduction of a another lens to the system called the standard (field or collimating) lens and using an optical trick called the badel principle.

✪ Badel principle:

- According to Knapp's law, ➔ the size of the retinal image does not change when the center of the correcting lens (to be precise, the posterior nodal point of the correcting lens) coincides with ➔ the anterior focal point of the eye (Fig 2-54).

- Manual lensmeters make use of the same principle, although for an entirely different reason. When applied to lensmeters, Knapp's law is called➔ the Badal principle.

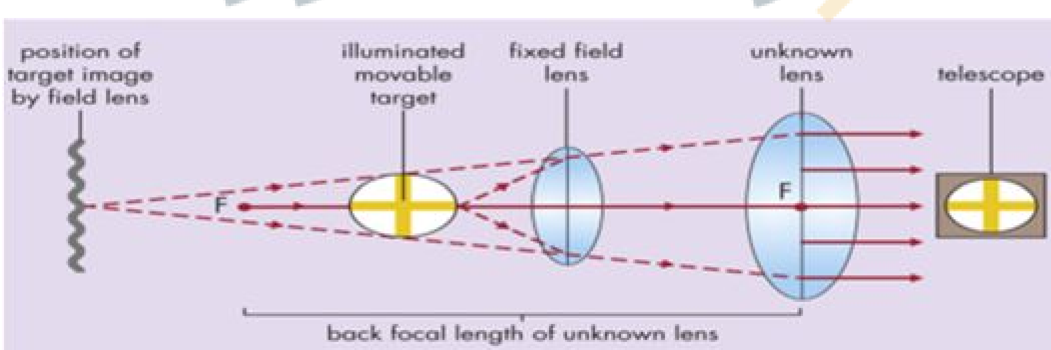


- For example, if eyes have identical refractive power and differ only in axial length, then placing a lens at the anterior focal point of each eye will produce retinal images identical in size. However, it is rare that the difference between eyes is purely axial. In addition, the anterior focal point of the eye is approximately 17 mm in front of the cornea but most people prefer to wear spectacles at a corneal vertex distance of 10- 15 mm.
- Because the clinician is rarely certain that any ametropia is purely axial, Knapp's law has limited clinical application.

- One type of optometer used for performing objective refraction is based on a variation of Knapp's law wherein the posterior focal plane of the correcting lens coincides with the anterior nodal point of the eye, The effect is the same, Retinal image size remains constant. In this application, the law is called ➔ the optometer principle,

- The fixed-field lens is situated so that its focal point is on the back surface of the unknown lens being analyzed, (Because the focal point of the field coincides with the position of the unknown lens, all final images are the same size (Badal principle)).

- The unknown lens, in turn, sends parallel light to the observation telescope. Thus, the small movement of the target is amplified optically and in such a way that the distance between the target and field lens is always directly proportional to the power of the unknown lens.



The lensometer resembles an optical bench. The moveable illuminated target sends light to the field lens, with the target in the endpoint position.

✪ Advantage:

A. The scale of measuring the power of the lens would be linear
B. Target magnification is independent of unknown lens, thus eliminating errors in high plus lens measurement.
C. The instrument wouldn't have to be too long.

A. Components:

- *Standard focimeter:* Consists of two main parts (Fig. 29.1):
  - ✪ *The focusing system:*
    1. *The illuminated target:*
       - Which is a light source is projected into a Disc with a ring of holes.
       - *Green light* ➔ is used to eliminate chromatic aberration.
    2. *A collimating lens:*
       - *A* high plus lens which renders light parallel.
    3. *The unknown lens:*
       - The unknown lens being tested is placed in a special rack against the lensmeter aperture stop.
    - ⇨ The position of the collimating lens is fixed but the target may be moved relative to it.
  - ✪ *The observation system:*
    a. *A telescope:* With an adjustable eyepiece.
       - Telescope is added for precise detection of parallel rays at neutralization thus prevents examiner refractive error from causing significant measurement error.

    b. *The eyepiece contains a graticule and protractor scale:* ➔To measure the direction of the axis of a cylinder.

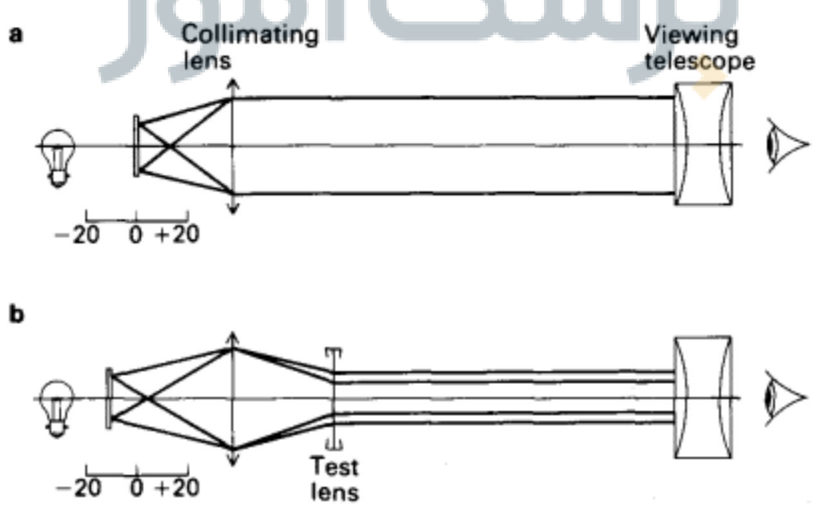


Fig. 29.1 The focimeter.

- *Automated focimeter*:
  - it replaces the viewing telescope by a projection screen
  - Badel principle can be applied to automated focimeters BUT most automated focimeters on the market employ the non-Badel type with a different optical system (astronomic optics) utilizing mirrors, prisms and lenses.

B. Operating principles:
- Before use the instrument should be set to zero and the eyepiece adjusted until the dots and the graticule scale are sharply focused.

1. *Measurement of the power of a spherical lens:*
   - ★ Focimeter measures the vertex power of the lens surface in contact with the lens rest and so the back surface of the spectacle lens must be against the lens rest.
     - The distance through which the target is moved is directly related to the dioptric power of the unknown lens under test.

2. *Measurement of the power of a cylindrical lens:*
   a) *The dots of the target are seen as ➔ lines:*
      - The length of the lines being proportional to the difference between the two principal powers
   b) *The line target must be focused:* For the two principal meridians separately.
   c) *Examination of a cylindrical lens on the focimeter:*
      1) The instrument is adjusted until one set of line foci is in focus (Fig 29.3a) and the reading (+1.00 D) is recorded.
      2) Instrument is further adjusted until second set of line foci come into focus (Fig.30.3b) and reading (+3D) and axis (180') of lines are recorded.
      3) The first reading gives the spherical power of the lens.
      4) The cylindrical power is calculated by algebraic subtraction of the first reading from the second i.e. (+3)-(+1) = +2D.
      5) The axis of the cylinder corresponds to the axis of the second reading, i.e. 180°. So, the lens power = $\dfrac{+1.0DS}{+2.0DC \text{ axis } 180}$

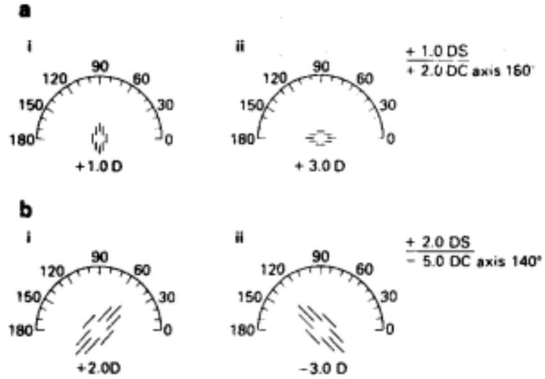
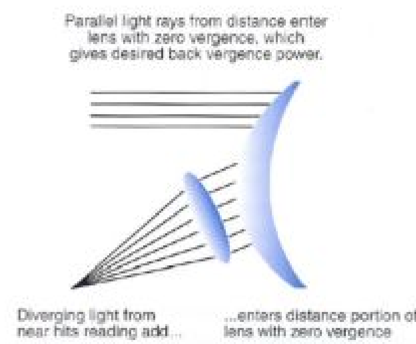


Fig.29.3: Identification of a cylindrical lens.

3. ***Measuring the bifocal add:***

- The bifocal add is different from the rest of the spectacle lens.
- The distance portion is designed to deal with essentially parallel light, The bifocal add, however, is designed to work on diverging light, originating, for example, at 40 cm from a +2.50 bifocal add.
- If one imagines the bifocal add as being an additional lens placed an infinitesimal distance in front of the distance lens, the principle becomes clearer.
  - Diverging light rays from the near object pass through the bifocal lens and are made parallel. The parallel light rays then enter the distance lens from its anterior surface and are refracted with the expected optical effect, yielding the back vertex vergence required to give the patient clear vision.
  - In a sense, the bifocal add exerts its effect on the light before it passes through the rest of the lens (Fig 8-4 1).



- Thus, the add segment should be measured from the front. The front vertex power of the distance portion is measured, and the difference in front vertex power between the distance and near portions specifies the add.
- With a distance lens of strong plus power, there will be a significant difference in the front and back vertex measurements of the add, which will cause errors if the add is not measured from the front. In cases other than a distance lens with strong plus power, there is usually li ttle or no clinically significant difference in the measurements.

4. ***Detection of the optical centre of the lens:***
   - By marking it by a marker which is incorporated in most focimeters.

5. ***Detection and calculation of the power of a prism:***

(1) Mark the optical centre on the spectacles then→ put it onto the patient and Mark where the line of sight (center of Pupil) passes through the spectacle lens (i.e. the degree of decentration of the lens).

(2) Then the prism power is given by the equation: P = D h
Where, P = the prismatic power in prism dioptres.
D = the lens power in dioptres.
h = the decentration in centimetres.

6. ***Measurement of the back vertex power of a soft contact lens:***

The contact lens surface is dried before being placed on the focimeter lens rest:
- Rapid measurement is done to avoid image distortion from lens dryness.
- The lens can be measured while it is immersed in a saline filled cell but the focimeter reading must be corrected by a specific conversion factor.

7. ***Measurement of posterior central curve(base curve)of hard contact lens:***

a. *An attachment (Fig.29.4) of the same material as the hard contact lens, fits over the lens stop of the focimeter with:*
- ☆ Its convex surface lies in the plane of the lens stop.
- ☆ Its concave surface supports the lens being measured.

b. *The hard contact lens is placed, convex surface down, on the concave surface of the attachment or holder:* With a small amount of fluid (of same RI of the lens) is placed between them.

c. *PCC(BC) of hard contact lens is calculated from the following equation:*

$$PCC=\frac{(1-n)1+\frac{t1+t2}{n}(Dv-D1)}{(Dv-D1)}$$

Where, PCC = Posterior central curve (base curve, BC).
Dv = Focimeter reading.
D1 = Power of the holder's front surface.
t1 = Holder thickness.
t2 = Thickness of the contact lens.
n = Refractive index (1.49).

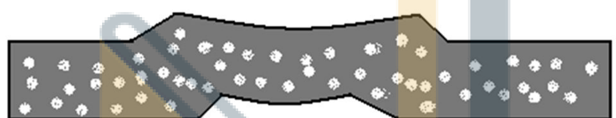


Fig.29.4: Attatchment to measure BC of hard CL.

KERATOMETER (OPHTHALMOMETER)

✱ *<u>Definition and indications</u>:*

- *It is an instrument which is used to measure:*
  1. <u>The radius of curvature</u> (r) of the central 3mm area of the anterior corneal surface (by using the first Purkinje image) for:
     - Contact lens fitting.
     - Progress of keratoconus.
     - Calculation of distances between ocular media.
  2. <u>Dioptric power of the cornea</u> (D) and corneal stigmatism.
  3. <u>Radius of curvature</u> (r) of contact lenses.

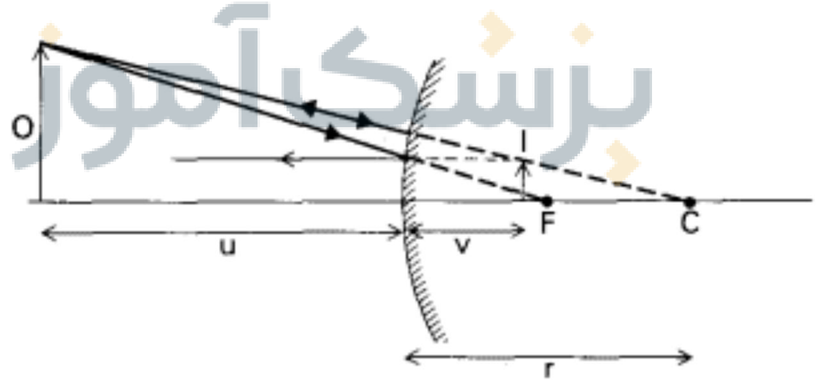
✱ *<u>The optical principles of keratometers:</u>*

(A) <u>Image formation on convex corneal surface (Fig.28.1a):</u>

➪ The anterior corneal surface reflects a small portion of any light incident upon it and thus acts as a convex mirror.

- ☛ Thus the corneal surface and curvature can be examined by studying the image reflected (1st Purkinje image).
- ☛ However, the anterior corneal surface is not spherical but elliposoid (cornea is prolate) so, ➔ it usually assumed that the central part (or axial) area us spherical and so➔ keratometer measures only the radius of curvature of the central 3 mm

★ *<u>Calculation of radius of curvature</u>:*



(a)Image formation on convex corneal surface

⭯ The principle on which the keratometer works is now explained (Fig. 28.1a).

$$\frac{I}{O} = \frac{v}{u}$$

- In practice, I is located very close to F, therefore v may be taken to equal r/2 where r is the radius of curvature of the reflecting surface. Substituting,

$$\frac{I}{O} = \frac{v}{u} = \frac{r}{2u}$$

$$r = 2u \times \frac{I}{O}$$

- In all keratometers, U is constant = focal distance of viewing telescope thus ➔ we need to know either the image or object size.
  - in Helmholtz and in Bausch & Lomb keratometers: O is fixed and I is adjusted to measure r.
  - in Javal Schiotz ophthalmometer: O is variable with a standard I

- However measuring the image formed by the reflection at the cornea is not an easy task because even small eye movements can cause image to dance about. Thus this difficulty can be overcomed by ➔ doubling the image seen by the examiner thus the examiner can easily align the images with each other even if the patient's eye were moving because both images are moving together.
- Examples of doubling:

A. in Helmholtz: ➔ 2 rotatory glass plates
B. in Javal Schiotz: ➔ Wollaston prism (2 rectangular quartz prism connected together)
C. in Bausch & Lomb keratometers: ➔ 2 doubling prisms

(B) Doubling of image seen by the examiner:

I. In Von Helmholtz ophthalmometer:

a. Doubling Device: 2 rotatory glass plates
- *Of known thickeness and RI*
- *Inclination can be varied by the observer*

- *Refraction through a glass plate:*
- A ray of light falling obliquely on a glass plate, is deviated through the glass and the emergent ray is parallel to the incident ray, but shifted laterally and this displacement depends on the angle of incidence (Chapter 4 and Fig.28.1a),

b. (O) Size: ➔ is constant (light passing through a graticule (circle).
c. (I) Size: ➔ Adjusted
d. Procedure:
1- *A beam of light is passed through a graticule (circle):* To be seen on patient's cornea (where an image I of graticule is formed by reflection).

2- *The reflected light passes back into the instrument:* Through two parallel-sided glass plates X and Y which displace light laterally as it passes through them, giving rise to ➔ two virtual images I' and I'' which are viewed through a telescope.

3- *The angle of inclination of the glass plates is varied by the observer*: Until➔ the edges of I' and I'' touch and the diplacement E produced by the 2 glass plates is measured.

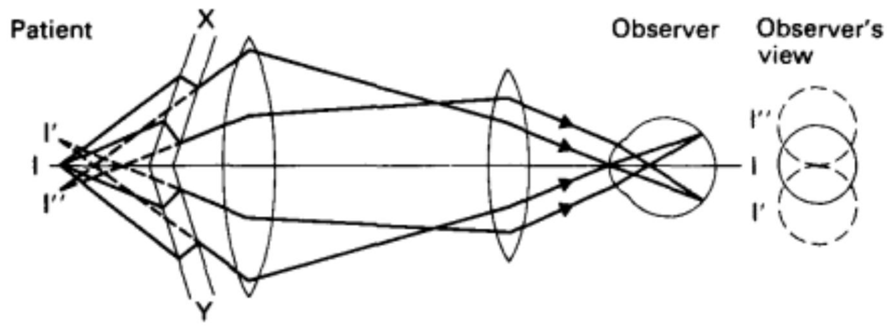


Fig. 28.1: Helmholtz ophthalmometer.

✪ *Calculation:*

- The displacement E ➔ equals the size of image I produced by the surface of unknown r

$$r = 2u \times \frac{I}{O}$$

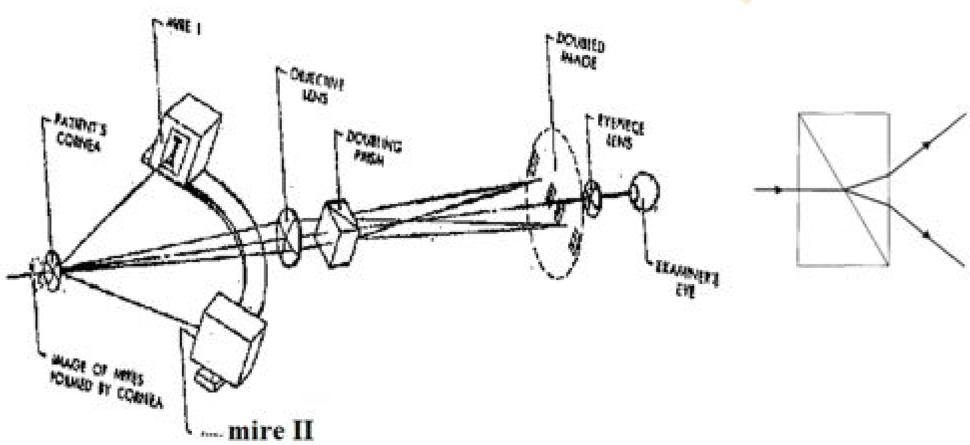
Where, U = Distance of object of known size from curved surface (known).
I = Size of image = Displacement E.
O = Size of object (Known).

- *Dioptric power of the cornea D:*
  - is determined from the formula of simple spherical refractive surface (Chapter4):

$$D = n2 - n1 / r:$$

Where, n2 = Refractive index of the cornea (l. 3375).
n1 = Refractive index of air (1).
So, D = 1.3375-1 / r = 0.3375-1 /r (in m.)= 337.5 / r (in mm)
So, Resultant keratometric formula D = 337.5 / r (in mm)

II. *in Javal-Schiotz ophthalmometer:*



(a) Optical system. (b)Wollaston prism

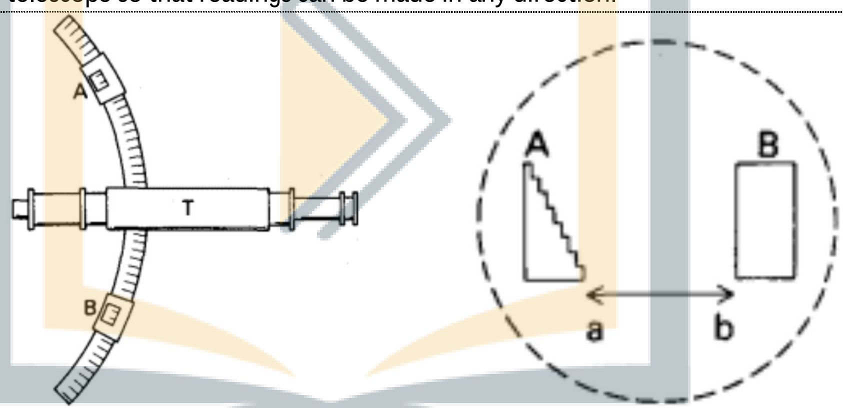
Fig. 28.3: Javal-Schoitz ophthalmometer.

a) *<u>Doubling Device</u>:* Wollaston prism (double refracting prism)

- *it consists of two rectangular quartz prisms cemented together in the viewing telescope (between the objective and eyepiece lenses) with the optical grain of the crystal at right angles (Fig.28.3a)*
  - *Quartz is a double refracting substance and thus it splits a single beam of incident light to form two polarized emergent beams.*
  - *The optical grain of crystal separates the two emergent beams by a fixed angle, while dispersion produced by first prism is neutralized by that of second prism →sharp images are formed (Fig.28.3b).*

b) *<u>(O) Size:</u>* ➔ Adjusted (it is the distance between the 2 mires and its adjusted to achieve a standard (I).

