Optics of Ophthalmic Instruments

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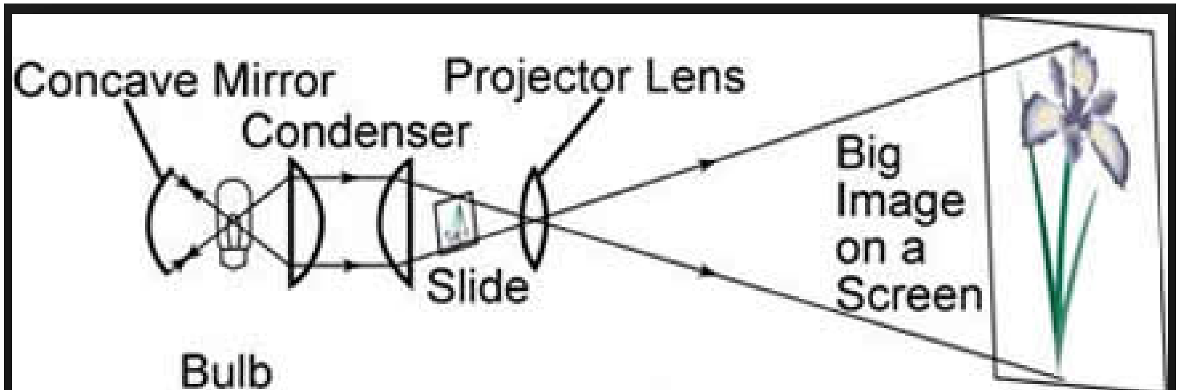
Most used instruments

- Binocular Indirect Ophthalmoscope
- Retinoscope
- Lensometer
- Keratometer

Binocular Indirect Opthalmoscope

Principles of a Slide Projector

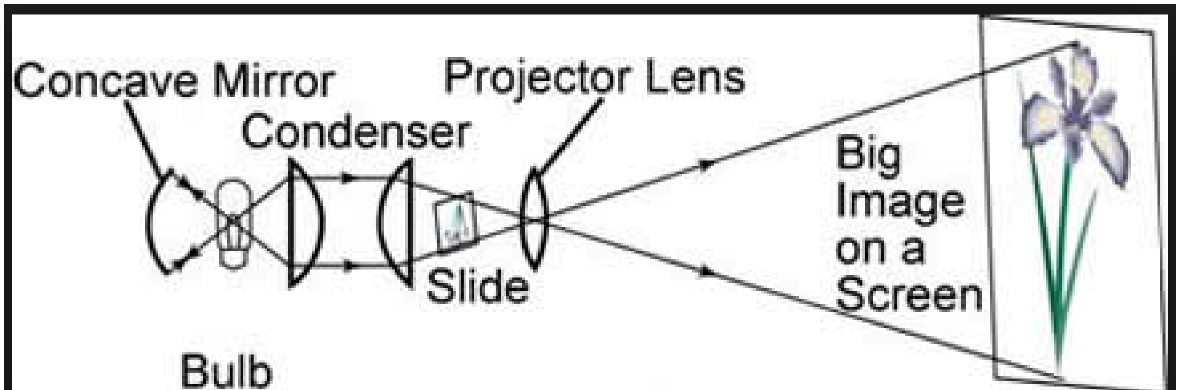
- An intense source of light illuminates a transparent slide from behind and makes that slide a Luminous object on its own
- That luminous object emits light which is picked up by the projector lens



5.70 Structure of a slide projector

Principles of a Slide Projector

- The lens is situated so that the object is just beyond its primary focal plane
- The final image can then be projected onto a screen