- It consists of a viewing telescope with a curved arm on which2 mires are mounted, One mire is step shaped while other is rectangular (Fig. 28.2b) and space ab between the two mires is ➔ <u>the object size</u> used in the measurement.
- The Arms on which the mires are mounted can be rotated about the axis of the telescope so that readings can be made in any direction.



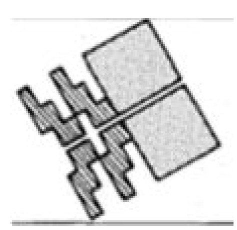
(a) Mires A and B. (b)Space ab (object size).

Fig. 28.2: Javal-Schiotz ophthalmometer.

c) *<u>(I)Size</u>*: ➔ is constant

d) *<u>Procedure:</u>*

1. *The mires are reflected upon the cornea and the observer sees four images:*
   - The two peripheral images are ignored while the two central ones are approximated until their inner edges touch (Fig. 28.4b)



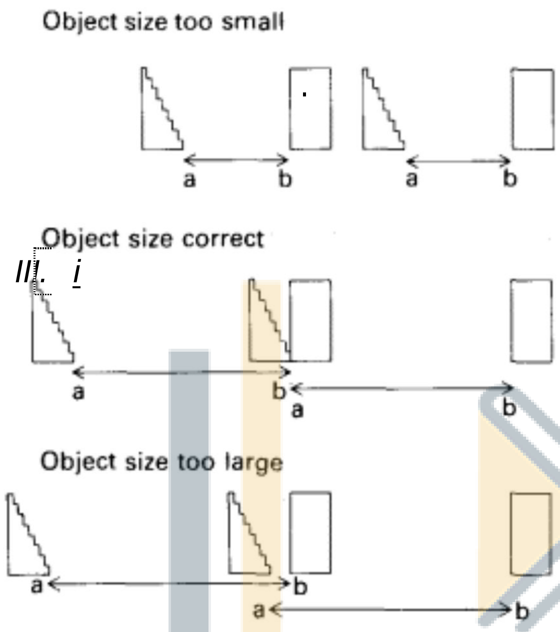
2. Determine the principal meridian by rotating the arm until the space between the 2 steps becomes aligned with the space between the 2 squares.

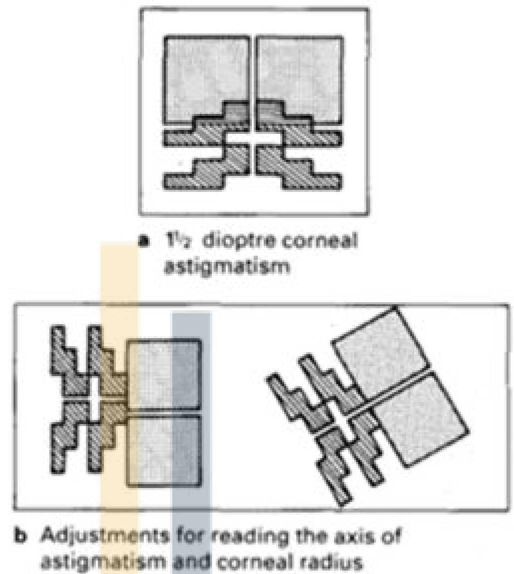
3. *Next the arc is turned at right angles to this meridian:*
   - ➜ *<u>If the images of the mires are still in apposition</u>*:
     - ✓ The curvature of the cornea is uniform and there is no corneal astigmatism.
   - ➜ *<u>if the relative position of the images of the mires has changed</u>*,

- ✓ *each step which is overlapped by the rectangular figure indicates 1.0 D of astigmatism:*

- ✓ Thus if the inner images of a and b (Fig. 28.4b) are aligned correctly in one corneal meridian but overlap by one and half steps in the meridian at 90° to the first, 1.5 D of corneal astigmatism is present (Fig. 28.5a).

III. i





IV. <u>in Bausch and Lomb keratometer (Fig. 28.6):</u>

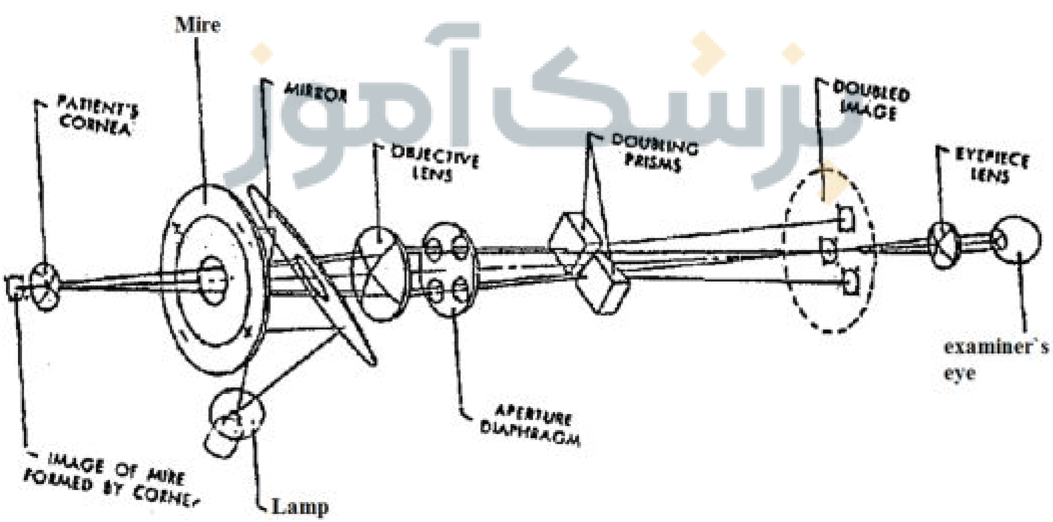
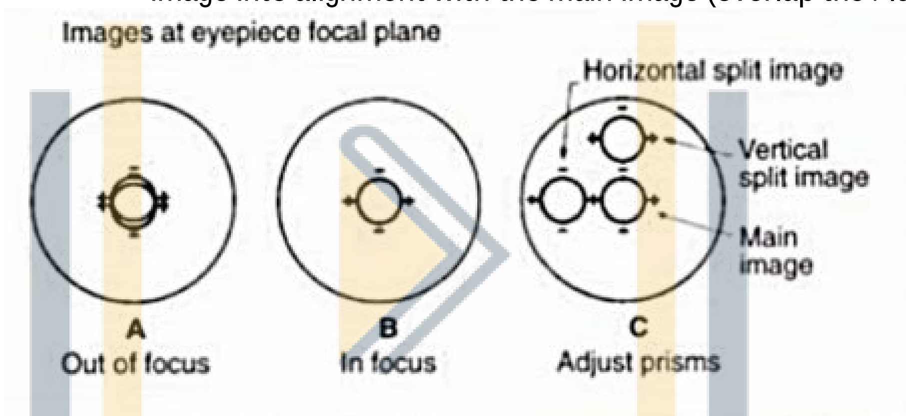
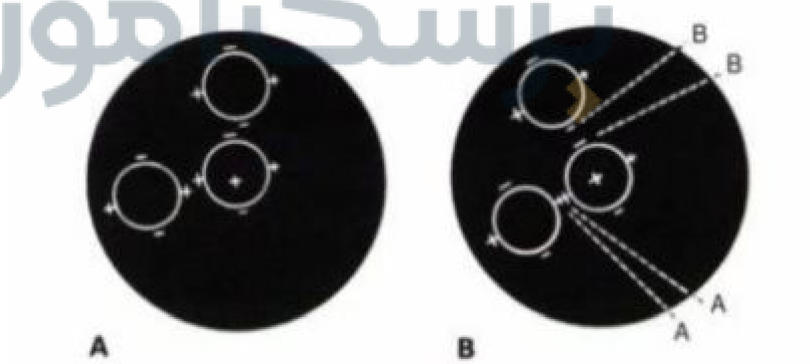


Fig.28.6: optical system of Bausch and Lomb keratometer.

- Doubling device: ➔ 2 doubling prisms (one vertical and one horizontal ➔ vertical and Horizontal displacement)
- Object size: ➔ object size is constant (object = A circle with a 2 +ve & 2 –ve signs)
- Image sizes: ➔ is variable.
- Procedure:
  1. The first step involve focusing the image using the eye piece, Then
  2. The vertical prism is adjusted to bring the vertical split image into alignment with the main image (overlap the minus sign),Then
  3. The corneal power in this meridian can read from the scale.
  4. Then the horizontal prism is adjusted to bring the horizontal split image into alignment with the main image (overlap the Plus sign)



- In oblique Astigmatism:
  - The vertical and the horizontal split image skew from the main image
  - The keratometer must be rotated around its axis to bring the vertical and horizontal split images into alignment with the main image.



Corneal Topography

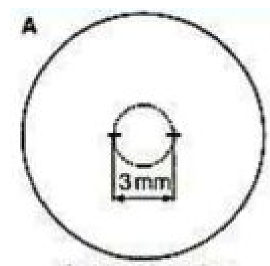
- Corneal Topography is study of the corneal surface which involve creating a map that describes the elevations and depressions on its surfaces.

✱ Optical principle:

- There are four popular methods for assessing cornea topography:
    1. keratometry,
    2. Placido disk,
    3. scanning slit topography, and
    4. Wavefront sensors.
    5. Raster-stereography
    6. Interferometry

1. Keratometry

- The first instrument to examine the shape of cornea.
- It measures the radius of curvature of the anterior corneal surface from four reflected points approximately 3 mm apart.
- Disadvantage:
    - ⇘ It provides no Information regarding corneal surface central or peripheral to these points.
    - ⇘ limited value in irregular corneas
    - ⇘ Less accuracy for corneal powers below 36 diopters (D) and above 50 D.

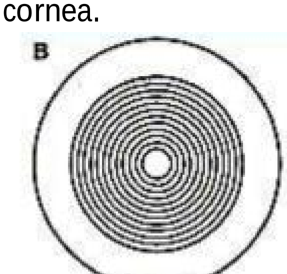


Keratometer mires

2. Keratoscopy

- Keratoscopy Is a general term that refers to the evaluation of topographic abnormalities of the corneal surface by direct observation of images of mires reflected from the surface of cornea.

1. Placido disc keratoscope:
    - Principle:
        - ⇘ The Placido disk reflects a series of concentric rings, or mires, off the cornea.
            - ☛ Distortions in the corneal shape appear as deviations from evenly spaced concentric circles.
    - Disadvantage:

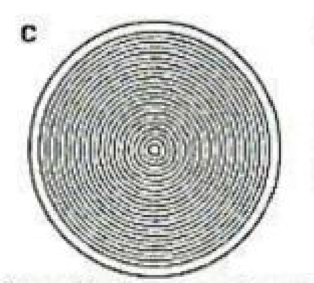


Keratoscope mires

A. Small degrees of abnormalities of corneal shape are not easily identifiable.
B. It cannot be used in corneas with epithelial defects and stromal ulcers.

- Thus Placido disc keratoscope is used only as a gross method of qualitative assessment of the corneal surface.

2. Photokeratoscopy:
   - When a camera is attached to a keratoscope, the instrument is called ➔ photoketatoscope.
   - The photokeratoscope can measure➔ 12 mires over 70% of the corneal surface and over an infinite diopteric range.
   - Principle:
     1. The Placido disk reflects a series of concentric rings, or mires, off the cornea.
     2. Each mire produces an upright virtual image in the anterior chamber of the subject's eye.
     3. The distance between each mire to the corneal apex is compared to the image's distance to the corneal apex;
        - ⇨ The ratio of image distance to mire distance determines the anterior corneal curvature along any particular meridian.
     - Placido devices use
       - The axial map: (sagittal, global, average, or standard)
         - Measures the perpendicular distance from the tangent at a point to the optical axis and therefore has a spherical bias.
           - This gives a global description of shape and may be less accurate in the corneal periphery and with irregular surfaces.
       - The tangential map: (instantaneous, true, or local)
         - Displays the radius of curvature of a point with respect to its neighboring points along a specific meridian.
           - It has a less spherical bias than an axial map and therefore may be preferred to assess the corneal periphery or in irregular corneas.
       - The refractive map:
         - Uses Snell's law to measure the focal power of the cornea.
   - Disadvantage:
     A. It provides no Information regarding the optically important central 2-3 mm as well as the peripheral cornea.
     B. Corneal cylinders up to 3 Diopter escape detection by use of photokeratoscopy.
3. Videokeratoscopy:
   - When a video camera Is attached to a keratoscope, it is called ➔ a videokeratoscope.



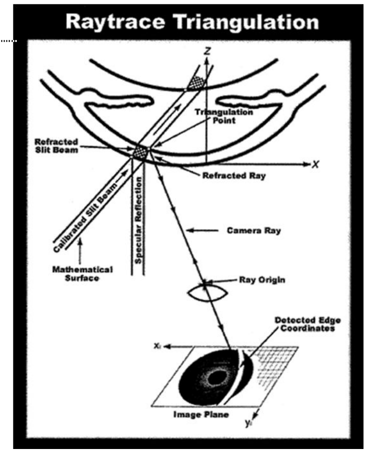
Corneal topography system mire

4. Computer Assisted Videokeratoscopy (Corneal Topography):
   - When computer is used to process data from videokeratoscope, it is called ➔ Computer Assisted Videokeratoscopy
   - It can measure 15 to 38 mires over 95% of the corneal surface and has a theoretical range of 8 to 110 D.

- The computerized videokeratoscope assumes that the corneal surface is spherical and of uniform refractive index;

- <u>Principle:</u>
  - Placido disk based.
- <u>Disadvantage:</u>
  - Data at the central zone have to be Interpolated (although this unmeasured central zone is very small in some devices)
  - Quality of Tear film is critical, since the images are obtained from light rays reflected off the tear film.

3. Scanning slit topography

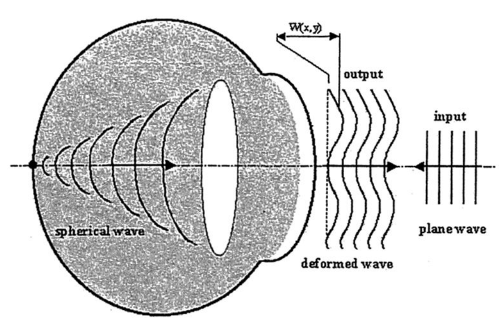


- Principle:
  - is a projection-based method that uses a series of slit-beam images to
    - ➔ 3D model of the cornea

1. Orbscan:
   - Principle:
     - o A slit lamp projects a slit beam at 45 degrees onto the cornea.
       - Twenty slits are projected sequentially on the eye from the left side, and 20 slits from the right, for a total of 40 slits that produce 240 data points per slit.
         - ➔ This produces an elevation map of the cornea relative to a best-fit sphere.
           - This generates data regarding;
             - Anterior surface curvature,
             - posterior surface curvature, and
             - Pachymetery.
     - Therefore, the cornea is represented as a 3D structure.
2. Pentacam:
   - See later.

4. Wavefront Topography

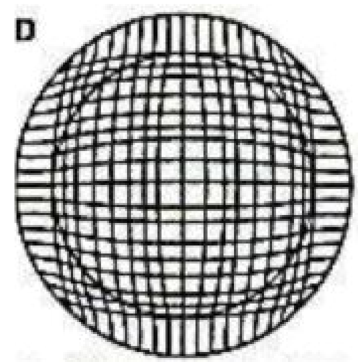
- Wavefront technology evaluates the entire optical system.
- Principle:
  - o See Wavefront.



5. Raster-stereography

- Is another projection-based system that produces an elevation map of the cornea.

- Principle:
  - It projects a calibrated grid ➔onto a corneal surface coated with fluorescein.
  - Fluorescein produces light emissions from the surface of the cornea.
  - Two or more camera systems at a different angle to the cornea from the projector, image the grid. The rays intersect in 3D space, creating the elevation map.



- Advantage:
  - It Includes information across the whole of the cornea and even Includes part of the sclera.
  - Furthermore, the projected nature of the test does not allow interference due to epithelial or stromal defects.

6. Interferometry

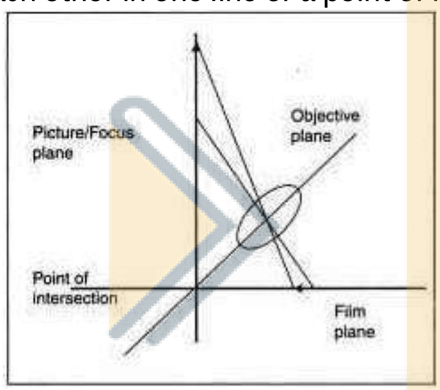
- Principle:
  - It uses the principle of light wave Interference.
  - It project interference fringes onto corneal surface.
  - The Interference fringes can cover the entire anterior ocular surface, not just the cornea.
  - This Includes both holography (Laser halographic Interferometry) and Moire fringe techniques.
- This method is not In widespread clinical use

PentaCam

✱ ***Definition:***
It is an imaging technique where a series of cross-sectional images are merged to allow for a computer generated 3D reconstruction of anterior segment.

✱ ***Principle:***
The Scheimpflug law says:

- ➜ To get a higher depth of focus, ➔ the picture plane, the objective plane and the film plane has to cut each other in one line or a point of intersection.

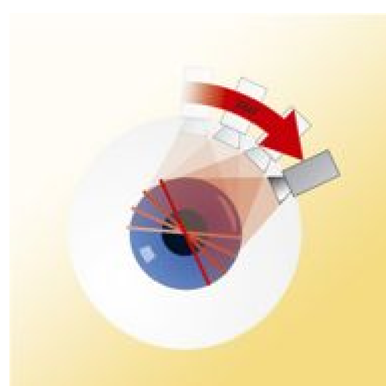


✱ Components:

1. Slit illumination System: Blue light (UV-free 475 nm) to ➔ illuminate the eye.
2. Rotating Scheimpflug camera ➔ taking images.
3. Processor➔ Digital signal processing.

✱ Procedure:
Pentcam scanning is non-contact procedure and takes less than 2 seconds to complete.

1. A thin layer within the eye is illuminated through the slit.
   - ⇘ Being not entirely transparent the cells scatter the slit light. In doing so they create ➔ a sectional image which is then photographed in side view by a camera.
2. This camera is oriented according to the Scheimpflug principle, thus
   - ⇘ The image of the illuminated plane will appears completely sharp from➔ the anterior surface of the cornea right up to ➔ the posterior surface of the crystalline lens.
3. Swiveling around the eye,
   - ➜ The slit camera generates a series of radially oriented images of the anterior chamber.
   - ➜ It obtains 50 scans In 2 seconds with 500 true elevation points per scan surface. (i.e. About 25.000 true elevation points is measured and analysed).