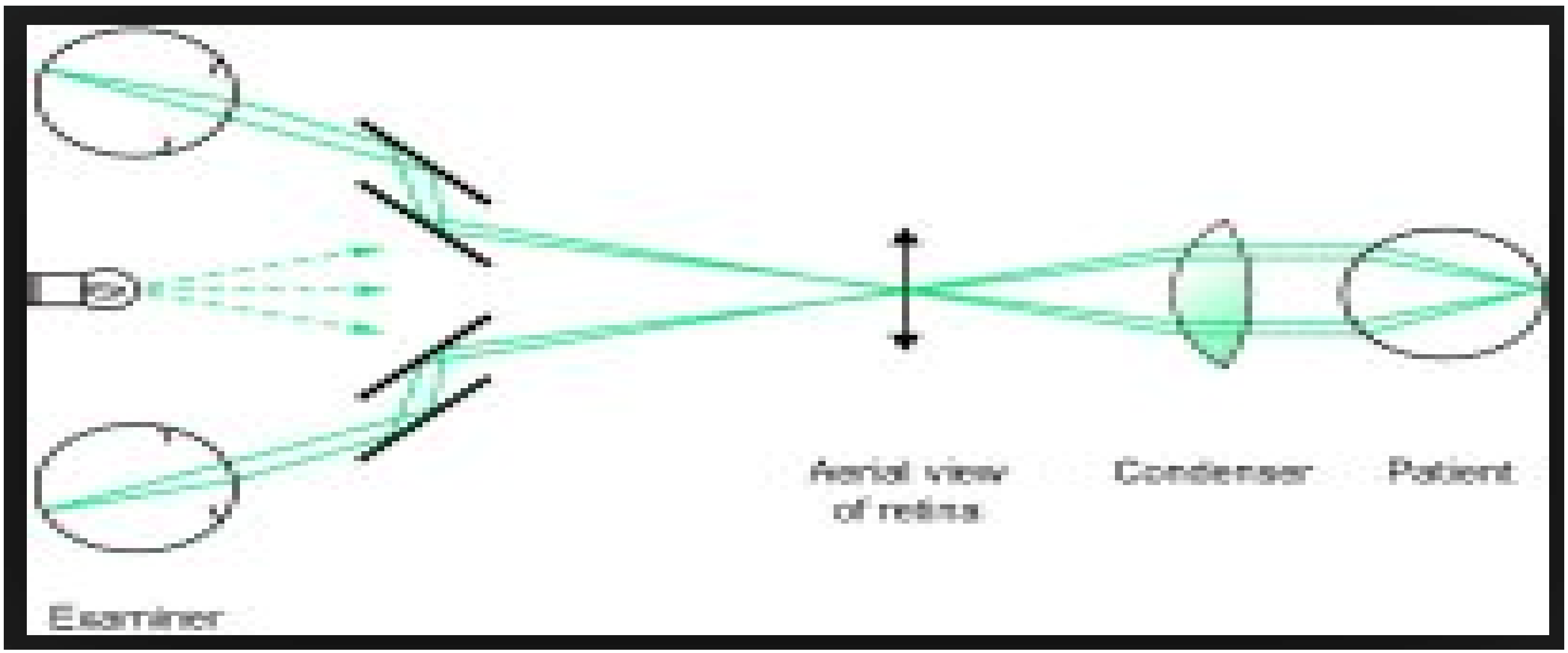


5.70 Structure of a slide projector

Binocular Indirect Ophthalmoscope

- With the indirect, you make the fundus a luminous object (the slide of the last example)
- The eye acts like a miniature opaque projector and projects that object out into space
- This is done by shining an intense source of light through the pupil – the fundus image is then projected out

- An emmetropic eye would project that image to infinity
- We use a 20D hand held condensing lens to create the image in its secondary focal plane
- This image is called an **aerial** image and is ***inverted*** when compared to the orientation of the fundus itself



Optics of BIO

- That aerial image has **thickness** representing any thickness present in the fundus itself
- Any excavation of the nerve head or elevated of a choroidal lesion will be manifested in the "depth" of the image
- The *longer* the focal length of the condensing lens, the farther from the lens the image will be → increased lateral magnification

Binocular Indirect Ophthalmoscope

- Axial images dimensions are especially **THICKENED** by the **LOWER** powered (longer focal length) condensing lens

$$\text{Magnification of the lens} = \frac{\text{dioptric power}}{4}$$

$$\text{Magnification of the Retina} = \frac{\text{D. P. of the eye}}{\text{D. P. of the lens}}$$

$$\text{Stereopsis} = \frac{\text{Magnification}}{4}$$

$$\text{Field of View} = \text{D. P. of the lens x 2}$$

Binocular Indirect Ophthalmoscope

- 30 Diopter Lens (highest magnification)
  - Yields LEAST magnification of retina 60/30=**2x**
  - Stereopsis is half that of the normal 2/4=1/2
  - Largest field of view 30x2= 60 degrees
- 15 Diopter Lens
  - Magnification of retina 60/15= **4x**
  - Stereopsis 4/4=1 → <u>FULL STEREOPSIS</u> = thickened image
  - Field of view 15x2= 30 degrees
- 20 D lens is most used since it provides adequate field of view, stereopsis and magnification

Advantages of Binocular Indirect Ophthalmoscopy

- Stereoscopic visualization
- Increased field of view vs. direct ophthalmoscopy (25° vs 8°)

Light Reflexes

- 3 bright reflexes (from the cornea, pupil and crystalline lens) when trying to visualize the fundus
- The condenser is a biconvex lens, the anterior surface forms a virtual reflected image of the illuminating headlamp, and the posterior surface, being concave to the illuminating source, forms a real image
- These images move in opposite directions if the lens is tilted
- The higher the D.P. Of the condensing lens, the more will be tilting necessary to move reflexes away from the center of view

Board Question

Which of the following optical instruments does NOT use an "aerial image"?