4. The sectional images are merged to create a 3D model of the entire anterior eye chamber.

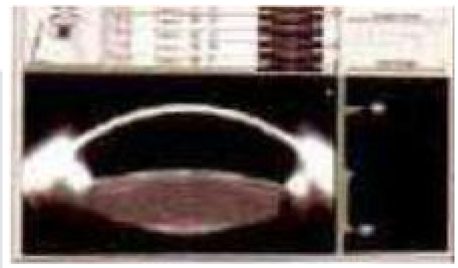
5. Eye movements during image acquisition are captured by ➔ a second camera (pupil camera) and also taken into account in the mathematical evaluation.

✱ Function (Outputs)

- Pentcam is a five-In-one device that generates the following outputs:

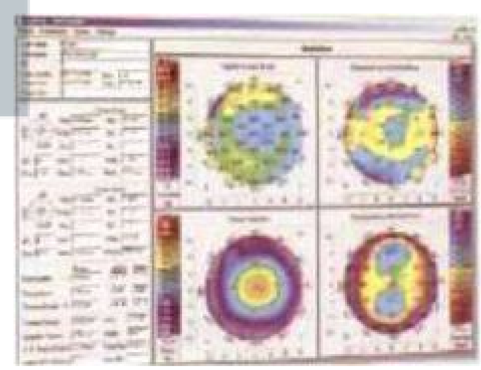
1. Scheimpflug image:

↳ It obtains a clear, sharp Scheimpflug Image showing ➔ <u>the entire anterior segment</u> from the cornea to the posterior lens surface, Including the angle area to the most distal 100-150 um



2. Corneal topography

- It provides topography maps of the anterior and posterior surfaces of cornea.
    - ↳ The topographic analysis of anterior and posterior corneal surface is based on measurement of approximately 25,000 true elevation points.



- Through the rotating measurement the center of the cornea is fine meshed.
- Applications include:
    1. Keratoconus detection
    2. Preoperative planning for any corneal refractive surgery.
    3. Improved IOL calculation for post LASIK patients.

3. Pachymetery:

- The corneal thickness from limbus to limbus.
- the most important points are displayed In values and location, such as
    - ☛ Thickness In the pupil center
    - ☛ Thickness in the apex
    - ☛ Thinnest location
    - ☛ Corneal volume
- Applications include;
    - ☛ Preoperative planning for corneal refractive surgery
    - ☛ Glaucoma screening
    - ☛ IOP modification with regard to corneal thickness
    - ☛ Keratoconus detection and quantification.

4. **3D** anterior chamber analyzer. It provides:

- Colored map of the anterior chamber allowing evaluation for
  - Chamber angle.
  - chamber volume,
  - chamber depth and
  - chamber height
- Applications include;
  - Allows preoperative planning for implanting phakic lenses
  - Glaucoma screening

5. Densitometry of the lens

- Pentacam densitometry of the lens provides analysis of the lens
  - Thickness
  - Structural alterations like radial opacities and
  - early or advanced calcification of the lens.

WAVEFRONT

- ✱ Wavefront Definition:
- ✱ Wavefront analysis:
  - ➯ Is study of the shape of light waves as they leave an object point and how they are affected by the optical media.
- ✱ Wavefront aberrometers:
  - ➯ Measurement of wavefront aberration is called wavefront aberrometers or sensing

- ✱ Types:
  1. Outgoing
  2. Ingoing

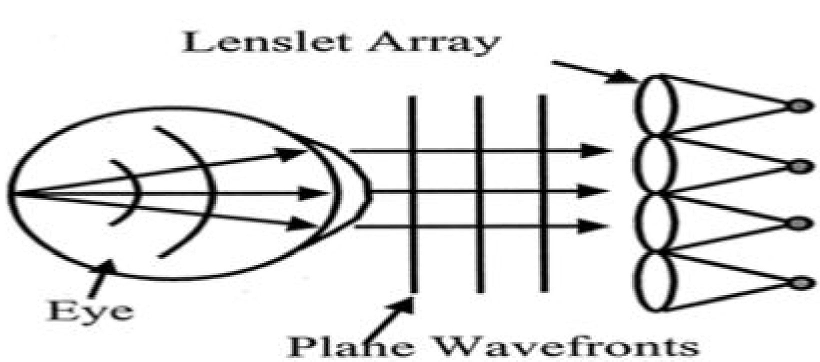
1. Hartmann shack aberrometery: (outgoing)

Principle:

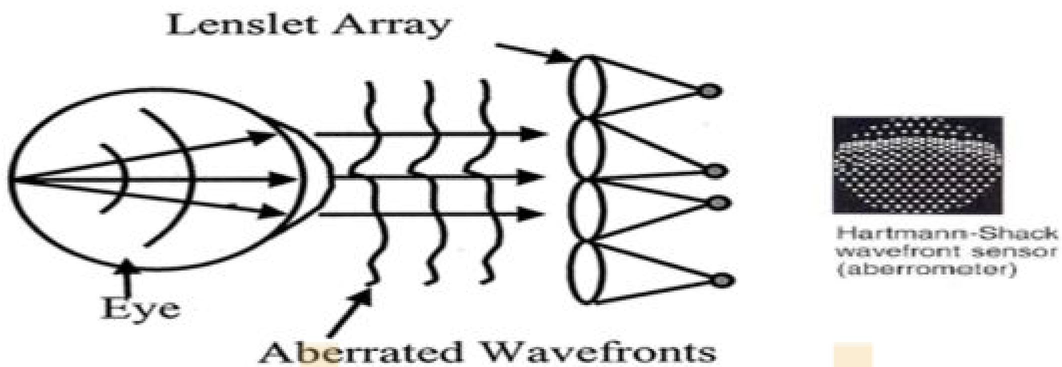
- It operate on the principle of reversibility of light
  - ☛ If a point source on the retina result in a plane wavefront (parallel rays) emerging from the eye then ➔ the plane wave incident on the eye will converge progressively (concave wavefront) to focus a perfect point on the retina.

Technique:

1. A narrow beam of light is directed into the eye to forms a small point of light on the retina. ➔ This light scatters off the retina and emerge out of the eye to be intercepted by➔ A lenslet array
   - ➯ <u>In the aberration-free eye:</u>
     - ➜ Plane wavefronts emerge from the eye, thus ➔ each lenslet intercepts a portion of the wavefront that is flat and is traveling in the direction of the axis of the lenslet, thus ➔ the lenslet focuses the light down to a point, and the result is ➔ a grid of uniformly spaced spots.

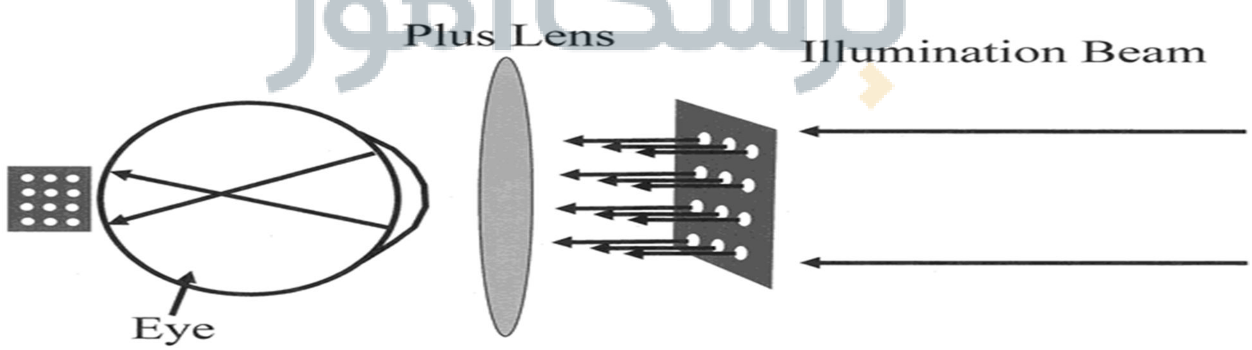


- ➪ <u>In the aberrated eye</u>,
  - ➜ The emerging wavefront is no longer planar, but instead takes on a complex shape, thus ➔ each lenslet intercepts a small portion of the aberrated wavefront that is not traveling in the direction of the axis of the lenslet, thus ➔ distorted grid of spots.



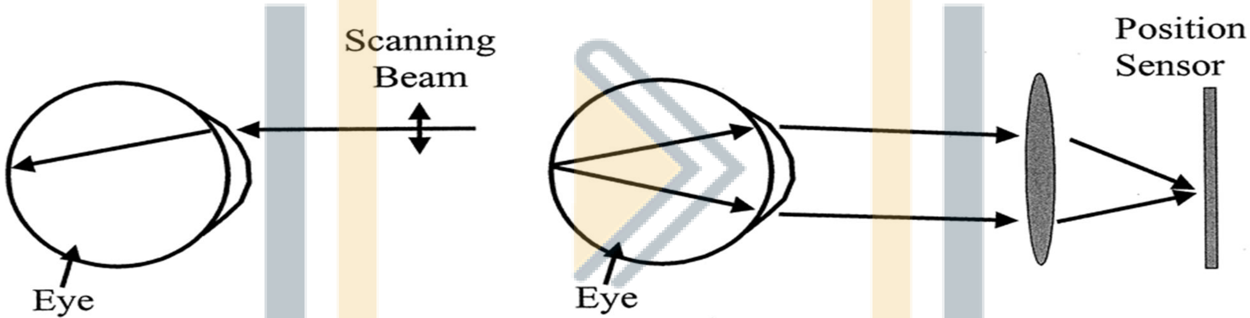
2. By comparing the deviation in spot locations between the aberrated and the ideal wavefronts, ➔ the wavefront slope and ultimately the wavefront shape can be recovered.

2. Tscherning aberrometery: (ingoing)
   1. A collimated beam is passed through a mask of holes and a plus lens into the eye.
      - ➜ The added power from the lens causes ➔ an <u>out-of-focus shadow of the mask</u> to be formed on the retina.
      - ➪ Aberrations in the eye distort the spacing between the shadow spots.
      - ➜ A high magnification camera then capture the image of the retina
   2. By comparing the deviation in spot locations between the aberrated and the ideal wavefronts, ➔ the wavefront slope and ultimately the wavefront shape can be recovered.



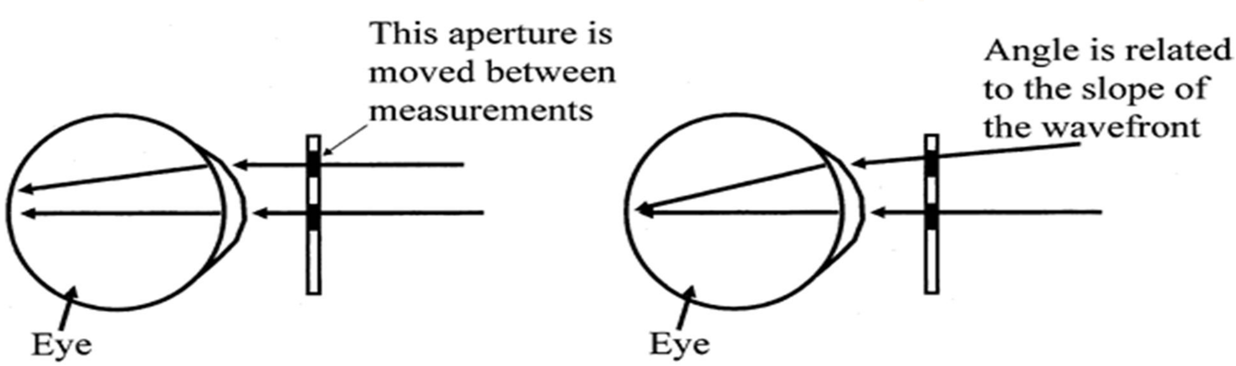
3. Retinal ray tracing technique: (ingoing)

1. A narrow laser beam is directed into the eye so that it is parallel to the visual axis.
   - ➜ Normally, this collimated beam would focus to a point <u>on the fovea</u>. However, aberrations in the eye cause the beam to deflect and strike the retina away from the fovea.
2. An imaging system is then used to records the position of the beam relative to the fovea which gives the transverse ray error for a particular pupil entry point.
3. The spot is then scanned to a new entry location within the pupil, and the measurement process is repeated.
4. By examining an array of entry points within the pupil, a map of the wavefront error within the eye can be calculated.



4. Spatially resolved refractometry technique: (ingoing)

- Two parallel beams enter the eye: one through the center of the pupil and a second through a peripheral point.
  - ➜ These beams entering the eye at two separate pupil locations would come to focus at the same point on the retina. However, in the presence of aberrations, the spots on the retina do not coincide.



OCT

✱ Principle:

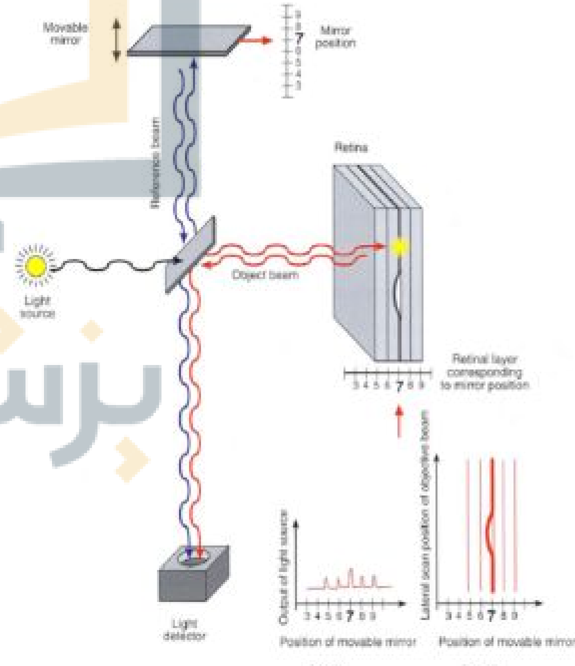
- Oct is based on ➔Low Coherence Interferometry or white light interferometer (Interference of low coherent light)

- Narrow band source (Laser) have long coherence lengths and produce a sinusoidal interference signals as a function of varying time delay, while:
  - ⇨ For short coherence light source (white light), interference signal is observed only when the light from the reference and sample arm has travelled the same optical distance.

Time domain OCT:

✱ Components:

- The major components of an OCT include
  1. a light source (usually a superluminescent diode),
  2. a light detector,
  3. a beam splitter, and
  4. a movable mirror

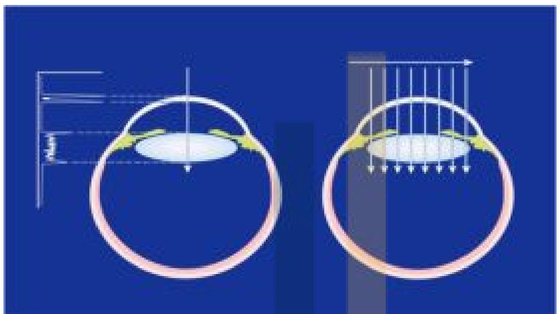


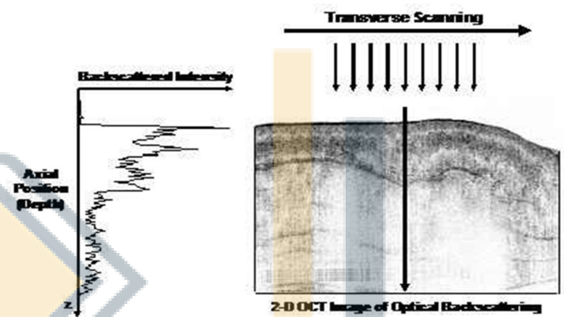
- Light from a low-coherence source (short coherence length light source), typically a (superluminescent diode) , is split by the beam splitter of the Michelson interferometer where
  - half the light is directed to the movable mirror (called the reference beam) and
  - Half to the retina (called the object beam).
- After reflections ➔these 2 beams are superimposed by the beam splitter and transmitted together to the light detector.
- Because the light is emitted from a broadband source (large range of optical wavelengths), ➔a strong interference signal is only detected when the light from the reference and sample arms has travelled the same optical distance.

✱ <u>Type of Scans:</u>

1. Axial scan (A-scan)
   - The various layers of the retina reflect light to different degrees. If light intensity is plotted against the position of the movable mirror, ➔an A-scan image of the retina cross section can be generated

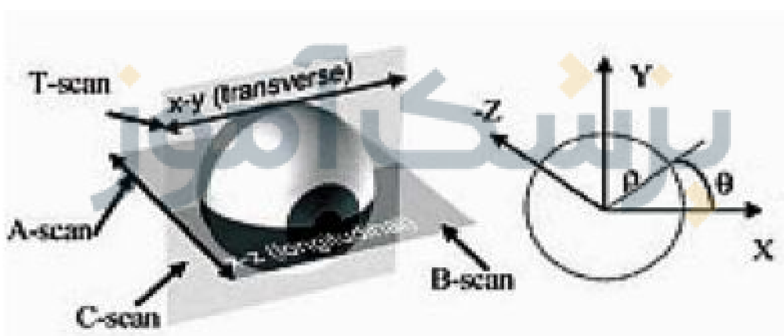
2. longitudinal slice(B-scan)
   - A cross-sectional tomograph (B-scan) may be achieved by➔ laterally combining a series of these axial depth scans (A-scan).





Axial Scan   Transverse Scan   Axial Scan   Transverse Scan

3. Transverse scan (x-y)
4. En-face or transverse slice(C-scan):
   - C scan may be achieved by ➔ combining a series of transverse scans at a constant depth.



- Figure 1. Relative orientation of the axial scan (A-scan), longitudinal slice(B-scan), x-y (transverse) scan (T-scan) and en-face or transverse slice(C-scan

Spectral domain OCT (SDOCT): also known as (Fourier domain OCT)

✱ Components:

➥ The light source and the interferometer scheme follow the same characteristics described before, but

- ➪ The detection system is a distinct (spectrometer).
- ➪ The reference mirror is kept stationary

- The main idea is that the optical path difference between the sample and the reference is obtained from the analysis of the interference pattern between the 2 beams detected as ➔ a spectrum.
  - This spectrum is commonly measured with a spectrometer.
  - Fourier-transformation of this interference spectrum produce an ➔ A-scan
  - In FDOCT, Only one lateral scan needs to be performed since a whole depth (z) profile is obtained at once without scanning in depth.
    - ➔ Because all depths are obtained in one measurement (without movement of the reference arm), SDOCT improves imaging speed dramatically.

- SDOCT can be also divided into
  1. swept source (SS) OCT and
  2. Fourier domain (FD) OCT (camera based).

- Fourier domain (FD) OCT:
  In FDOCT,
  - ➔ A broadband optical source is used and
  - ➔ The spectrum is acquired using a dispersive detector, such as
    - a diffraction grating and
    - A linear detector array.
  - ➔ The depth resolution determined by the optical source bandwidth while
  - ➔ The axial range is limited by the spectrometer resolution.

- Swept source (SS) OCT: or optical frequency domain imaging (OFDI).
  In SSOCT,
  - ➔ A narrow band optical source is used, whose frequency is tunable in time.
  - ➔ Point photodetectors are used.
  - ➔ The depth resolution is inverse proportional to the tuning bandwidth while
  - ➔ the axial range is limited by the coherence length of the source, the narrower the linewidth, the longer the axial range.

> - Uses a wavelength-tunable laser to rapidly sweep through a range of wavelengths, allowing the spectrum of the interferometer output to be recorded sequentially using a single detector.
> - Here the spectral components are not encoded by spatial separation, but they are encoded in time

LOW VISION AIDS

✱ *Definition of low vision:*

- Magnifying devices of several kinds are designed to be used as reading aids for patients of Subnormal visual acuity or abnormal visual field, that can't be corrected by spectacles or contact lenses (usually less than 6/24).