- A. fundus camera
- B. Hruby lens
- C. indirect ophthalmoscope
- D. 78 D lens

Indirect ophthalmoscopy, slit-lamp fundus lenses (e.g. 78 D, 90 D), and the fundus camera all make use of an "**aerial image**." Specifically, all of these instruments produce a **real and inverted image** that "floats" above the condensing lens (i.e. between the lens and the observer's eye).

In contrast, the high-minus (i.e. concave) **Hruby lens forms a virtual and erect image** of the illuminated retina within the focal range of the slit-lamp. This image is located "behind" the lens (i.e. between the patient's retina and the lens). Similarly, all of the planoconcave contact lenses (e.g. Goldmann) do not use an aerial image, and instead produce a virtual and erect image within the focal range of the slit-lamp.

Retinoscope

- To determine the refractive error of an eye objectively
- It is a small projector which emits a spot or streak like image of the lamp filament itself
- This projector is aimed at the patient's eye

Retinoscope

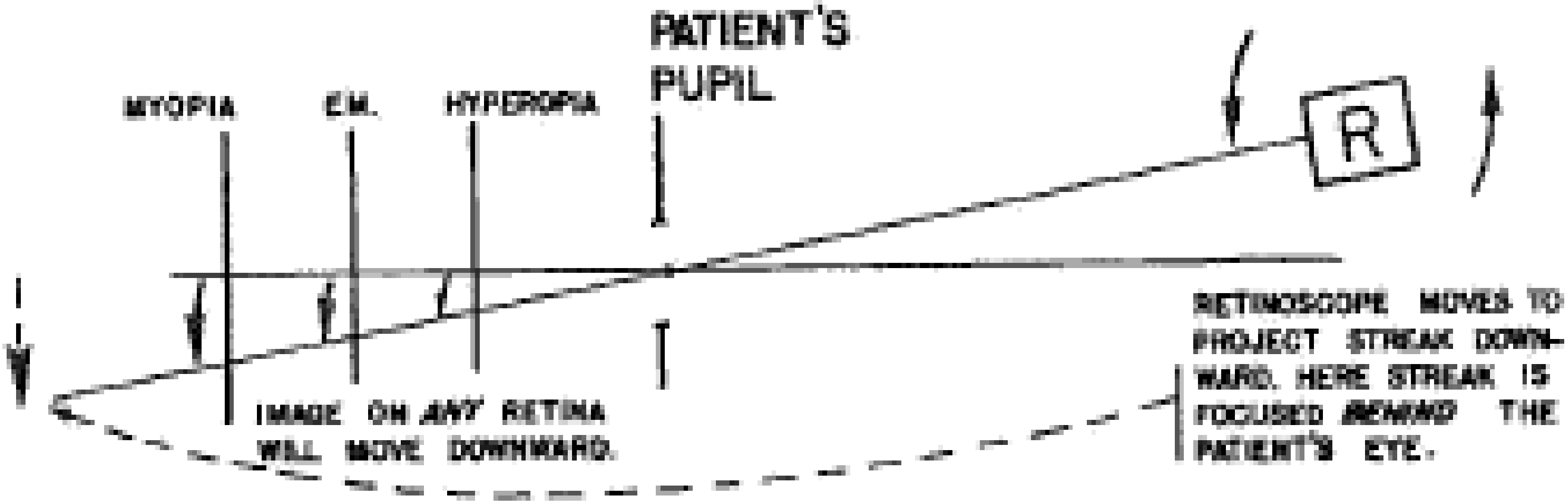
- The retinoscopist can project that image onto a wall any distance away and focus it sharply, from infinity to any place behind or in front of the patient's eye

- 2 principals:
  - Plano-mirror Effect
  - Concave-mirror Effect

Plano-Mirror Effect

- Effective light source lies behind the plane of the mirror (most common used)
- The rays of light from the source goes parallel or slightly diverging
- Does not cross between the source and the patient's eye
  - With movement – hyperopia
  - Against movement – myopia
- Direction of motion of the light source on the retina will always be in the *same* direction as the motion of the retinoscope light as it crosses along the patient's face