✱ *Indications of low vision aids:*

A. Retinal diseases as in:
   1. Macular lesions.
   2. Advanced glaucoma.
   3. Diabetic retinopathy.
   4. Optic atrophy.
   5. High myopia.
   6. Toxic and strabismic amblyopia.

B. Corneal diseases as in:
   1. Corneal opacities.
   2. Irregular astigmatism.

✱ *The basic optics of low vision aids:*

1. *Increase the visual angle subtened by the object: (i.e. angular magnification)*

   - Magnifying power (MP) of such an optical system:

$$= \frac{\text{retinal image size with use of instrument}}{\text{retinal image size without use of instrument}}$$

2. *Increasing the size of the object*: ➔ To view an enlarged image on a screen.
3. *Magnification of the retinal image*: ➔ By projection devices on a screen.

✱ *Types of low vision aids:*

I. Magnifying glasses:

- *Principles:*

  The convex lens acts as a magnifying loupe (Fig.20.1 &Fig.6.8):

  - The object is placed inside F1 of the lens ➔ A magnified virtual image is viewed by the eye.

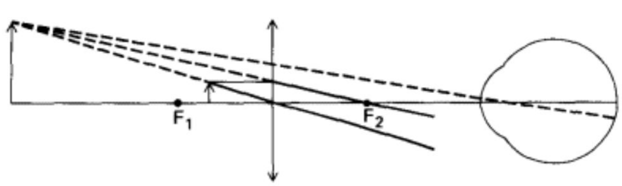


Fig. 20.1: Convex lens used as a magnifying loupe.

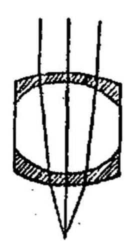


Fig.20.2: Triplet design.

- ***Types of magnifying glasses:***
  1. *Hand-held magnifiers:*
     1. ***Magnifying lens:***
        - Forms:
          - A biconvex or planoconvex reading lenses of different sizes and powers (from +4 D to +20 D usually).
        - Shapes:
          - ✓ Circular lens. ✓ Rectangular lens.
        - Advantages:
          - ❑ Easy to carry. ❑ Easy to use.
          - ❑ Increased reading range.
            - ✓ The distance between the eye and the lens can be varied quickly depending on the reading distance and the magnification needed.
        - Disadvantages:
          - ✪ Small visual field.
          - ✪ Distortion of image.
     2. ***Press-on membrane Fresnel lens*** *(stepped lens):*
        - *Form:* Thin plastic flexible membrane (see before).
        - *Advantages:*
          a. No disadvantage of reduced lens diameter with increased magnification.
          b. Very thin lens.
  2. *Stand magnifiers:*
  3. *Neck-held magnifiers:* Are resting on the chest leaving the hands free.
  4. *Spectacle-born high-plus reading lenses:*
     - Powers: +4 D to +20 D.
     - Forms:
       (a) Single vision forms:
         - ☆ Monocular reading correction.
         - ☆ Binocular reading correction.
       (b) Bifocal forms:
         - ✓ Bifocals with powers up to +32 D.
         - ✓ Decentration or incorporation of a prism base-in.

II. Telescopic lenses:

- *Galilean telescopic lens.*
- *Astronomical telescopic system.*

III. Contact lenses:

- *To produce magnification:*
  - *Spectacle lens of highly positive power as objective and a contact lens of highly negative power as negative eyepiece of a Galilean telescope:*
    - Advantages:
      1. Magnified and normal vision in high myopia.
      2. Variations in magnification can be done by changing any of the following variables:
         - Power of contact lens.
         - Power of spectacle lens.
         - VD between the 2 lenses.
    - Disadvantages: rarely successful for regular wear and is difficult to fit.
  - *Reversed telescopic system in which the contact lens becomes high positive objective lens and the spectacle lens high negative eyepiece:*
    - To increase the visual field (useful in patients with visual field constriction as in retinitis pigmentosa).

- *Pinhole contact lens:*
  A small clear rounded area at the centre (pinhole) in a coloured contact lens:
  1. *Cornea:*
     - Scarred cornea.
     - Diffuse corneal opacities.
  2. *Pupil:*
     - Visually impaired patients with permanent dilatation of the pupil or distorted pupil.
  3. *iris:*
     - Coloboma of the iris.
     - Aniridia.

- *For corneal irregularities in:*
  1. Keratoconus.
  2. Irregular astigmatism.
  3. Corneal scarring.
- *Better than spectacles as in:*
  1. Aphakia.
  2. High myopia
  3. Severe astigmatism.

IV. Projection devices:

- *Types of projection devices:*
  i. *Projection magnifiers:*
  ii. *Compact optical projectors:*

- Same as microfilm reading unit with a light source behind a screen.

iii. *Closed-circuit television magnification system (CC-TV):*

- They are useful for reading and writing

- *Principles:*
  - Project a magnified Inverted image onto a screen (the object is between F and 2F of a convex lens.
- *Advantages:*
  - They are easily adopted by the patient.
  - Projection magnifiers form an enlarged image on a translucent screen at a variable distance.
  - High relative distance magnification in addition to the relative size magnification by projection.
  - Major advantages of CC-TV over other magnification systems:
    - Image with greater brightness and more contrast than the original object.
    - Greater magnification range up to 40 times with reduced aberrations.
    - A more normal viewing or reading distance.
    - Reversed polarity (with white print on black with improved contrast).

V. Non-magnifying low vision aids:

1. *Pinhole spectacles:*
   - *Indications:*

   1- To improve reading vision in opacities of ocular media.

   2- To determine the potential vision if retinoscopy is not possible.

2. *Reading slit (typoscope) :*

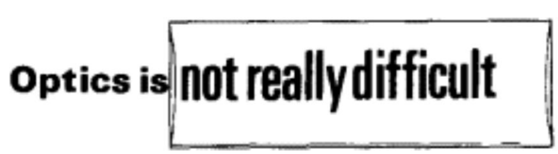
   Black device with a rectangular opening to read one or more lines at a time in:
   - Early cataracts due to increased contrast.
   - Training of centric viewing in macular diseases.

VI. Non-optical low vision aids:

Are aids other than lenses especially writing aids as black ink marking pens, large-type books, signature guides and telephone dials.

VII. Convex cylindrical lenses:

The bar-shaped lens which has no refractive power or only a low converging power in its long axis and high converging power in cross section is laid on a line of print and produces vertical magnification of the letters (Fig 20.3).



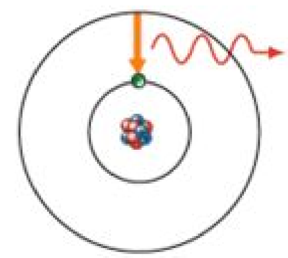
LASER

Laser is an acronym for ➔ light amplification by stimulated emission of radiation-(a phrase that highlights the key events in producing laser light)

Principle:

➪ In the most simplified sequence, an energy source ➔excites the atoms in the active medium (a gas, solid, or liquid) to➔ emit a particular wavelength of light. The light produced isèamplified by an optical feedback system that reflects the beam back and forth through the active medium to increase its coherence, until the light is emitted as a laser beam.

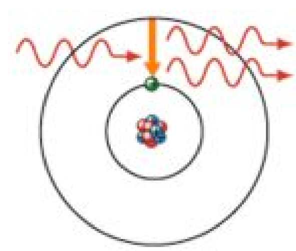
Stimulated emission:



spontaneous emission

- All atoms are most stable in their lowest energy state, known as➔ the ground state .
- If Energy is delivered to an atom ➔the absorption of energy by the atom elevates its electrons from their ground state to a higher energy level.
- Because the lowest energy state is the most stable ➔the excited atom soon emits a quantum of energy in order to return to the ground state. ➔ Spontaneous emission (energy released through spontaneous emission occurs incoherently in all directions)

➪ If the atom at a higher energy level is stimulated further by a photon whose wavelength is that which the atom would naturally emit, ➔ the result is the emission of a photon of the same wavelength with the stimulating photon (coherent), and the atom will drop to a lower energy level ➔ this Process is called Stimulated Emission



stimulated emission

Elements of a laser

- All ophthalmic lasers require 3 basic elements:
  1. An *active medium: (a gas, solid, or liquid)* to emit coherent radiation
  2. Energy input: known as *pumping;* and
  3. Optical feedback. To reflect and amplify the appropriate wavelengths.

A. The active medium: (photon emitter) ➔ makes the light monochromatic

➪ It is an atomic or molecular environment that supports stimulated emission. \

- The active medium allows a large number of atoms to be energized above the ground state so that stimulated emission can occur.

- Lasers are usually named for the active medium, the medium can be a
  - Gas (argon, krypton, carbon dioxide, argon-fluoride excimer, or helium with neon),
  - A liquid (dye),
  - A solid (an active element supported by a crystal, such as
    - neodymium supported by yttrium-aluminum-garnet [Nd:YAGj and
    - Erbium supported by yttrium-lanthanum-fluoride [Er:YLF]), or a semiconductor (diode).

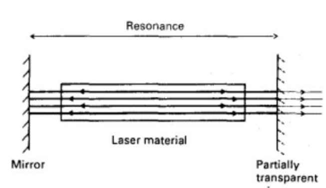
B. Energy input (Pumping): → makes light coherent

- It Provide energy to the active medium so that a majority of the atoms are in an energy state higher than the ground state. This condition is known as →a population inversion (because it is the inverse of the usual condition in which the majority of atoms are in the ground energy state).
- The energy input that makes possible population inversion is known as→ pumping.
  - Gas lasers are usually pumped by electrical discharge between electrodes in the gas.
  - Dye lasers are often pumped by other lasers.
  - Solid crystals are usually pumped by incoherent light such as the xenon arc flashlamp.

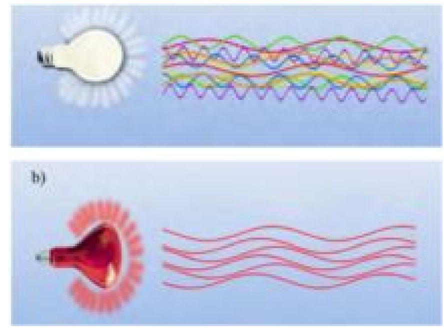
C. Optical feedback (Amplification by resonance)

- Once population inversion in an active medium has been achieved, optical feedback is required to promote stimulated emission and suppress spontaneous emission.

- The active laser medium is housed in a tube which has a mirror at each end (Fig. 15.2).
  - The distance between the mirrors must equal a multiple of the wavelengths of the light emitted so that resonance can occur.
- When a photon encounters an excited electron and stimulated emission occurs, the light emitted travels down the tube, and is reflected and re-reflected at both mirrors.
  - Because the mirrors are precisely aligned and a whole number of wavelengths apart, the light which has traversed the tube is still exactly in phase with itself on its second and subsequent journeys.→Thus it reinforces itself. This is known as →resonance.
- Meanwhile other stimulated emissions are taking place so that the light traversing the tube gets stronger and stronger while remaining exactly in phase (coherent).

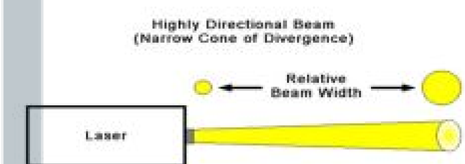


D. The last element in this schematic laser design is a mechanism for releasing some of the oscillating laser light from the cavity.
- If one of the mirrors is made partially transparent, some of the light may be allowed to leave the tube.
- This light will be
  - coherent (the wavefronts in phase),
  - monochromatic (of one wavelength) and
  - Collimated (all the rays parallel).



Properties of Laser:

1. Monochromaticity
   - Lasers emit light at only 1 wavelength
     - Monochromatic light is not affected by chromatic aberration in lens systems. Thus, monochromatic light can be focused to a smaller spot than can white light.
2. Directionality (Non spreading)
   - it implies laser light is of very small divergence.
   - In a typical laser, the beam increases by approximately 1 mm in diameter for every meter traveled.



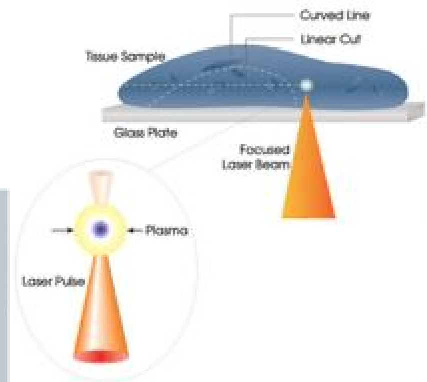
3. Coherence
   - Coherence, meaning that all the propagated energy from the source is in phase.
     - Coherence of laser light is utilized to create the interference fringes of the laser interferometer.
     - In therapeutic ophthalmic lasers, coherence, like directionality, is important because it improves focusing characteristics.
4. Polarization
   - Many lasers emit linearly polarized light.
   - Polarization is incorporated in the laser system to allow maximum transmission through the laser medium without loss caused by reflection.
5. Intensity
   - Delivering large amount of energy to a small area
     - The most important property of lasers is intensity.
     - Directionality, coherence, polarization and to some degree monochromaticity enhance the most important characteristic of lasers which is ➔ light intensity.

Laser- Tissue Interactions

- Radiation wavelengths from 400 to 1400 nm can enter the eye and reach the retina.
- The effects can be ionising, thermal or photochemical.

1. Photodisruption (Ionisation):

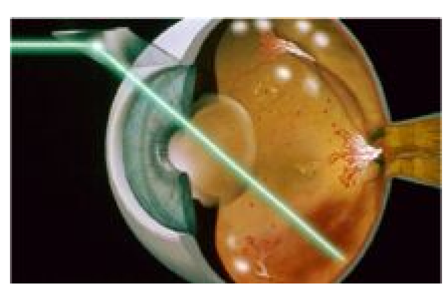
- Typically, light energy causes electrons to oscillate as they travel around their nuclei.
  - ⇨ Extremely high electromagnetic field strengths, from a laser for example, can actually strip electrons from their nuclei, producing an entirely different physical state of matter called ➔ Plasma. (A cloud of electrons and ionized molecules) ➔the chemical nature of the material is destroyed.



- Plasma has a very high temperature and rapidly expands to cause ➔ a mechanical shock wave sufficient to displace tissue. (plasma mediated ablation or optical breakdown)
  - Shock wave pushes the surrounding medium away from its center, resulting in a cavitation bubble
  - The maximum diameter of the cavitation bubble can reach 10 to 100 um.
  - After the collapse of the cavitation bubble,➔ a gas bubble is left b hind, containing carbon dioxide and other gas molecules
- In clinical practice, this process (known as photodisruption) uses laser light as➔ a pair of virtual microsurgical scissors,
- <u>Example</u>: Currently,
  1) the Nd:YAG and
  2) Er:YAG lasers
  3) Femto lasers.

2. Photocoagulation (thermal):

- Light energy is converted into heat energy if
  1. the wavelength coincides with the absorption spectrum of the tissue pigment on which it falls and
  2. If the pulse duration is between a few microseconds and 10 s (A relatively long exposure time).
- The important ocular pigments are
  1. Melanin, (located in RPE and choroid): absorbs most of the visible spectrum;
  2. Xanthophyll at the macula, which strongly absorbs blue light (green is therefore safer) and
  3. haemoglobin, which absorbs blue, green and yellow wavelengths.



- In the retina, heat is transferred to the adjacent layers of the retina to cause a 10–20°C rise in tissue temperature. The result is photocoagulation and a localised burn.
- <u>Example</u>: A variety of photocoagulating lasers are currently in clinical use:
    1) argon,
    2) krypton,
    3) dye,
    4) holmium, and
    5) the solid-state gallium arsenide lasers.

3. Photovaporization (thermal):

- When visible or infrared light raises the tissue temperature to 100°C, ➔ Water vaporises & accompanied by thermal denaturation of adjacent tissue.
- It is used in conventional surgery where blood vessels are coagulated to stop bleeding during the cut, this technique is rarely used in ophthalmic surgery due to the wide collateral thermal damage
    - Carbon dioxide (CO_2) lasers also work by this mechanism:
    - Vaporisation may also be produced by argon retinal photocoagulation if it is too intense.

4. Photoablation:

- The UV Excimer laser can precisely remove corneal tissue without any thermal side effects ➔ this revolutionary finding has led to the development of LASIK
- With photocoagulation and Photovaporization, there is localized heating of adjacent collagen tissue
- In short wavelength, the individual photon energy is significantly greater than energy required to break individual molecular bond, which Is not true for longer wavelengths
- With UV laser, the photon energy is fully absorbed ➔ molecular bond breakage. ➔ Ejection of the tissue fragment (this is called Ablation) (Ejection of the tissue fragment is driven by the kinetic energy provided by the energy of the photon in excess of that required for bond breaking)

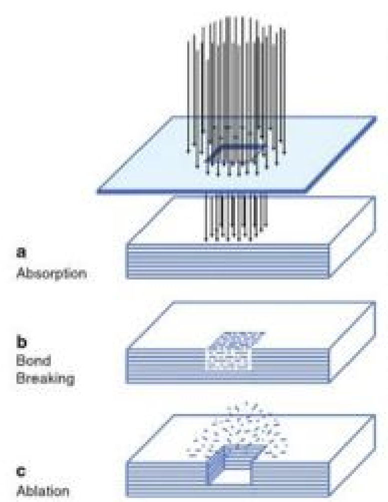


Fig. 3.12 Mechanism of interaction with the excimer laser photoablation: absorption, bond breaking and ablation

Photochemical Effects

- When a pulse duration of 10 s or more is required to cause damage, formation of free radical ions which are highly reactive and toxic to cells ➔ is the mechanism.
- Shorter wavelengths (blue, ultraviolet) cause damage at lower levels of irradiance and are therefore more harmful.
- Argon lasers for retinal photocoagulation incorporate a filter to protect the operator from the photochemical effects which might otherwise be caused by reflected light.

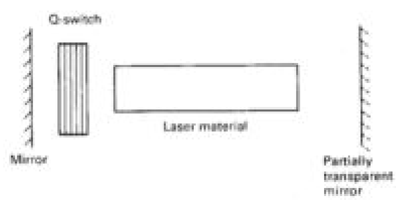
Laser Modes

- Two modes-
  1. Continuous wave mode
  2. Conventional pulsed mode
     1) Q switched
     2) mode locked

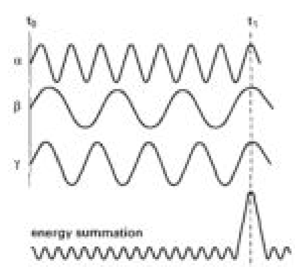
1. CONTINUOUS WAVE OPERATION
   - Output is relatively constant with respect to time.
   - Delivers overall more total energy.
   - Less power.
   - Delivers Energy over a relatively long period (fraction of a sec to a sec)
   - Argon, krypton, dye.

2. PULSED WAVE OPERATION
   ☒ Power is increased by delivering some energy over a shorter time)

A. <u>Q switched:</u>
   - o Q-switching is a mechanism whereby a shutter is placed in front of one of the two mirrors in the laser tube.
   - o This maximises the energy state of the laser medium by limiting energy loss to spontaneous emission alone.
   - o Opening the shutter allows ➔ a single pulsed surge of stimulated emission with a duration of 2–30 nanoseconds



B. <u>Mode-locking</u>
   - o Mode locking is a refinement of Q-switching which synchronises the various wavelengths so that periodically they are in phase and summate as a train of very high energy pulses.
   - o A pulse lasts about 30 picoseconds and produces up to 100 times as much power for the same energy compared with Q-switching.