A. PLANO-MIRROR EFFECT

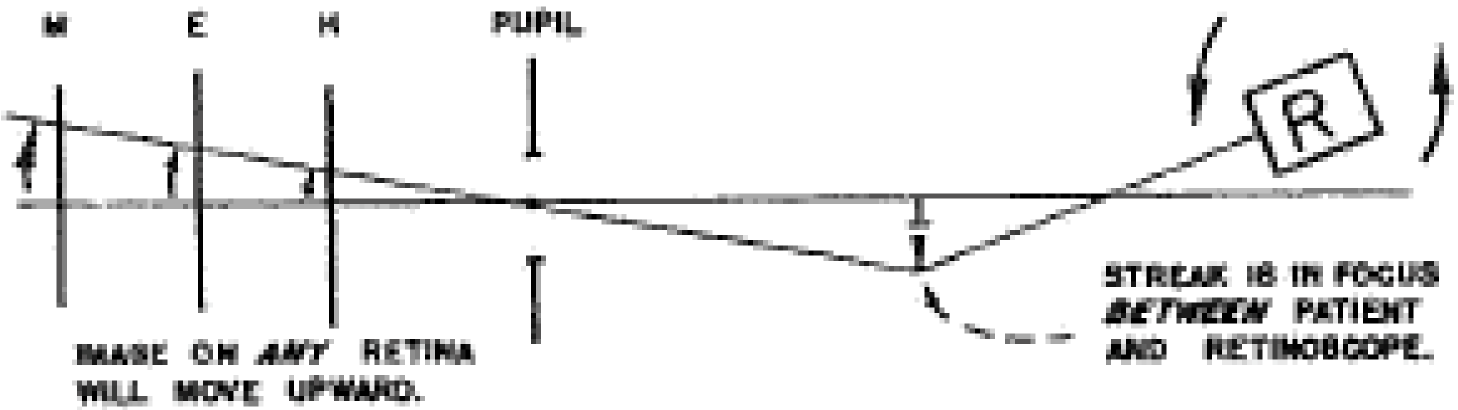


Concave-Mirror Effect

- Keep the effective source in front of the plane of the mirror
- rays emitted from source are more converging
- cross at a certain distance between patient and the source
  - With movement – Myopia
  - Against Movement – Hyperopia
- Not used as often

- Direction of motion of the light source on the retina will always be in the *opposite* direction as the motion of the retinoscope streak

B. CONCAVE MIRROR EFFECT



Retinoscopy

- The closer the observer's eye the patient's luminous retinal image is located, the larger and brighter will be the illuminated shadow and the quicker it will move
- Plus lens used to counter any observed "with" motion
- Minus lens for "against" motion
- Goal is to "Neutralize" the observed motion with the lens

Working Distance

- To find the "corrective" lens to help the patient see optical infinity, we must image the retina not at the retinoscope but further back behind the observer, at infinity
- The lens has to be a power of 1/d
  - Ex. 50 cm working distance
    - 1/0.5=2
    - Means subtract 2D from the lens you found to neutralize the reflex
- For an astigmatic eye, each meridian must be neutralized separately

Board Question

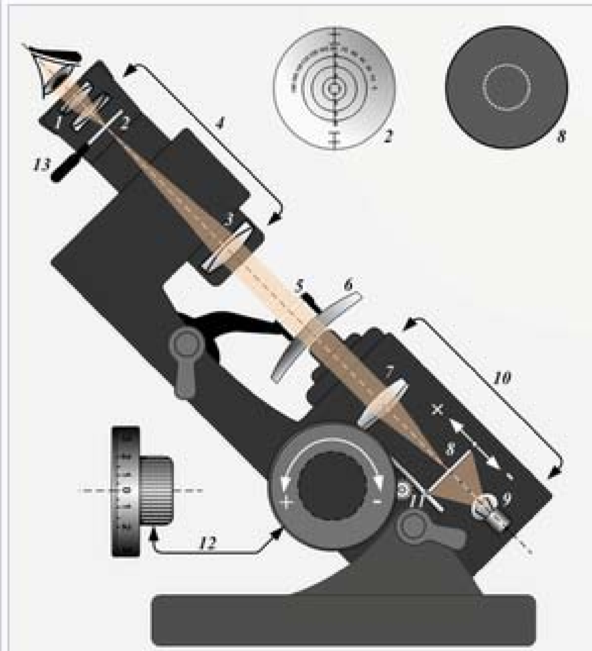
You perform a streak retinoscopy using loose lenses to determine the refractive error of a 6-year-old child. You are able to neutralize the first reflex, with the beam in the 1:30 – 7:30 o'clock position (relative to you as the examiner) with a +3.00 sphere. You are able to neutralize the second reflex, with the beam in the 10:30 – 4:30 o'clock position (relative to you as the examiner) with a +5.75 sphere. What is the eyeglass prescription you will dispense to this patient? Assume your working distance is 50 cm.

- A. +1.00 + 2.75 x 135
- B. +1.00 + 2.75 x 045
- C. +3.00 + 2.75 x 135
- D. +3.00 +2.75 x 045

In this example, we notice that the first axis (45 degrees) was neutralized by +3.00 D sphere. The second axis (135 degrees) was neutralized with +5.75 D sphere. Converting this to spherocylindrical notation (and since we want to work in plus cylinder as the answer choices are all in plus cylinder), we get +3.00 + 2.75 x 135. But we are not finished yet. We have to account for our working distance (given as 50 cm), so this is approximately 2D. We have to subtract this ONLY FROM THE SPHERE (not the cylinder!). So our final refraction will be: +1.00 + 2.75 x 135 **(Answer Choice A).**

As an alternate exercise, had we chosen the +5.75 as our sphere, then our prescription would have been: +5.75 - 2.75 x 045. We would have then subtracted 2 D from this sphere, yielding a final prescription of +3.75 - 2.75 x 45. We could then convert this back to plus cylinder to arrive at **+1.00 + 2.75 x 135 (Answer Choice A)**.