- Output varies with respect to time (alternating "off' and "on" periods)
- Energy is concentrated into very brief periods (micro to milliseconds)
- Modest amount of energy .
- Each pulse has relatively high power.
- E.g., femtosecond laser, Nd:YAG
  - ⇨ This, in turn, minimizes collateral tissue damage
  - ⇨ Inflammation and thermal damage to the surrounding tissue is confined to less than 1 pm.
  - ⇨ With the laser, tissue can be cut very precisely and with practically no heat development

Lasers Used in Ophthalmology

Laser light can be delivered along a fibre optic cable to a slit lamp, an indirect ophthalmoscope, or an intraocular endolaser probe.

The Argon Blue-Green Gas Laser

- Type & wavelength:
  - ⇨ Gas laser emits a mixture of 70% 488 nm (blue) and 30% 514 nm (green) light.
- Application:
  1. Argon lasers are most commonly employed for retinal photocoagulation.
     - ➔ Photocoagulation aims to treat the outer retina and spare the inner retina to avoid damaging the nerve fibre layer.
     - ➔ Xanthophyll in the inner layer of the macula absorbs blue light (but not green) and thus the use of blue light at the macula is contraindicated in order to avoid direct damage to the retina in this region.
     - ➔ Argon green (blue screened out) photocoagulation of the macula does not cause direct retinal damage.

The He–Ne Laser (helium-neon)

- Type & wavelength:
  - ⇨ Gas laser that emits visible red 632.8 nm light.
- Application:
  - ➔ Is used as an aiming beam for lasers with invisible output (e.g. Nd–YAG,diode).

Diode Lasers

- Type & wavelength:
  - ⇨ Solid laser that emits a wavelength of 810 nm infrared
- Application:
  1. In the eye, diode laser light is absorbed only by melanin and consequently is most commonly used for retinal photocoagulation.
     - ➔ Low scattering of this wavelength ensures good penetration of the ocular media and of oedematous retina.
  2. The 810 nm wavelength also penetrates the sclera.
     - ➔ Thus, even if the retina is obscured from view through the pupil, photocoagulation may still be performed by placing the delivering probe on the surface of the eye.
     - ➔ The transparency of the sclera to diode laser also allows photocycloablation of the ciliary body in 'end stage' glaucoma.

3. Diode photocoagulation of vascular structures (e.g. neovascular membranes and tumours) is enhanced by intravenous indocyanine green dye with an absorption peak of 800–810 nm.
4. Diode laser light has been used endoscopically to create a DCR.

The Nd–YAG Laser (neodymium–yttrium–aluminium–garnet)

- Type & wavelength:
  - ➪ Solid laser that emits 1064 nm infrared radiation.
- Application:
  - ▫ It is commonly used to disrupt the posterior capsule of the lens following cataract surgery, or the iris in narrow angle glaucoma.

☒ The 1064 nm wavelength is invisible and requires a He–Ne laser red aiming beam.

The Frequency-Doubled Nd-YAG Laser

- Type & wavelength:
  - ➪ The frequency-doubled Nd-YAG is solid laser that emits 532 nm radiation.
    - ➜ This is achieved by passing 1064 nm radiation from a YAG crystal through a potassium titinyl phosphate (KTP) crystal, thereby converting some of the energy to 532 nm radiation.
- Application:
  - The photocoagulation effect is similar to that of continuous wave argon green laser.

The Excimer Laser (argon–fluorine (Ar–F) dimer)

- Type & wavelength:
  - ➪ argon–fluorine (Ar–F) dimer
- Application:
  - ▫ High absorption of UV by the cornea limits its penetration.
  - ▫ Each photon has 6.4 eV, sufficient to break intramolecular bonds.
  - ▫ The delivery of a relatively high level of energy to a small volume of tissue causes tissue removal (i.e. ablation).
- The excimer laser is therefore ideally suited to PRK and LASIK to reshape the corneal surface as well as PTK to remove abnormal corneal surface tissue.

- The excimer laser derives its name from 'excited dimer', two atoms forming a molecule in the excited state but which dissociate in the ground state.

The Erbium:YAG Laser

- Type & wavelength:
  - ➪ Solid laser that delivers 2940 nm infrared radiation which is absorbed by water
- Application:
  - ▫ The absorption of energy by a very small volume of tissue results in the explosive evaporation of tissue, and thermal effects are limited to the surrounding 5–15 μm.
  - ▫ This laser has been used experimentally to emulsify the lens in cataract surgery.

The Carbon Dioxide Laser

- Type & wavelength:
  - ➪ Gas laser that emits 10600 nm mid-infrared radiations which is strongly absorbed by water, and therefore by most tissues.
- Application:
  - ▫ The only effects are thermal; the diffusion of heat from the target coagulates adjacent tissues, and water vaporisation releases steam.
  - ▫ Such lasers are used in other branches of surgery to produce a nearly bloodless incision but have yet to find a use in ophthalmology.

Femtosecond Laser:

- ➢ *Definition:*
  - ➪ it is an ultrafast pulsed laser whose time duration is of the order of a femtosecond (1fs = $\mathbf{10^{-15}}$ sec. = one millionth of a billionth of a second)
    - ➢ Such pulses can be created by ➔ mode-locked oscillators.
    - ➢ Amplification of ultrashort pulses almost always requires ➔ the technique of chirped pulse amplification, (in order to avoid damage to the gain medium of the amplifier).

> - The 1999 Nobel Prize in Chemistry was awarded to Ahmed H. Zewail for using ultrashort pulses to observe chemical reactions on the timescales they occur on, opening up the field of femtochemistry.

- ➢ *Principle:*
  - When the pulse duration is shortened from nanoseconds to the femtosecond time domain ➔ the engery required to produce tissue breakdown is reduced.

- ➢ *Characters:* ➔ It work by the principle of Photodisruption

  Three major events:

  (a) Plasma creation.

  (b) Plasma expansion: Which mechanically disrupt tissue adjacent to the Disintegrated area.

  (c) Cavitation buble creation: Will be absorbed by the normal mechanisms.

- ***Femtosecond laser wavelength:***
  - *The titanium-sapphire laser ➔ emits pulses of 785 nm with a total spread of 20 nm:*
    - Only a small portion of the bandwidth is in the visible range (red).
    - The rest of the bandwidth is in the infrared (invisible).
  - *The diode-pumped femtosecond CPA ➔ emits at 1053nm (infrared invisible).*

- ***Femtosecond LASER duration, energy and frequency:***
  - The titanium-sapphire laser pulses has 120 fs duration at 1.4mj.
  - The diode-pumped laser has 500 fs duration at 0.025 mj with a repetition rate of up to 1000 Hz.

- ***Advantages of femtosecond LASER:***
  1. Minimal collateral damage.
  2. Highly localized healing.
  3. Subsurface surgery.
  4. Reproducible micron size cuts.
  5. Negligible heat affected zones.
  6. Machining of materials with high thermal conductivity.
  7. Multiphoton absorption.

- ***Indications of femtosecond LASER:***

A. Refractive surgery:
  - 1- Femtosecond LASIK: The laser corneal flap and then Excimer laser ablate the cornea.
  - 2- Femtosecond lenticule extraction (Flex): the femtosecond laser create the flap and ablate the cornea.
  - 3- SMILE:

B. other therapeutic applications:

  - *I. In treatment of corneal disorders:*
    - (1) Intra-stromal corneal ring segment (ICRS): The creation of the entry and tunnel cuts (cut channels) in ICRS implantation.
    - (2) The treatment of post LASIK or keratoconic ectasia.
    - (3) In custom ablations.
    - (4) Therapeutic keratoplasty:
      - a) Full thickness.
      - b) Partial thickness:
        - ✓ Anterior lamellar keratoplasty (ALKP).
        - ✓ Deep lamellar endothelial keratoplasty (DLEK).

  - *II. Transscleral photodisruption in glaucoma:*
    - *Procedures:*

a. By changing the optical properties of the laser pulse: A long WL of 1700 nm is used to penetrate the full thickness of the sclera.
b. By changing the optical properties of the tissue: The sclera is soaked in Hypaque60 until significant transparency occurs.

- *<u>Advantages of subsurface femtosecond glaucoma surgery:</u>*
  i. The laser beam can be focused beneath the easily scared layers.
  ii. Any pattern with less than 10 µm can be cut in the sclera.
  iii. The procedure is completely computer controlled.
  iv. The incision has very little collateral damage.
  v. Total treatment time may be less than 5 minutes.
  vi. Minimal risk of infection (as the surface is never broken).

III. *In treatment of cataract.*

IV. *In treatment of retinal disorders.*

LASER CONTACT LENSES:

1. Argon LASER contact lenses:

1. Posterior segment argon laser lenses:

1. Mainster retinal laser lens set:

	Mainster standard (S) lens:	*Mainster wide field (WF) lens*	*Mainster high magnification (HM) lens:*	*Mainster ultra field (u F) lens*
Magnification	*0.96X*	0.68 X	1.25 X	0.53x
Field of View	*90°*	wider field (125°)	75°	wider field (140°)
laser spot size	*105 µm*	147 µm	80µm	189µm
Uses	Good for macular diseases	Good for PRP	Good for macular diseases	ideal for PRP than Mainster WF lens

2. Karickhoff laser lens:
    - With 4 mirrors of 62°, 67°, 76° and 80° plus a central axis view.
    - Its field of view overlaps exactly covering the arcades (missed with Goldmann 3-mirror contact lens) with observation of the AC angle, ora serrata, mid-equator and mid-peripheral area.

3. *Goldmann 3-mirror lens (Chapter 22)*:
    - M is 0.93x
    - laser spot of 108µm in tissues.

4. McLean prismatic fundus lens:
    - It provides a 35° field of view to facilitate visualization of the retina and related structures in the mid-peripheral fundus.

2. Anterior segment argon laser lenses:

1. *Abraham iridectomy argon laser lens:*
    - It is a modified Goldmann fundus contact lens with
        - +66 planoconvex button lens with
        - 1.6 x magnification.
    - *The lens delivers more energy to the iris with less thermal damage to cornea and retina due to:*
        A. F of +66 D is ≈ 13 mm and thus its f is at the iris and thus causes a sharp convergence of the laser light on the iris.
        B. The laser beam at the cornea is less convergent and has a large area and so the energy delivered to the cornea is decreased.

2. *Wise iridectomy laser lens:*
- 103 D lens with 2.6 x magnification to facilitate the small spot laser delivery.
- It increases efficiency of iris perforation with less energy and shorter bum duration, as compared to Abraham lens.

3. *Ritch trabeculoplasty laser lens:* it consists of
   1. Two 59° mirrors with a round top Treating inferior 180° of the angle.
   2. Two 64° mirrors with a flat top Treating superior 180° of the angle.
   3. A planoconvex button:
      - It is superimposed over one of 59° mirrors and one of 64° mirrors.
      - It provides magnification of 1.4 x with reduced laser spot size (from 50 µm to 35 µm) .

4. *Hoskins nylon suture laser lens:*
- It is a 120 D lens with 1.2 x magnification.
- It is designed to compress the overlying conjunctival vessels, allowing visualization and laser cutting of nylon sutures.

5. *Goldmann 3-mirror lens: Chapter 23.*

2. YAG LASER contact lenses:

1. Posterior segment lenses:

1 . Peyman wide field YAG laser lenses:
- *A lens with 12.5 mm anterior radius:* For treating anterior vitreous and AC.
- *A lens with 18 mm anterior radius:* For treating mid-vitreous.
- *A lens with 25 mm anterior radius:* For treating deep vitreous.
- *A convex surfaced Peyman contact lens is used in vitreous surgery to increase the safety of intraocular use of YAG laser:* As this lens reduces the focal spot and aids diverging the laser beam beyond the focal point.

2 . LASAG lenses (Trade name lenses specific to YAG laser units):
- *CGA lens:* For chamber angle irradiation.
- *CGI lens:* For use on the iris.
- *CGP lens:* For pupil and retropupillary spaces and anterior vitreous.
- *CGV lens:* For posterior segment from the center of the eye to retina.

2. Anterior segment lenses:

1 . Abraham iridectomy YAG laser lens:
- It is a modified Abraham iridectomy argon laser lens in which the planoconvex +66 D button lens is of larger diameter(10mm)and of smaller M(1.5 x).

2 . Abraham capsulotomy YAG laser lens:

- It is a modified Abraham iridectomy argon laser lens in which the planoconvex +66 D button lens is of larger diameter(l0mm), of larger M (1.8 x) magnification.

3 . Peyman capsulotomy YAG laser lens:

- It has 14 mm diameter anterior surface with a spherical radius of 12 mm, it provides M of 1.8 x and is used for posterior capsulotomy procedures.

3. Transscleral contact lenses:

As Shields transscleral cyclophotocoagulation YAG laser lens

3 . DIODE LASER contact lenses:

- *Argon laser lenses:* With additional antireflective coating.
- *Schields transscleral cyclophotocoagulation laser lens:* As with YAG laser.
- *Cycloscopy:* Is visualization of the ciliary body through a large peripheral or sector iridectomy for:
  - Examination of the ciliary body.
  - Transpupillary cyclophotocoagulation for glaucoma in aphakic eyes usually

STERILIZATION OF HAND-HELD CONTACT LENSES:

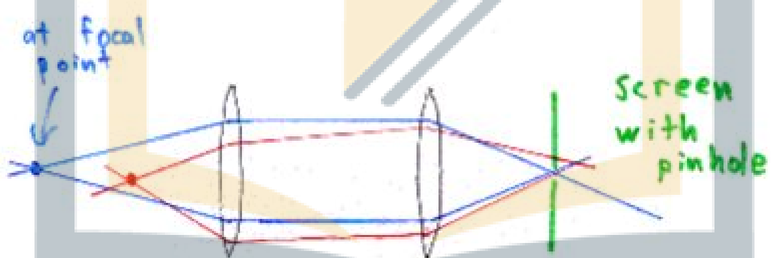
- *Laser, diagnostic and other acrylic lenses:*
  - a) *Cleaning:* With cold or tepid water.
  - b) *Disinfection:* With sodium hypochlorite 1:10 solution (for 10 minutes).
  - c) *Sterilization:* With ethylene oxide gas at a temperature less than 52° C.
- *Quartz, surgical and other glass lenses:*
  - Are sterilized by ethylene oxide gas or steam autoclave.

DIAGNOSTIC LASER BEAMS

✱ *Confocal Optics:*

When an imaging system and illumination system focus on the same small point, the system is described as➔ being confocal.

- The contrast and resolution of the image are increased by ➔minimizing the amount of scattered light by means of
    1) a very small area of illumination and
    2) A very small field of view.
  - This is achieved by
    1) Using a ➔Laser source of illumination and
    2) By the observer viewing through ➔ a pinhole or slit.
- The overall field of view is then increased by scanning across the area being examined.



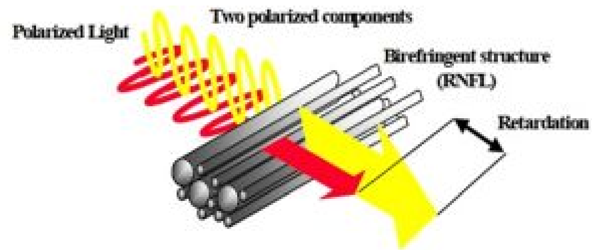
Pinhole aperture for viewing□eliminates scatter from rest of tissue□very sharp image
Pinhole conjugate to focal point of lens=confocal pinhole=confocal microscope

1. *Confocal Microscopy:*
    - ❑ A microscopic examination of the living cornea.
    - ❑ *Principle:*
        - The principle of confocal optics is used in laser scanning confocal miscroscopy,

2. *Scanning Laser Polarimetry (LASER Nerve fiber analyzer):*
    - Use:
        - Measurement of the *thickness of* RNFL to ➔ detect early glaucomatous damage.
    - Principles:
        - It measures the thickness of the RNFL rather than the surface topography of the retina as it measures the retardation of laser beam which double passes the RNFL:
        - When polarized light travels through the RNFL :

➔ Beam parallel to the RNFL ➔ slows down compared to the one that travels perpendicular to the fiber layer.

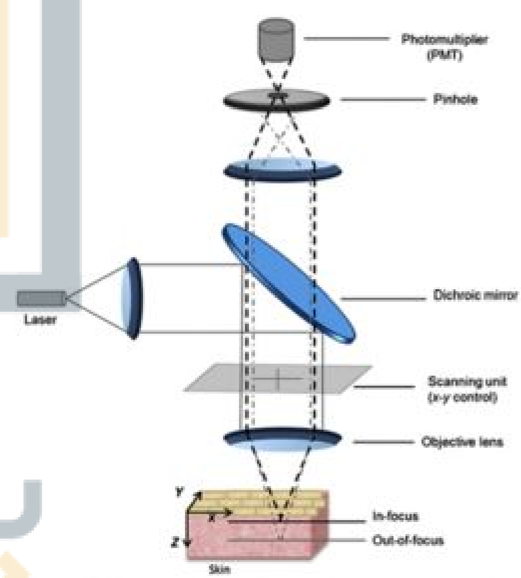
➔ This difference in the speed between the two beams is called retardation and is proportional to the RNFL thickness.



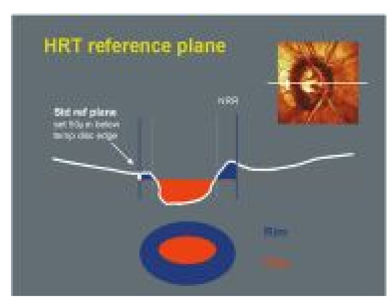
3. *Confocal LASER scanning ophthalmoscope:*

- The CSLO technology is used by the Heidelberg Retinal Tomograph (HRT, Heidelberg Engineering, Heidelberg, Germany).

- Principles:
  - It is based on the principle of two conjugated pinholes.
    - A. Laser light (670nm) enters through➔ one pinhole and focuses on <u>a plane</u> of the retina or the optic disc.
    - B. The reflected light passes through ➔ the confocal pupil which allows only the light reflected from that specific plane to enter the photodetector.
      - ➔ The focused laser light scans many planes at different depth across the ONH and RNFL acquiring a series of images. This series is reconstructed to produce a three dimensional image.



  - SCLO has a transverse resolution of 10 µm and an axial resolution of 300 µm.
  - The field of view of the image is 15°×15°
  - A fundamental part of the SCLO technology is the ➔ reference plane.
    - It is defined as a plane parallel to the retina and lies 50 µm below the temporal part of the scleral ring of Elsching.
    - In ONH analysis
      - ➔ structures above the reference plane are read as neuroretinal ring (blue) and
      - ➔ structures below are read as disc cup (red).



- Applications:
  1) Real-time angiographies:
  2) Infrared light benefits:
     - i. Examination of cataracts as scattering is less with infrared light.
     - ii. Examinations with naturally dilated pupil.
     - iii. Comfortable examination with less light stress.
  3) Benefits with additional modules:
     - (a) <u>Fixation module:</u> By a fixation cross in the scanning field.

(b) <u>Static and kinetic scotometry module:</u> *With 2 scotometry versions to project:*
- ❑ Dark stimuli on a light background.
- ❑ Light stimuli on a dark background with the infrared laser.

(c) <u>Visumetry module</u>: For acuity tests with a choice of different brightness and acuity level (from 20/60) with synchronous observation of the fundus.

4. *Confocal scanning laser tomography:*
   - o *Use:*
     - Topographic scanning of the optic disc analysis (as regards diameter, total area, light, depth and cup/disc ratio) and of the neuroretinal rim area.
   - o *Principles:*

     It Uses a CSLO to produce topographic map of optic nerve head.

5. *LASER interferometer:*
   - ▪ Definition:
     - ➯ It uses coherent laser light and interference to estimate VA in the presence of opaque media.

       > ✱ Laser interferometers usually use➔ red He Ne laser light while other interferometers use white light from incandescent source.