The Lensometer



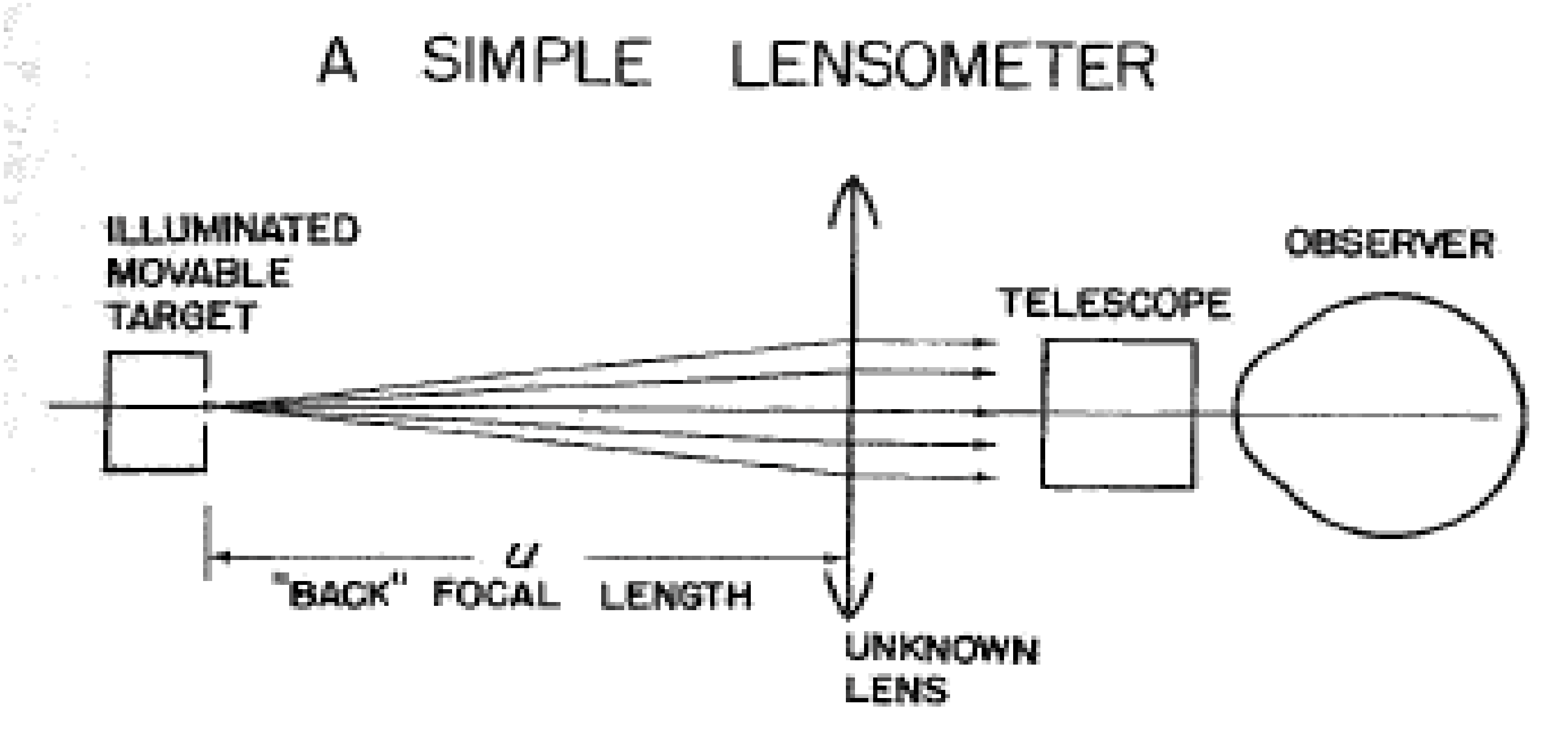
A simple lensmeter cross sectional view. 1 – Adjustable eyepiece **2** – Reticle
3 – Objective lens **4** – Keplerian telescope
5 – Lens holder **6** – Unknown lens
7 – Standard lens **8** – Illuminated target
9 – Light source **10** – Collimator
11 – Angle adjustment lever
12 – Power drum (+20 and -20 Diopters)
13 – Prism scale knob

Lensometer

- To quickly determine the power, cylinder and axis of an "unknown" lens
- Can measure the amount and direction of any prism that may be incorporated or induced by the lens
- Most clinically important information about any corrective lens is the distance between its back surface and its secondary focal point = *back focal length*

A Simple Lensometer

- The *vertex* power (*effective* power) = the reciprocal of the back focal length



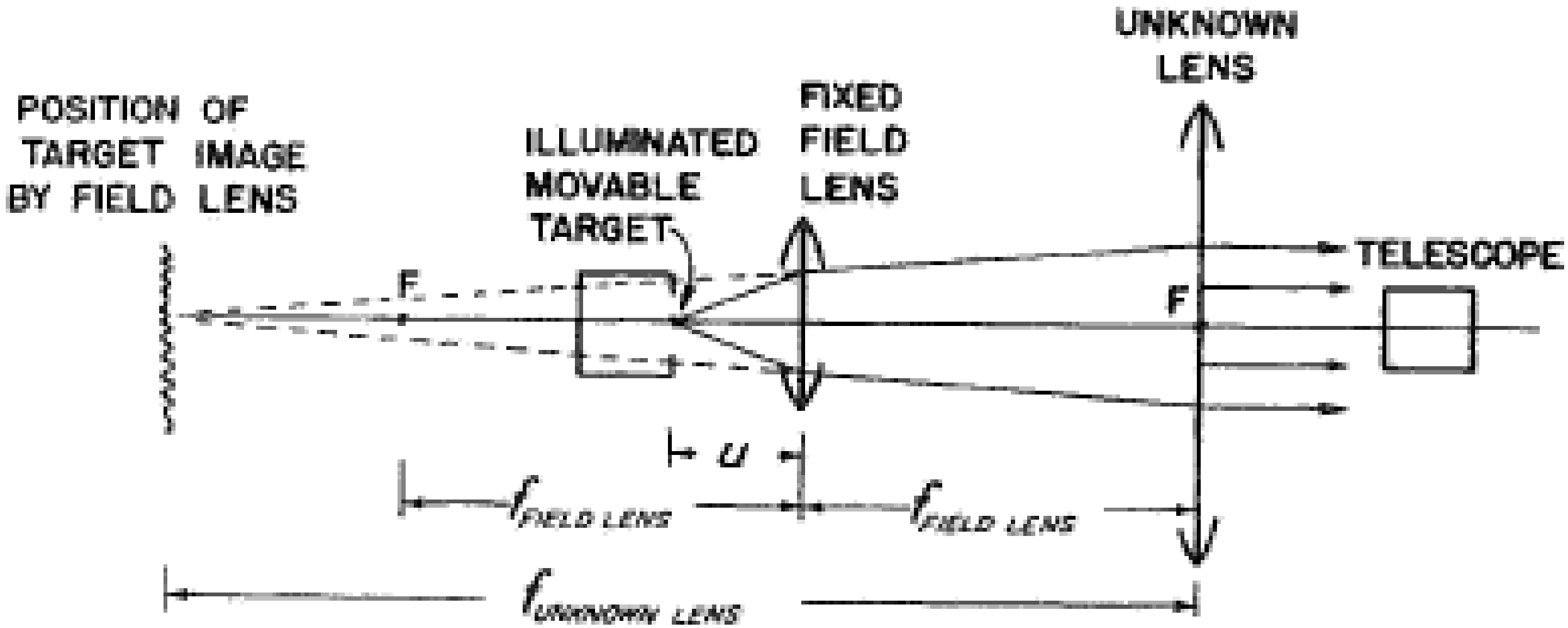
A Simple Lensometer

- A grid like, luminous target is moved back and forth until light rays leaving the lens are parallel
  - (as detected by a small eyepiece telescope which is focused for infinity so that only the parallel light bundles will appear to be clear)
- The target must then be located at F' of the lens
- Its distance *u* is simply measured and converted to diopters
- This method is impractical because the instrument would have to be ***too long***

A Lensometer

- Uses Badal's Principle to shorten the length needed to measure the power of an unknown lens
- The fixed field lens is placed so that its focal point exactly coincides with the posterior vertex of the unknown lens
- The observer moves the illuminated target back and forth in relation to the fixed field lens until the reticle target appears sharply in focus through the eyepiece telescope