   - ▪ Principles:
     - ➯ The laser interferometer ➔ utilizes two separate sources of coherent laser light (two coherent laser beams)
       - ☛ The two coherent laser beams ➔ are focused in the anterior segment of the patient's eye with formation of 2 point images
       - ☛ Light then diverge and interfere with each other with the formation of interference fringes on the retina.

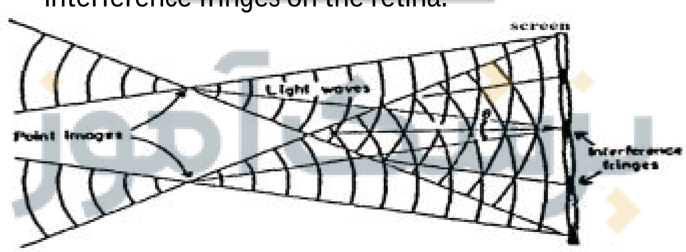


Fig. 31.14: Interference fringes.

- ➯ Reducing the separation between the 2 light source reduce the spatial frequency of the grating and allow the estimation of potential visual acuity of an eye when the macula cannot be seen because of cataract.

> ▪ *The ability of a cataractous patient to see the grating with laser interferometer :* Is dependent upon the slit lamp finding of two relatively clear points in the lens through which the laser light can pass.

1. Laser Microperimetry:
   - This technique uses a laser beam to determine the light sensitivity of very small areas of the retina and to identify small scotomas.

2. Laser Doppler Flowmetry:
   - This is a means of measuring retinal capillary blood flow.
   - It is based on the Doppler principle.
     - Laser light incident upon moving blood cells is reflected at a different frequency from the incident beam.
     - A greater shift in frequency indicates → a greater blood flow velocity.

Multifocal lenses:

- ***Definition:***
  These are lenses with more than one focal power.

- ***Types:***
  I. Bifocal lenses: With two focal powers.
  II. Trifocal lenses: With three focal powers.
  III. Varifocal lenses (progressive addition lenses): With gradual change of power:

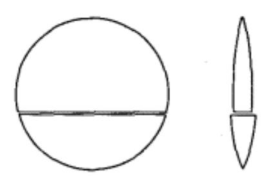
BIFOCAL LENSES:

- ***Definition:***
  Are lenses with two focal powers, one for distant vision and the other for near vision.

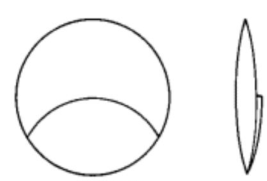
- ***Indications:***
  1. *Presbyopes:* With distant ametropia.
  2. *Myopes with:*
     - Esophoria for near.
     - Poor accommodation.
  3. *Aphakia:* Young aphakics can tolerate them (but not old aphakics).
  4. *Hypermetropia with* Esotropia for near.

- ***Contraindications:***
  1. *Unstable patients:* As intolerance often occurs.
  2. *Handicapped patients as limping:* To keep eyes opposite lens optical centre.
  3. *Marked astigmatism and anisometropia:* Due to the prismatic effect of lenses.
  4. *Certain occupations:*
     - Sports as golf because a full field of distant vision is required.
     - Sailors and builders due to loss of balance.

- ***Types:***
  1. Franklin bifocals (split bifocals):
     - Two separate lenses in the same frame (obsolete).
     - Good optical performance because optical center are situated at the dividing line.



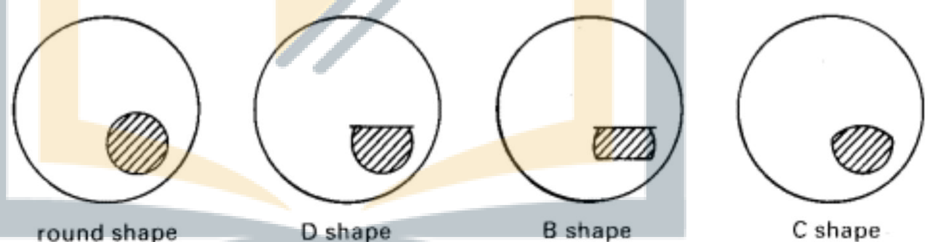
  2. Cemented wafer bifocals:
     - A supplementary lens (wafer) is cemented on the surface of the main lens by Canada balsam with the same refractive index glass (obsolete).



3. <u>Fused bifocals</u> (invisible bifocals):

- <u>*Characters:*</u>
  - *Are made by combining a lens of crown glass with ➔ a segment of flint glass of higher refractive power cemented on a hollow of crown glass lens.*

- <u>*Types:*</u>
  1. *Round segment (conventional type):*
     - The edge of the segment for near forms a part of a circle (which is liable to optical defects).
  2. *Flat-topped "D segment":*
     - The edge of near segment is flat topped (to get rid of the part with most optical defects).
  3. *Flat topped "rectangular segment":*
     - Permits distant vision below it.
  4. *Curve topped:*
     - The near segment is as D segment but its upper border is curved with its convexity upwards.

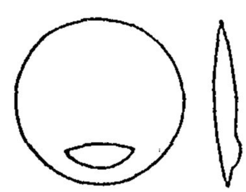


1-Rounded. 2-Flat top (D). 3-Flat top (rectangular) .4-Curve.

- <u>*Disadvantages*</u>*: More in conventional round segment type:*
  - A. Chromatic aberration (due to difference in dispersion of two types of glass).
  - B. Less definition on reading (due to contact surface of two types of glass).
  - C. limited field for near (due to restricted size of near segment).
  - D. Thicker and heavier than other types.

4. <u>Solid bifocals</u> (one-piece bifocals):

- <u>*Characters :*</u>
  - *These are made of one piece of glass or plastic:*
    - Two curves are ground upon one spherical surface which is the segment side while any cylinder is ground on the other side.
    - Segment side is usually posterior except in higher ametropia.

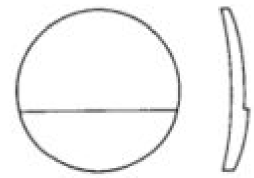


- <u>*Advantages over fused bifocals are:*</u>

A. No chromatism.
B. Belter definition through the reading portion.
C. Thinner and lighter.
D. Larger field for near, as the segment diameter is 22-45 mm.

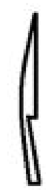
✱ <u>*Special types of solid bifocals:*</u>

1. *Executive bifocals:*
    - As Franklin bifocals, but is one piece of glass or plastic.
    - The optical centres of both portions are situated at the dividing line so
        - there is a wide field for near and
        - there is no prismatic jump.



2. *Centre-controlled solid bifocals*: In which there is a selection of the sites of optical centres.

5. Other types of bifocals:
    1. *Prism-controlled bifocals:*
        - Contains a prism to counteract their intrinsic prismatic effect.



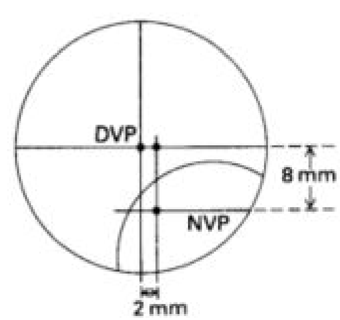
    2. *Up-curve bifocals:*
        - To look up from near work.
    3. *Monocentric bifocals:*
        - In which the optical centres of the two portions coincide at the interface and so both centres are away from their visual points.
    4. *Rising-front bifocals :*
        - Spectacles can be raised or lowered by an adjustable step in the nose-piece:
    5. *Hook-fronts:*
        - Are separate pairs of lenses placed in front of the distant lenses.

✪ <u>*Characteristics of an ideal bifocal lens:*</u>

A. Optical requirements:

1 . <u>DVP coincide with the Optical center of distant segment and NVP coincide with the optical center of the near segment</u>

- <u>*Distance visual point*</u> *(DVP):*
    - A point through which the visual axis pass when looking to distant objects,
    - It coincides with the optical centre of the distant segment and is above the top of the lower segment.



- <u>*The near visual point*</u> *(NVP):*
    - A point through which visual axis pass on reading,
    - It is usually 8 mm below and 2 mm nasal to the DVP .

2. *Clear vision with no aberrations by the two segments of a bifocal lens:*
   - By bending to a toric form (but oblique astigmatism is unavoidable on eccentric viewing through the lower segment).
3. *No sudden change at junction of 2 segments to avoid prismatic jumping by:*
   - Monocentric bifocal (optical centre of distant segment coincides with that of the near portion).
   - Optical centres of distant and near segments are at or near the junction of two segments.
   - Prism base-up in the reading segment.

B. The needs of the individual patient:
   - ☆ *A typist or supermarket cashier:* A larger near segment.
   - ☆ *Outdoor person for a wide field of distance vision:* A smaller near segment.

➢ *Optical defects of bifocals:*

- o *Aberrations of spectacle lenses:* see before.
- o *other optical defects of bifocals:*

1. Prismatic effect at the near visual point (Image displacement):
   - *Prentice rule:* P = D X h.
     - With a bifocal segment, the gaze is usually directed 8 mm below and 2 mm nasal to the distance optical center of the distance lens ➔ Prismatic effect
       - ⇨ As long as the bifocal segments are of the same power and type, the prismatic displacement is determined by the power of the distance lens alone.
       - ⇨ If the lens powers are the same for the 2 eyes,➔ the image displacement will be the same. However, if the patient is anisometropic, a phoria will be induced by the unequal prismatic displacement of the 2 lenses.
   - *Causes:*
     a. A prism base-up in convex distant lenses and base-down in concave distant lenses.
     b. A prism base-down in the reading segment in conventional types.

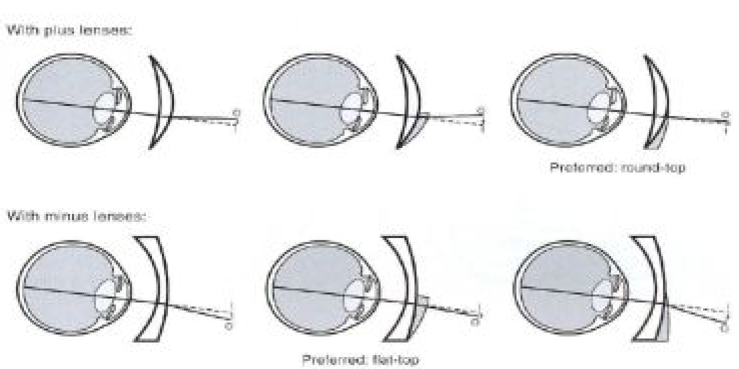
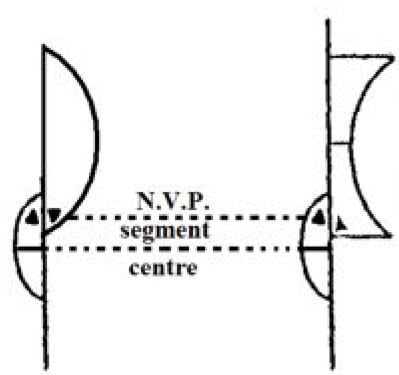


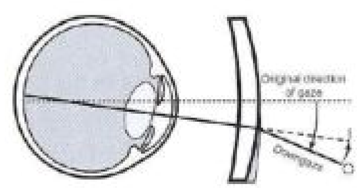
Figure 4-26 Image displacement through bifocal segments. (From Wisnick HJ. Bifocals, trifocals, and



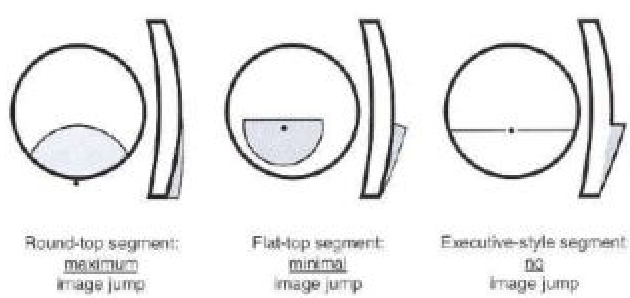
- *Correction:*
    1. *Base-up prism in reading segment to cancel its prism base-down effect.*
    2. *The optical centre of reading segment is brought dose to the NVP as in:*
        - ✓ Flat topped fused bifocals.
        - ✓ Curve topped fused bifocals.
        - ✓ Executive solid bifocals.
    3. *The optical centre of the distant segment is lowered (decentration) to approach the NVP.*
    4. *Bicentric grinding (slab-off)*
        - ➔ *In this method, 2 optical centers are created in the lens having the greater minus power, counteracting the base·down effect of the greater minus lens in the reading position.*
        - ➔ *It is convenient to think of the slab·off process as creating base up prism over the reading area of the lens.*
    5. *Reverse slab-off Prism*
        - ➔ *adding base-down prism to the lower half of the more plus lens. This technique is known as reverse slab-off.*
    6. *Press on prisms*

2. Prismatic jumping at the top of the reading segment:

- Definition:
    - It is abrupt displacement of image with change of vision due to prismatic effect at the top of the lower segment with prism base-down effect.
    - More in high-powered bifocals.



- Cause:
    - As the eyes are directed downward through a lens, the prismatic displacement of the image increases.
    - When the eyes encounter the top of a bifocal segment, they meet a new plus lens with a different optical center ➔ the object appears to jump upward (unless the optical center of the add is at the very top of the segment)
- Corrections:
    1- Executive solid bifocals.
    2- Flat topped or curve topped fused bifocals.
    3- Prism-controlled bifocals (Fig. 17.22).
    4- Monocentric bifocals.



3. Oblique astigmatism at the near visual point:

- *Cause:*
  On reading, the near visual axis is oblique to the optic axis of the near portion of the lens.
- *Correction:*
  Hard to correct but most patients can overcome its effects,

4. Limitation of the visual field:
   Both for near and for distance and this is adjusted according to the patient needs.

TRIFOCAL LENSES:

✱ *Definition:*

- Are lenses with 3 focal powers.

✱ *Indications:*

- For certain activities in advanced presbyopes when amplitude of accommodation has declined to the point where intermediate distances are blurred.

✱ *Advantages:*

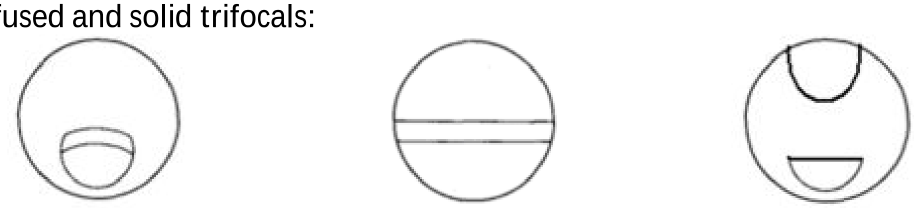
a) Larger field of vision.
b) No prismatic jump effect.
c) Clear vision at intermediate distances.

✱ *Disadvantages: not suitable for:*

- ❑ Anisometropes.
- ❑ Prism use for near work.
- ❑ Very small segments as in fishing spectacles.

✱ *TYPES:*

A. Fused trifocals:
B. Solid trifocals:
C. Combined fused and solid trifocals:



(a) Fused trifocal (D-segment) lens. (b)Solid trifocal lens. (c)Combined trifocal lens.

PROGRESSIVE ADDITION LENSES

✱ *Definition:*

- A lens with progressive change of power from top to bottom.

✱ *Progressive lens power:*

- The PAL form has 4 optical zones on the convex surface
  1. Spherical distance zone.
  2. Spherical reading zone.
  3. Transition zone (corridor).
  4. Peripheral distortion zones.
- The concave surface is reserved fo r the sphere and cylinder of the patient's distance lens prescription.

✱ *Advantages:*

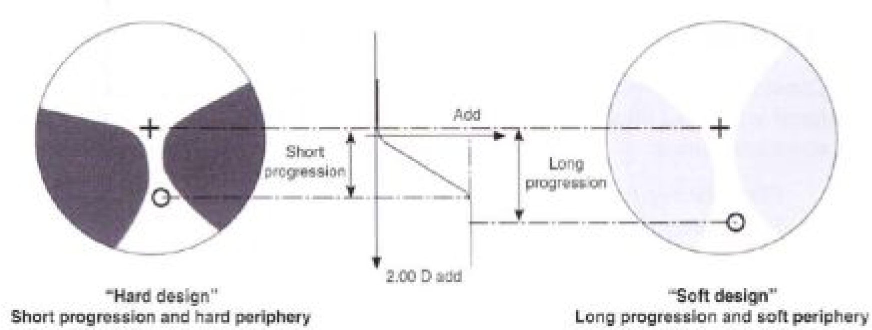
1. PALs offer clear vision at all focal distances
2. No abrupt change in power.
3. No prismatic effect.
4. No apparent lens segment.

✱ *Disadvantages:*

1. Restricted visual field.
2. Gross distortion on looking to the side (especially if there is high degree of astigmatism at an oblique axis) due to aberrations by the lateral parts of the lenses. ➔ these distortions produce a "swimming" sensation with head movement.
3. Not suitable when there is a large cylinder in the prescription.
4. *Difficult verification of multifocal spectacles:*
   - ❑ By neutralization method: On centering over maximal add reading portion.
   - ❑ By focimeter But the correct position can be obtained from:
     a. The regularity of the circles of dots.
     b. If axis of cylinder in reading segment is same as in distance portion.

✱ *Designs:*

- ☆ Hard lens design:
  - With large area of sharp definition but with greater degree of astigmatism on looking downwards, and nasally or downwards and temporally.
- ☆ Soft lens design:
  - With minimal degree of astigmatism but with small area of sharp definition (but is preferred).



INTRAOCULAR LENSES (IOLs)

Calculation of IOL power:

- *Formulae for calculation of IOL power*
  - *IOL power calculation formulas fall into two major categories:*
    1. *Regression formulas and*
    2. *Theoretical formulas.*

A. Regression formulae:

- The regression formulas are empiric formulas generated by retrospective analysis of the postoperative refraction of large numbers of IOL implantations in an attempt to predict IOL power
- The most common regression formulas are the SRK and SRK II

B. Theoretical formulas: (are based on geometrical optics).

- They are called theoretical formula because they are based on theoretical model of the eye (the Gullstrand eye).
- The eye is considered a two lens system (i.e. IOL and cornea) and different assumption are made e.g.
  - the refractive index of the cornea,
  - the predicted distance between them which is called the estimated lens position (ELP) ,
  - The distance of IOL to the retina

  ➔ To calculate the power of the IOL.

IOL calculation formulas differ in the way they calculate ELP.

1 . 1st Generation Formula:

- The 1st generation formulae has given the ELP a constant value of 4 mm for every IOL in every patient
  - Initially, most IOLs were either AC or prepupillary IOLs. Thus, in the original theoretical formulas, this factor was called the anterior chamber depth (ACD), and it was a constant value (usually 2.8 or 3.5 mm).

Example:

A. Regression formulae:

- SRK-1 formula: (Sanders, and Retzlaff and Kraff)

$$P = A - 2.5L - 0.9K$$ Where

P = IOL power in D (to produce E in aqueous).
L =Axial length of the eye.
K = Average keratometric reading In D.
A = Specific constant for IOL style.

B. *__Theoretical formula__:*

- The 1st theoretical formula was based on Geometrical optics as applied to the schematic eye.
  - These formulas is based on 3 variables
    - Axial length
    - K reading
    - Estimated postoperative ACD
- Subsequent formula from Colenbrander , *Hoffer and Binkhorst* incorporated ultrasonic data.

2. 2nd Generation formula:

- The 2nd generation formulae calculate the ELP based on the Axial length of the eye
  - Thus, in second-generation formulas, ACD was no longer a constant in all eyes but rather varied with axial length. (better predict the ACD).