A LENSOMETER

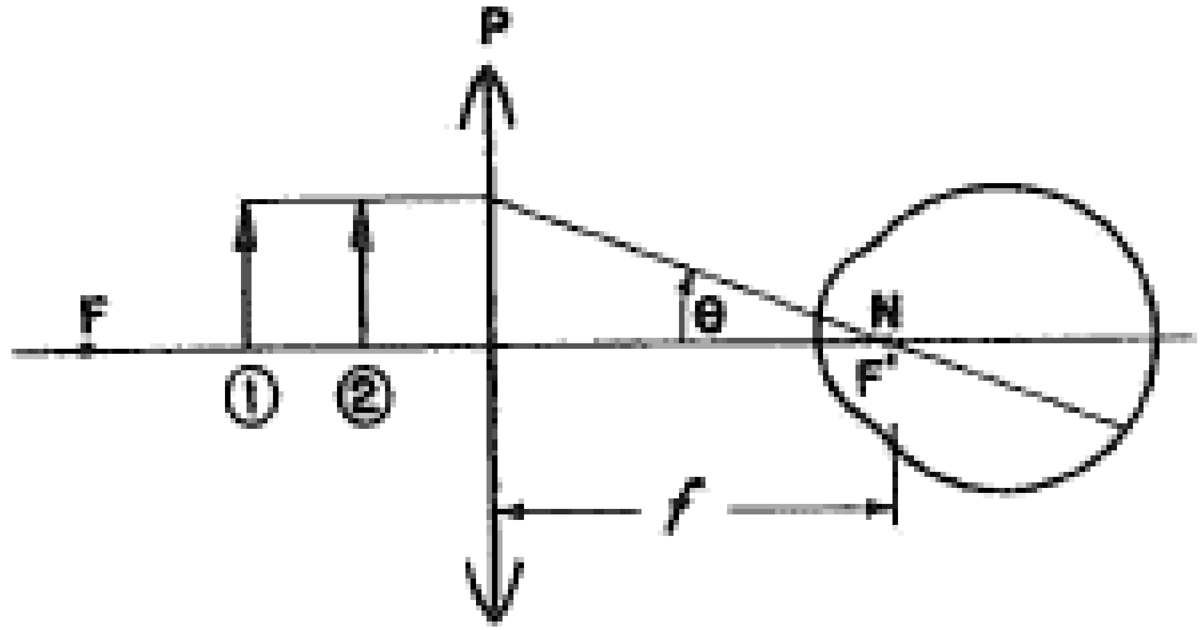


The Lensometer

- With the focal point of the field lens situated exactly at the posterior vertex of the "unknown" lens, the proper optical condition is set up so…
  - The distance *u* is DIRECTLY proportional to the power of the unknown lens
- The scale will not shrink as higher power lenses are tested

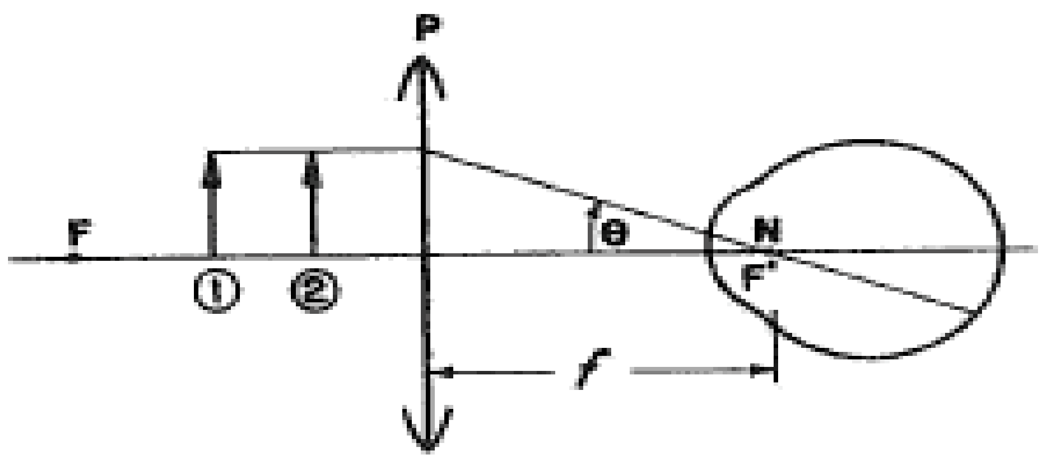
The Badal Principle

- Knapp's Law applied to Lensometers



The Badal Principal

- Place any **plus** lens in front of the eye so that the lens' F' coincides with the eye's nodal point
- An object is put in front of that lens, but closer than its primary focal point F



The Badal Principal

- The object tip will emit one ray which is parallel to the axis
- After refraction, that ray will pass through F’
- Since F’ was made to coincide with the nodal point of the eye, the ray will continue undeviated

Determining an Add with a Lensometer

- To obtain the distance power of any lens, you must use the Lensometer to measure the *back* focal length
- The *front* focal length is a better indicator of the ability of a "thick lens" to deal with near objects
- If the add on the aphakic lens is read with the lens in the 'normal' instead of 'reversed' position, the indicated power will be too high in plus compared to its actual effectivity

Board Question

A light source falls on an unknown lens. A line is formed at 45° at 20 cm. When the screen is moved to 33cm, the line is at 135°. At what distance from the lens is a circle seen on the screen?