- Others (SRK II, Binkhorst) developed different mechanisms to apply this predictive relationship

A. __Example:__

- SRK-II formulae: For shorter or longer eyes (as SRK-I formula is not accurate):
  - The only change was that the A constant is modified according to the axial length of the eye
    - *Short AL (below 22 mm):*
      - Add 1 to constant A if it is 21 -22mm, add 2 to constant A if it is 20-21 mm and add 3 to constant A if it is less than 20mm.
    - *Long AL (above 24.5 mm):*
      - Subtract 0.5 mm from constant A.

less than 20 mm,	A1 = A + 3
20 mm to less than 21 mm,	A1 = A + 2
21 mm to less than 22 mm,	A1 = A + 1
22 mm to less than 24.5 mm,	A1 = A
24.5 mm and above,	A1 = A - 0.5

3. *3rd Generation formula:*

- The 3rd generation formulae calculate the ELP based on the axial length and the corneal curvature.
  - These formulas were shown to be significantly more accurate than previous theoretic formulas and the SRK II.

Example:

1. *__Holiday 1__:* used the K reading and AL as factors.

2. *Hoffer Q:* modified his previous regression formula with a theoretic formula (Hoffer Q) & used the AL and a tangent factor of K
3. *SRK/T:* combined the advantages of retrospective data analysis & theoretic advantages of a physiologic optics approach.

4. 4th Generation Formulae:

- *The 4th generation formulae calculate the ELP based on more than 2 variables.*
- *Example:*
    A. *Holliday 2:*
    - *Holliday 2 formulae takes into account (Beside AL and K reading) :*
        A. *Corneal white to white diameter*
        B. *Preoperative AC depth*
        C. *Phakic lens thickness*
        D. *Patient age and sex*
        E. *Beside AL and K reading*

    B. *Haigis:*
    - Eliminated the K as a prediction factor and replaced it with the preoperative ACD measurement
    - Haigis proposed using 3 constants (a_0, a_1 and a_2) based on the characteristics of the eye and the IOL to predict the ELP (500- 1000 eyes implanted with IOLs of a Single design, combined Regression and theoretical).

$$ELP = a_0 + a_1 + ACD + a_2 + AL$$ where;

ELP = predicted IOL position.

a_0 = IOL specific constant

a_1 = a constant to be effected by the measured preoperative ACD

a_2 = IOL specific constant to be be effected by the measured preoperative Axial length

ACD = distance from the cornea to the front surface of the lens

AL = Axial lenght

- The most accurate way to measure the preoperative ACD or the postoperative ELP is to use
    1. An optical pachymeter (Haag-Streit).
    2. Ultrasonography is usually less precise and provides a shorter reading.
    3. The IOLMaster is fairly accurate.
    4. The ACMaster (Carl Zeiss Meditec AG, Jena, Germany), based on the partial coherence interferometry technique, has recently been introduced.

✱ Formula choice

- Several studies have indicated that the
    - Hoffer Q formula is more accurate for eyes less than 24.5 mm;

- the Holladay 1, for eyes from 24.5 to 26.0 mm;
- the SRK/T, for eyes greater than 26.0 mm (very long eyes).
- The Haigis may be superior to these formulas, for all eyes, but only after 3 personalized constants (ao, ai' and a,) have been generated based on 500-1000 eyes implanted with IOLs of a Single design (triple optimization)-a difficult undertaking for the average ophthalmic surgeon.

✱ Biometric formula requirements:

A. Axial length

- *The AL is the most important factor in the formula.*
- *A 1mm error* in AL measurement results in a refractive error of approximately
    - *3.75 D/mm in a 20 mm eye.*
    - *2.35 D/mm in a 23.5mm eye.*
    - *1.75 D/mm in a 30-mm eye*
        - Therefore, accuracy in AL measurement is more important in short eyes than in long eyes.

✱ Ultrasonic measurement of the axial length of the eye:

- A-scans do not measure distance but rather the time required for a sound pulse to travel from the cornea to the retina.
- The sound transit time measured is converted to a distance using the formula

$d = t/V$ where

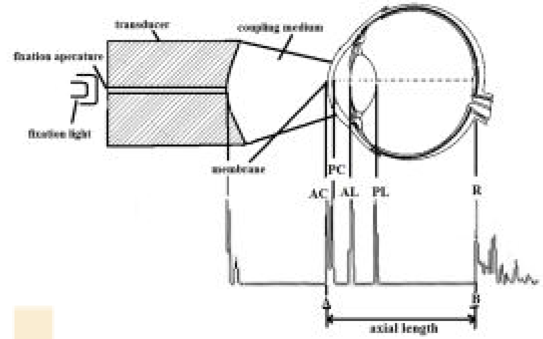
d= the distance in meters
t= the time in seconds
V = the velocity in meters per second

- The velocity of sound wave is:
    - Faster through the lens and cornea (1640 m/sec).
    - Slower through the aqueous and vitreous (1532 m/sec).
    - 1590-1670 m/sec (average of 1629 m/sec) in cataractous lens.

- The average velocity through a phakic eye of normal length is 1555 m/s; however, it is 1560 m/s for a short (20-111m) eye and 1550 m/s for a long (30-m111) eye. This variation is due to the presence of the crystalline lens; thus, 1554 m/s is accurate for an aphakic eye of any length.
    - Correction:
    1. Measuring the eye at 1532 mls and adding 0.34 to the result to account for the effect of the lens
    2. Using the following formula: ALe = ALM x V c/V"

ALM is the resultant AL at the incorrect velocity,
Vc is the correct velOCity, and
VM is the incorrect velocity used.

- *Technique:*
  - ✰ *Immersion method:* While the patient is in the supine position.
  - ✰ Applanation method: ultrasonic probe replaces applanation tonometer on the slit lamp.
    - ⇨ *<u>The features of a correct pattern</u>:* Are high anterior and posterior lens echoes (AL and PL), a high and steep retinal echo (R), and a low membrane reduplication echo.



> The applanation method has been proven to give a shorter AL measurement. Due to inadvertent corneal indentation. In the immersion method, accepted as the more accurate of the 2 techniques

- When ultrasonography is used to measure the AL in biphakic eyes (phakic I0L in a Phakic eye).
  - ⇨ The following formula can be used:

$$AL\ corrected = AL_{1555} + C \times T \quad \text{where}$$

AL_{1555} = the measured AL of the eye at a sound velocity of 1555 mls
C = the material -specific correction factor, which is +0.42 for PMMA, - 0.59 for silicone, +0.11 for collamer, and +0.23 for acrylic
T = the central thickness of the phakic 10L

✱ *<u>Optical measurement of the axial length of the eye : (partial coherence interferometery)</u>*

- ⟲ The IOL Master uses a partial coherence laser for AL measurement. In a manner analogous to ultrasonography,
- ⟲ The IOL Master measures the time required for infrared light to travel to the retina. Because light travels at too high speed to be measured directly, light interference methodology is used to determine the transit time and thus the AL.

B. Cornea l power

- The central corneal power is the second important factor in the calculation formula,
- A 1.0 D error in corneal power results in a 1.0 D postoperative refractive error.
- Central corneal power can be measured by
  - ⟲ keratometry
  - ⟲ Corneal topography,
    - ☛ Neither of which measures corneal power directly.
  - ⟲ The Pentacam & the Galilei (dual Scheimpflug camera and a Placido disk).

C. Estimated lens position

All formulas require an estimation of the distance that the principal plane of the IOL will sit behind the cornea- a factor now known as the ELP.
The most accurate way to measure the preoperative ACD or the postoperative ELP is to use

1. An optical pachymeter (Haag-Streit).
2. Ultrasonography is usually less precise and provides a shorter reading.
3. The IOLMaster is fairly accurate.
4. The ACMaster (Carl Zeiss Meditec AG, Jena, Germany), based on the partial coherence interferometry technique, has recently been introduced

- Error of 0.1 mm in AC depth: Results in a postoperative refractive error of 1D.

> - Calculation of IOL power for 2ry IOL implantation is more accurate due to:
>   1. Aphakic glass power and its vertex distance are known.
>   2. AL measurement is more accurate due to absence of crystalline lens.
>   3. Keratometry is more accurate as conical curvature and refraction are settled.
>   4. AC depth is well measured postoperatively.

✱ IOL Power Calculation After Corneal Refractive Surgery

- Intraocular lens power calculation is a problem in eyes that have undergone radial keratotomy (RK) or laser corneal refractive procedures such as PRK, LASIK, LASEK.
- The difficulty stems from 3 errors:
  1. instrument error,
  2. index of refraction error, and
  3. formula error

1. Instrument Error:
   - The instruments used by ophthalmologists to measure the corneal power (keratometers, corneal topographers) cannot obtain accurate measurements in eyes that have undergone corneal refractive surgery
     - Most manual keratometers measure at the 3.2-mm zone of the central cornea, which often misses the central flatter zone of effective corneal power.
     - The flatter the cornea, the larger the zone of measurement and the greater the error. Topography units do not correct this problem either; rather, they usually overestimate the corneal power, leading to a hyperopic refractive error postoperatively.

2. Index of Refraction Error:

- The assumed index of refraction (IR) of the normal cornea is based on the relationship between the anterior and posterior corneal curvatures. This relationsh ip is changed in PRK, LASIK, and LASEK eyes but not in RK eyes.
  - RK causes a relatively proportional equal flattening of both corneal surfaces, leaving the IR relationship essentially the same.
  - The other procedures flatten the anterior surface but not the posterior surface, thus changing the IR calculation. This leads to an overestimation of the corneal power by approximately I D for every 7 D of correction obtained.

3. Formula Error
   - With the exception of the Haigis formula, all of the modern I0L power formulas (Hoffer Q, Holladay 1 and 2, and SRK/T) use the AL and K reading to predict the position of the I0L postoperatively (ELP).
     - The flatter than normal K in RK, PRK, LASIK, and LASEK eyes causes an error in this prediction because the anterior chamber dimensions do not really change in these eyes commensurately with the much flatter K.

- Power Calculation Methods in the Postkeratorelractive Eye
  1. the Double-K method,
     - which uses the pre-LASIK corneal power (or 43.50 D if unknown) for the calculation of the ELP, and the post-LASIK (much flatter) corneal power for the calculation of the I0L power.
     - This can be done automatically in the Hoffer Programs and in the Holladay I0L Consultant program(Holladay 2).

  2. Clinical history method; Either
     - Calculate the true corneal power **or**
     - Adjust the calculated I0L power to account for the errors discussed in the preceding sections.
     - Some require knowledge of prerefractive surgery values such as refractive error or K reading.

$$K = K_{pre} + R_{pre} - R_{po}$$ where

K = calculated corneal power

K_{pre} = preoperative average K

R_{pre}=preoperative refractive error

R_{po} = postoperative refractive error

  3. the contact lens method:

$$K = B + P + RCL - Rbare$$ where

K = calculated corneal power

B = base curve (in D) of hard PMMA contact lens (CL)

P = power of CL

RCL = refraction with CL on the eye

Rbare ::: bare refraction without the CL

✱ IOL Power in Corneal Transplant Eyes

- Hoffer recommended th at th e surgeon wait for the cornea to completely heal before implanting an IOL
- If simultaneolls IOL implantation and corneal transplant are necessary, it has been suggested that surgeons use either
  - ⇨ The K reading of the fellow eye or
  - ⇨ The average postoperative K of a previous series of transplants..

✱ Silicone Oil Eyes

- 2 major problems.
  - ➢ The first is obtaining an accurate AL measurement with the ultrasonic biometer because the velocity of sound differ in silicone oil (980 m/sec) versus (1532 m/sec) for vitreous.
    - ⇨ Using the IOL Master to measure AL solves this problem. It is recommended that retinal surgeons perform an immersion AL measurement before silicone oil placement
  - ➢ The second problem is that the oil filling the vitreous cavity acts like a negative lens power in the eye when a biconvex IOL is implanted. This must be offset by an increase IOL power of3- 5 D.

✱ Pediatric Eyes

- There are several issues that make IOL power selection for children much more complex than that for adults.
  1. The first is obtaining accurate AL and corneal measurements, usually with the patient under general anesthesia.
  2. Second, because shorter AL causes greater IOL power errors, the small size of a child's eye compounds power calculation errors, particularly if the child is very young.
  3. The third problem is selecting an appropriate target IOL power, one that will not only provide adequate visual acuity to prevent amblyopia but also allow adequate vision in adulthood.
     - ➔ A possible solution to the latter problem is to implant 2 (or more) IOLs simultaneously:
       - one with the predicted adult emmetropic power and
       - The other (or others) with the power that provides childhood emmetropia.
       - When the patient reaches adulthood, the obsolete IOL(s) can be removed.
     - ➔ Alternatively, hyperopic corneal refractive surgery could be used to treat the myopia developed in adulthood.

✱ Lens-Related Visual Disturbances

- The presence ofIOLs may lead to the occurrence of a number of optical phenomena. Various light-related visual phenomena encountered by pseudophakic (and phakic) patients have been termed ➔ dysphotopsias.
- Such optical phenomena may be related to light reflection and refraction along the edges of the IOL
- Dysphotopsias is subdivided into positive and negative dysphotopsias.
    - A. Positive dysphotopsias are characterized by brightness, streaks, and rays emanating from a central point source of light, sometimes with a diffuse hazy glare.
    - B. Negative dysphotopsias are characterized by subjective darkness or shadowing. Such optical phenomena may be related to light reflection and refraction along the edges of the IOL.

Multifocal lOls

✱ Types of MultifocalIOLs

1. BifocalIOL

- The bifocal concept was based on the idea that when there are 2 superimposed linages on the retina, the brain always selects the clearer image and suppresses the blurred one.
    1. Split bifocal.
        - ☛ half the optic was for distance vision and the other half for near
            - o The additional power needed for near vision is not affected by the AL or the corneal power but is affected by the ELP.
            - o This design, which was independent of pupil size
    2. bullet bifocal,
        - ☛ which had a central zone for near power, with the surrounding zone being for distance.
            - o When the pupil constricted for near vision, its smaller size reduced or eliminated the contribution from the distance portion of the IOL.
            - o For viewing distant objects, when the pupil dilated, more of the distance portion of the IOL was exposed and contributed to the final image.
        - ☛ One problem with the design itself was that the patient's pupil size did not always correspond to the desired visual task.

2. Multiple-Zone IOL

- To overcome the problems associated with pupil size, ➔ a 3-zone bifocal was introduced.
    - a. The central and outer zones are for distance vision;

b. The inner annulus ➔is for near.
   - The diameters were selected to provide near correction for moderately small pupils and distance correction for both large and small pupils.

- Another design uses several annular zones (Fig 6-22D), each of which varies continuously in power over a range of 3-5 D.
  - The advantage is that whatever the size, shape, or location of the pupil, all the focal distances are represented.

3. Diffractive multifocal IOL
- The diffractive multifocal IOL designs use ➔ Fresnel diffraction optics to achieve a multifocal effect.
  - The overall spherical shape of the surfaces ➔ produces an image for distance vision.
  - The posterior surface has a stepped structure, and the diffraction from these multiple rings produces a second image, with an effective add power.
- Second-generation diffractive multifocal IOL
  - Today, 3 newer diffractive multifocal IOLs are available that have increased independence from spectacles and decreased the incidence of optical side effects.
    1. The AcrySof ReSTOR IOL (Alcon) is an apodized diffractive lens.
       - Apodization refers to the gradual tapering of the diffractive steps from the center to the outside edge of a lens to create a smooth transition of light between the distance, intermediate, and near focal points.
    2. The ReZoom lens (AMO,) has 5 anterior surface zones for distance and near, and the grading between the zones provides intermediate vision.
    3. The TECNIS ZM900 lens (AMO) adds an aspheric surface, whereas the ReSTOR and ReZoom lenses do not

✱ <u>Disadvantage</u>:
1. The brain must process the clearest image, ignoring the other(s). Most patients can adapt to this, but not all.
2. The performance of certain types of IOLs is greatly impaired by decentration if the visual axis does not pass through the center of the IOL.
3. Other disadvantages of a multifocal IOL are
   - linage degradation, "ghost" images (or monocular diplopia),
   - decreased contrast sensitivity, and
   - Reduced performance in lowerlight (eg, trouble with night vision), making them less desirable in eyes with impending macular disease.

3) Accommodative IOL:

- *Dual-optic accommodating IOL:*
  - o Principle:
    Theoretically, each of these 2 IOLs will focus the distant and near objects on the fovea simultaneously.
  - o Optical-designs:

a) *Dual flex:* Two lenses are inserted:
  - ✪ A plate haptic IOL is inserted in the capsular bag to make up a two-thirds of the total lend power.
  - ✪ A three-piece silicone IOL is inserted in the sulcus to makes the remaining one-third of the lens power.

b) *Dual-optic system:*
  1- This lens was designed with:
     - ★ An exaggerated anterior optical power.
     - ★ A negative posterior diverging lens.
  2- This design allows for great amplification effect of small degree of movement by increasing the power of the plus component.

c) *Piggy back IOL:*
  - I. Implantation:
    - (a) A standard IOL is implanted as a first stage.
    - (b) A new complementary lens is inserted after one month.
  - II. This design creates a multifocal multizones system.
  - III. It is a posterior chamber IOL with a concave posterior surface to avoid any risk of contact between the two optics.

- *Physiologically accommodative IOL:*
  - ▪ *Principle:*
    1. The ciliary body presses on the lens and causes anterior displacement of the vitreous, moving the lens forward.
    2. Axial translation of the lens optic resulting from ciliary muscle contraction (the so called shift principle) by either:
       - ☆ Axial movement of the lens optic forwards, or
       - ☆ By using a flexible polymers designed for injection into nearly intact capsular bag.
  - ▪ *Optical designs:*
    1) The C&C -AT45 vision crystalens:
       a- The 2 main types are:
         - ✓ C&C crystalens: A three-piece lens with a T-shaped modified plate haptics and polymide loops to fixate in the bag.
         - ✓ AT lens: With a long space in front of silicone lens with a hinge at the junction of haptic with the optic to facilitate forwards movement of optic.

b- <u>Performance is by contraction of the ciliary body with vaulting of the IOL by either:</u>
   - ❑ Direct action, or
   - ❑ By displacing the vitreous body anteriorly.

c- <u>Placing the hinge between haptic and optic makes it easier for lens to move.</u>

d- <u>The use of longer haptics increase the amplitude of movement.</u>

2) The human optics ICU lens:
   i. It was developed to allow transmission of the contracting forces of ciliary muscle to lens optic to move anteriorly for pseudophakic accommodation.
   ii. It is one- piece lens made of hydrophilic acrylic with ultraviolet inhibitor.

3) The human optics AG lens:
   - It is a deformable accommodative IOL with similar natural properties of the crystalline lens →the single piece lens is inserted in the capsular bag and the haptics are unfolded manually (needs additional surgical skills).
   - it is a hydrophilic acrylic foldable IOL designed to be three dimensional as the capsular bag and stretching the sac horizontally and vertically →to allow the bag to assume its preoperative shape and to maintain the functions of ciliary muscle and zonular fibres and so allows deformation of the lens.

4) The smartlens:
   - ✪ A novel concept using a new smart material to be implanted as a small lens through a small corneal incision.
   - ✪ It uses a thermodynamic hydrophilic acrylic material (packed as a solid rod) which is transformed into a soft gel-like material with the shape of a full-sized biconvex lens that fills the capsule.

5) The injectable IOL(still under research) :

The lenses is formed form an injectable chemically modified soluble collagen that is extracted, purified and processed from human tissue.

CONTACT LENSES

✱ <u>*Optical principles:*</u>

1. The basic optical principle of contact lenses:

   The contact lens corrects ametropia by replacing the anterior surface of the cornea as it ➔ eliminates the refraction at the anterior corneal surface (which is the primary-refractive surface of the eye)

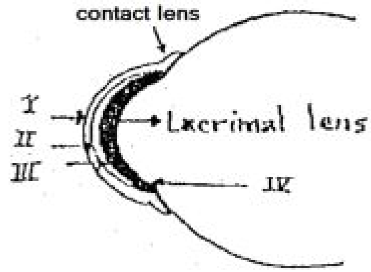
   - Because the RI of contact lens(1.495), of the cornea (1.376) and of the lacrimal (fluid) lens in-between (1.338) are almost alike.

> Light Refract occurs only at interfaces (i.e. between air / glass - Air/cornea etc). when using contact lens ➔ the CL , tears and cornea is considered as one material because of similar RI so light refract only at the Air/contact lens interface)

2. The optical system of a contact lens:

   ➩ <u>*The resulted combined optical system consists of two lenses:*</u>

   1. *The Tear (lacrimal) lens:*
      - Surfaces:
        - Anterior convex surface.
        - Posterior concave surface.
      - Importance:
        - It abolishes the refraction at the anterior surface of the cornea even if irregular.
   2. The *contact lens:*
      - Surfaces:
        - Anterior convex surface.
        - Posterior concave surface.
      - Importance:
        - It determines the curvature of the anterior surface of the lacrimal lens.
        - Its anterior surface (the main refractive surface of the eye) can correct ametropia.



(a)Surfaces of contact lens: Ant.I and post.II. (b)Surfaces of lacrimal lens: Ant.III and post.IV,
Fig.I8.1: Combined optical system of a contact lens.

3. Calculation of the power of a contact lens:

- *Mathematical theory*:
  - A. *Determined by its shape*:
    D = n_2-n_1/r
  - B. *From spectacle prescription :*

$$Dc = \frac{Ds}{1 - dDs}$$

- *From special tables*.

4. Power *rules: Are applied as follows:*

1. *Lacrimal power change:*
   - *Soft contact lens:*
     - Since the soft contact lens conform the shape of the cornea ➔ the curvature of anterior and posterior surface of intervening tear lens are identical thus ➔ the power of their fluid lens is always plano
   - *Hard contact lens:*
     - *In rigid contact lens ➔ the anterior and posterior surface of the fluid lens is not identical so*
       - *The power of the tear lens is* 0.25D for every 0.05 mm difference in the radius of curvature between the
         - o base curve of contact lens &
         - o central curvature of the cornea (K)
       - Tear lens created by rigid lens having a base curve steeper that K ➔ have a plus power
       - Tear lens created by rigid lens having a base curve flatter that K ➔ have a minus power

- *Rules of steeper and flatter PCC:* Flatter PCC will create a minus meniscus power (minus lacrimal lens) and so a same plus power must be added (the reverse with steeper PCC).

NB: Steeper add minus (SAM) and flatter add plus (FAP).

2. *Vertex distance and closer add plus (CAP):*
   - When refraction at the spectacle plane is ±4D or more ➔ refraction at the corneal plane is determined by the addition of plus power *closer add plus (CAP)*
3. *A spectacle sphere power:* if the curvature of the flattest corneal meridian is identical to the posterior central curve (PCC) of a corneal contact lens.
4. *Spectacle refraction:* In minus cylinder form.

5. Tear Lens and Astigmatism: (Spectacle refraction in minus cylinder form)

- The tear lens allows a spherical contact lens to neutralize corneal astigmatism. This can be done by;

- Fitting the base curve of the contact lens to the flattest corneal meridian;
    - So that where the cornea is steeper the tear lens is thicker (has a minus power) and thus neutralizes the astigmatism.
- It is therefore convenient to express the prescription using negative cylindrical powers because at that time ➔ only the spherical component need be prescribed.

- Whereas rigid lenses can normally correct large degrees of corneal astigmatism, soft contact lenses neutralize no more than 1.00 D in this way because they tend to adopt the shape of the cornea. Corneal astigmatism of more than 1.50–2.00 D is therefore an important limitation to the use of soft contact lenses.

- Astigmatism arising from the crystalline lens or an implanted intraocular lens will only be neutralized by a front surface toric contact lens.

6. Magnification of image by contact lenses:
    1- *Positive contact lenses:* Smaller image than the spectacles which is:
        a) A disadvantage in moderate hypermetropia.
        b) An advantage in anisometropia and in unilateral aphakia as the magnification is 10% only.
    2- *Negative contact lenses:* Larger image than the spectacles which is an advantage in myopia.

✱ Indication of contact lenses:

1. Diagnostic
    1. Pachymetery
    2. Specular microscopy
    3. Gonioscopy
    4. ERG
    5. Fundoscopy
2. Refractive
    1. Myopia & hyperopia: High errors
    2. Presbyopia
    3. Anisometropia: especially >4D
    4. Aphakia especially unilateral
    5. Irregular Astigmatism
    6. LVA: as a part of Galilean telescope
3. Therapeutic
    1. Bullous keratopathy
    2. Lagophthalmous
    3. Drug delievery
    4. Corneal ulcer
    5. Corneal thinining and perforation
4. Cosmetic: females , leukoma , aniridia
5. Occupational: sport CL
6. Occlusive: Amblyobia

Types of contact lenses

1. *hard(conventional) contact lenses:*
    - Hard corneal lenses.
    - Hard scleral lenses.
2. *Rigid gas permeable contact lenses.*
3. *Soft (hydrophilic) contact lenses.*

(1) HARD CONTACT LENSES:

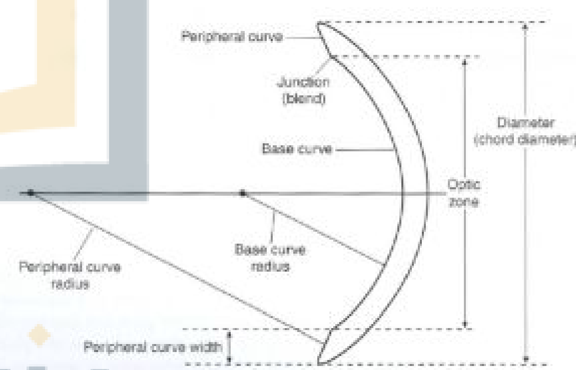
1) Hard corneal contact lenses:

➢ ***Lens material:***
Polymethylmethacrylate (PMMA) is the standard material with:

a. Refractive index 1.495.
b. Chemically inert.
c. No clinical toxicity.
d. Light weight.
e. Machined easily.

➢ ***Physiology:***

- *With blinking ➔ Tear gets beneath the lens.*



➢ ***Parameters of a hard corneal contact lens:***

(1) Regions of a corneal contact lens (Fig. 18.2):

a) The axial (corneal) region:

- The central portion of the posterior surface: Is the most steeply curved posterior optical zone (POZ) with a spherical curvature called ➔ *the posterior central curve* (PCC) or base curve (BC).

b) The peripheral (scleral) region:

i. Peripheral part of the posterior surface of a corneal lens: Is less curved than the axial region with a
    - o A posterior peripheral curve (PPC),
    - o a posterior peripheral curve width (PPC/W) &
    - o a posterior intermediate curve or curves (PIC).
ii. Edge: with a front bevel (FB) of the anterior surface at the periphery.

(2) Curves of a corneal contact lens:

I. *Continuous curve lens:* Which flattens in a non-spherical fashion from the axis to the periphery.
II. *Bicurve lens:* It has a single peripheral curve and a central curve.
III. *Tricurve lens:* It has two peripheral curves and a central curve.
IV. *Multicurve lens:* It has more than two peripheral curves and a central curve.

(3) Edge:
- Smooth, rounded, not too blunt to be felt by the lid and not too sharp to irritate the cornea.
- Edge lift (Z factor): Is the difference between the most peripheral band and the posterior central curve (PCC) and is slightly more in hard than in rigid lenses because of the greater need to ensure tear flow.

(4) Diameter: 8.5-9.5 mm. usually.
(5) Thickness: 0.1-0.2 mm.
(6) Power: ± 25 D are commonly available.

2) Hard scleral contact lenses:

➢ *Definition:*

A scleral contact lens is a large lens covering the entire cornea and a portion of the sclera.

➢ *Indications of scleral lenses:*
1) Cosmetic shell: A plastic shell for a grossly disfigured eye in which the scleral portion is clear or white and corneal portion is coloured with the iris pattern.
2) Occupational: An under water scleral lens which incorporates an air space with a flat front allowing the swimmer good vision both in and out of water.

➢ *Types of scleral lenses:*
(a) *Sealed lenses:* Which are non-ventilated (rarely used now).
(b) *Fenestrated lenses:* With one or more perforations in the scleral portion.
(c) *Channelled lenses:* With grooves along posterior surface of the scleral portion.

➢ *Parts of a scleral lens:*
I. Corneal (central optical) portion.
II. Scleral (haptic) portion.
III. Transitional zone: Between the corneal and scleral portions in modem lenses.

(2) RIGID GAS PERMEABLE (RGP) CONTACT LENSES:

- *Lens material:* *A gas (oxygen) permeable material such as:*
  - Cellulose acetate butyrate (CAB).
  - Polymethyl methacrylate - Silicone copolymers (PMMA-S).
  - Silicone/acrylate (S/A).

- *Advantages:*
  1. Gas permeable with good oxygen transmission.
  2. Very thin (80- 120 mμ).
  3. Very small (7-9.5 mm diameter) and so the lens covers 2/5 of the cornea only.
  4. Flexible and increases the tear flow between it and the cornea.
  5. Easy to manipulate.
  6. If the lens is scratched it can be repaired,
  7. The posterior surface and the edge of the lens are less annoying.

(3) SOFT (HYDROPHILIC) CONTACT LENSES:

- *Lens materials:*
  - *Hydroxyethylmethacrylate (HEMA):* Basic plastic polymerized in the soft lens.
  - *Additional or other materials:*
    - a) Ethylene glycol dimethylacrylate (EDMA).
    - b) Polyvinyl pyrolidone (PVP).
  - *Water content:*
    - ★ Moderate (35-50%): In daily wear lenses.
    - ★ High (50-80%): In extended wear lenses.

- *Advantages of soft contact lenses:*
  - I. The advantages of hard contact lenses: Discussed.
  - II. The other advantages of soft contact lenses are:
    - *1) Well tolerated:*
      - (a) Pliable and elastic when hydrated.
      - (b) Shaped to the cornea with no friction.
      - (c) Stable with no enzymatic action.
    - *2) Hydrophilic:*
      - ❑ The lens contains 35-80% water.
      - ❑ Permeable to gases, water and water dissolved substances (more with thin lenses).
    - *3) Soft:* With less damage to the eye.
    - *4) Optical suitability:* Is more.
    - *5) Complications:* Are less.

Complications of contact lenses:

A. Medical complications:

1. *Corneal abrasions:*
   - *Causes: Mechanical trauma by:*
     a) ill lens fitting
     b) High degree of astigmatism.
     c) Riding high lens edge.
     d) Lens insertion.
     e) Drying of the cornea.
     f) Foreign body under the lens.
     g) Lens defect as poor polishing of the lens or of lens edge.
   - *Clinical features: The corneal epithelial defect may be:*
     i. *Arcuate (curved) with a ring of contact:* Due to tight fitting.
     ii. *Linear:* At the least meridian in high degree astigmatism.
     iii. *Zigzag or irregular:* Due to foreign body under the lens.
     iv. *Central with a central touch:* Due to too steep fitting, or too loose fitting.
     v. *Vertical:* Due to too loose fitting or foreign body.
     vi. *Staining at 3 and 9 o 'clock:* Due to drying of the cornea with poor tear interchange.

2. *Chronic corneal erosions:*
   - Cause: Chronic corneal irritation due to ill fitted lenses.

3. *Corneal oedema (Sattler's veil):*
   - *causes:*
     (1) Mechanical trauma to the cornea.
     (2) Hypoxia of the epithelium.
     (3) Negative hydrostatic pressure under the lens.
     (4) Drying of the cornea.
     (5) Anomalies of the tear film particularly its lipid layer.

4. *Desquamation of corneal epithelium:*
   - ✓ In the initial period of adaptation or,
   - ✓ Due to a trauma usually with lens edge.
5. *Corneal vascularization and opacification:* Especially in aphakia and in keratoconus.

6. *Displacement of the lens off the cornea:* Into the upper fornix, subconjunctivally or rolling of lens off the eye (due to loose filling).

7. *Breaking and loss of the lens:* May occur.

8. *Corneal warpage:*

- It is the change in corneal curvature induced by wearing a contact lens which is not associated with corneal oedema. It regresses after the lens is removed over hours or days.
- Warpage is more pronounced and of longer duration when more rigid lenses are worn.
- It is important not to perform refractive surgery or biometry (to estimate intraocular lens power) or to prescribe spectacles before these changes have stabilized.

B. Optical complications:

1. Residual astigmatism:
   - *Incidence:* Of more than 0.50D especially with spherical soft contact lens.
   - *Causes:*

     a- *The true residual astigmatism of the eye itself (largely lenticular astigmatism):*
       - ★ Corneal astigmatism: From its posterior surface.
       - ★ Lenticular astigmatism: Which appears after contact lens filling as it is partially counteracted by the corneal astigmatism at the anterior surface.

     b- *The factors caused by the contact lens:*
       - ❑ Difference in the refractive indices of the spherotoroidal tear film and the cornea.
       - ❑ Tilt, eccentricity or warping (bent, curved or twisted) of the corneal lens.
       - ❑ Intended or accidental toroidicity of the lens surfaces.
   - *Correction (Fig18.6):*

     1- toric contact lens: With a toric anterior surface in which rotation is prevented by :
       (a) Toric posterior peripheral curve lens.
       (b) Prism ballast (usually of 2 A).
       (c) Truncation (usually with prism ballast).
       (d) Oval, rectangular or triangular lens.

     2- Other lenses:
       - ☆ Lens with a hard centre and a soft edge.
       - ☆ Rigid lens with a soft periphery.
       - ☆ Soft lens with a hard lens fitted over its centre.
       - ☆ Toric soft lenses and toric gas permeable lenses are available.

     3- Cylindrical spectacle correction: If the above lines fail.

2. Spectacle blur:

- *Causes:*
  Ill-lens fitting specially a steep fit lens with corneal oedema, distortion or increased thickness of the cornea.
- *Correction:* By giving the proper lens fitting.

3. Increased light intolerance:
   - *Causes:*
     a. More light allowed by the contact lens than spectacles.
     b. Irritation of the corneal nerve endings due to ill fitted lens.
   - *Correction:*
     - ✓ Proper lens fitting.
     - ✓ Tinted contact lenses (in albinism, aniridia and iris coloboma).

4. Induced imbalance:
   - *Causes:*
     This is due to decentration of the lens (less than with spectacles as the lens is nearer to F of the eye):
     2. Vertical decentration :
        a) Tight lid which takes the lens up.
        b) Lax lid in which the lens sags down.
        c) Heavy lens and so it sags down.
        d) Thick lens edge.
     3. Horizontal decentration: usually with astigmatism against the rule.

5. Post wear effect:
   - ❑ Blurring of vision.
   - ❑ Lacrimation.
   - ❑ Photophobia.

6. Optical complications of bifocal contact lenses:

(1) Smaller field for distance specially the lower field.
(2) Jumping up of objects due to the prismatic effect of the near segment.
(3) The need of raising up the head and lowering the eyes in order to read.

✱ *Advantages over spectacles:*

A. Optical:
   1. Better VA (especially in high myopia, high regular astigmatism and irregular astigmatism).
   2. Increased field of vision.
   3. Less magnification (essential for aphakia and anisometropia to correct aniseikonia).

4. Less prismatic effect (i.e. no ring scotoma).

B. Non-optical:

1- The lens does not become misty easily (in rain, snow and dust).
2- Less danger from cuts (than with broken spectacles).
3- More cosmetic and psychological advantages.

✱ <u>*Disadvantages:*</u>

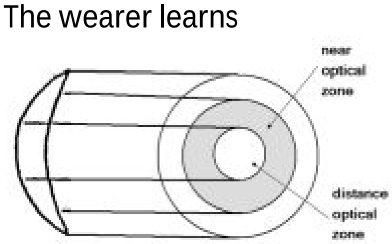
a) Costly.
b) Requires time for patient's instructions.
c) Complications of the lens use.

✱ Bifocal contact lenses:

- <u>*Principle:*</u>
  i. *Simultaneous vision (bivision):* Retina receives optical images of both distance and near vision and patient can ignore one of no interest mentally.
  ii. *Alternating vision:* Different portions of the lens have different functions.
  iii. *Both simultaneous and alternating vision:* With a different extent.
  iv. *Monovision:* entails fitting one eye (usually the one with better vision) with a distance contact lens and the fellow eye with a lens which corrects the near vision. Patients must learn to adapt to having to concentrate on the clearer image from one eye. Binocularity and stereopsis are diminished.

- <u>*Types of bifocal contact lenses:*</u>

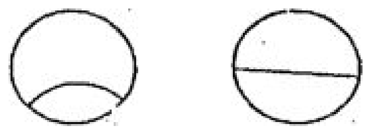
  a. *Annular (concentric) bifocals: it is the most commonly used:*
    - Annular bifocal contact lenses have a central zone which usually corrects for distance, surrounded by an annular zone for near.
      - In down gaze, the contact lens rises relative to the cornea, placing the near portion in front of the visual axis.
    - Light from a distant object that passes through the portion of the lens which focuses for distance produces a clear retinal image. However, under these circumstances, the light passing through the near portion of the contact lens produces a superimposed out-of-focus image.
      - The blurred image reduces the quality of the clear one. The reverse applies when viewing a near object. The wearer learns to concentrate on the better focused image.



    - A major drawback of annular bifocals is that the peripheral (annular) portion of the lens is not as effective when the pupil diameter is small.

b. Segment bifocals:

- It is usually crescentic and rarely executive in shape (Fig. 18.5b).
- Segmental bifocal contact lenses incorporate the near addition over the lower portion of the lens.
  - The eye looks through the distance portion in the primary position.
  - In down gaze, the contact lens rises relative to the cornea, placing the near portion in front of the visual axis.
- Segmented bifocals must be prevented from rotating by truncation or by ballasting with a base-down prism.



1-Crescentic. 2-Executive.

c. Aspheric multifocal contact lens:

- The central part of the lens corrects for distance and
- there is a gradual transition in power to the peripheral portion which corrects for near.
  - Only a small amount of the total light entering the eye through the contact lens is in focus on the retina.

d. Diffractive bifocals:

- A series of concentric rings at the posterior surface of the lens which acts by diffraction.
  - The image is less bright than with a single-focus contact lens and this may be a problem in dim illumination.

✱ Prismatic contact lenses:

i. Prism ballast:

- *Characters:*
  - ❑ A hard contact lens with a prism added to it during its manufacture (usually about 1.5 Δ).
  - ❑ The lens tends to orient itself with the prism down as it adds weight to the lower portion of the lens but actually the prism ballast is inclined to ride about 10° nasally (Fig. 18.3a).
- *Indications:*

(1) To orient the axis of the cylinder correctly in toric anterior surface lenses.
(2) To orient the reading segment of bifocal contact lenses.
(3) To help centring of a high riding lens.

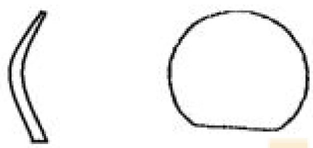
ii. Lens truncation (truncated lens):

- *Character:*

  It is a hard contact lens with cutting off of one edge which is thicker and thus heavier and so acts much like a prism ballast (Fig. 18.3b).

- *Indications:*

  As prism ballast but used to modify an existing lens rather than an initial lens design.



(a)Prism ballast (b) Lens truncation,

(a) Single cut plus lens. (b) Lenticular plus lens..