A. 20cm

B. 22.5 cm

C. 25 cm

D. 26.5 cm

This is admittedly a tricky problem that tests multiple optics concepts. It helps to always draw a diagram in these situations to help visualize the scenario being asked. We know that the lens focuses light at 20 cm, so the power in the 45° axis (135° meridian) is 100/20= +5 D. We also know that at 33 cm, the power in the 135° axis (45° meridian) is 100/33= +3 D. The **circle of least confusion** will be seen **halfway between these lines** (not distance wise) **in terms of dioptric power**, so this would be at +4 D. Solving for this, we get 1/4 = 0.25 m or **25 cm** from the lens.

Board Question

A light source falls on an unknown lens. . A line is formed at 45° at 20 cm. When the screen is moved to 33cm, the line is at 135°. What is the prescription of the lens?

A. +3.00 +2.00 x 045
B. +4.00 Sphere
C. +3.00 + 5.00 x 045
D. +5.00 + 3.00 x 135

This is admittedly a tricky problem that tests multiple optics concepts. It always helps to draw a diagram in these situations to help visualize the scenario being asked. We know that the lens focuses light at 20 cm, so the power in the 45° axis (135° meridian) is 100/20= +5 D. We also know that at 33 cm, the power in the 135° axis (45° meridian) is 100/33= +3 D.

We can draw a power cross (see below) to help determine the power of the lens using: +5.00 x 135 and +3.00 x 45. Based on our preference to work with plus cylinder (over minus cylinder), we can set the "more minus" lens as the sphere (+3.00). So the power of this lens is: **+3.00 + 2.00 x 45** (Choice A). If we wanted to work in minus cylinder, the power of the lens would be: +5.00 -2.00 x 135.

Keratometer

The Keratometer

- To measure the corneal curvature
- Measures the anterior 2-3mm surface of the cornea
- Used mainly for contact lens fitting
- Keratometer measures the *size* of the reflected image to give the ***radius of curvature*** of that anterior corneal surface

Information provided by a Keratometer

- The radii of curvature of the cornea

- The directions of the principal meridians of the eye, determining whether the astigmatism is with-the-rule or against-the-rule
  - a key factor in contact lens fitting

- The degree of corneal astigmatism

- The presence of any corneal distortion (keratoconus, pterygium, corneal scarring)

Optical Principles

- Cornea is a convex refracting surface
- To find the refracting power of the cornea, we need to reflect an object of a known size at a known distance off the corneal surface.
- Then determine the size of the reflecting image with measuring telescope and calculate the refractive power of the cornea based on the refractive index of n=1.3375

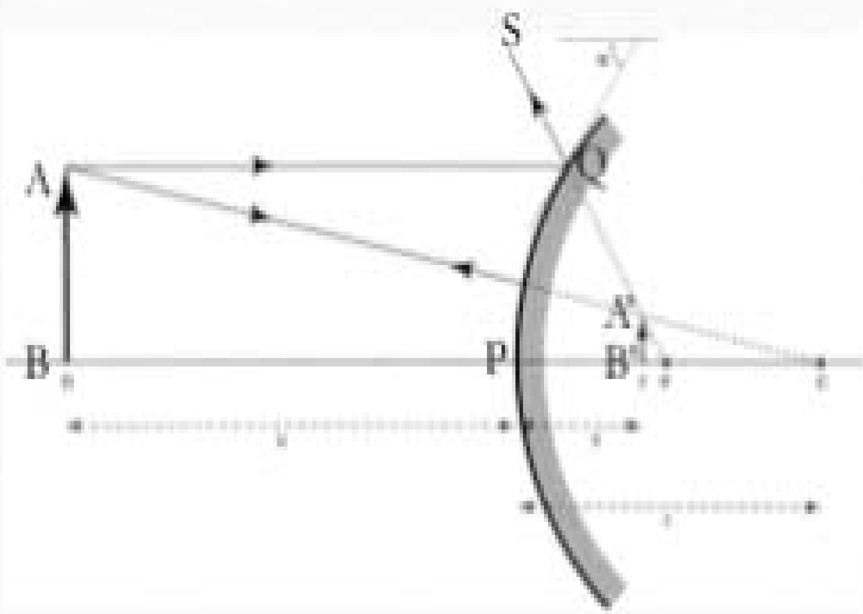
Keratometer

- The radius of curvature of of a mirror will determine the size of the image it produces from a given sized object
- If we illuminate an object of *known size*, place it a *known distance* from the cornea, are are able to measure the size of the reflected image, we can deduce the radius of curvature
- The cornea is considered a high powered mirror (-250 D), an object does not have to be too far away to be effectively at the cornea's optical infinity

Principle

- Anterior surface of cornea – CONVEX MIRROR
- ↑ Curvature – ↓ Image Size.
- From Image Size formed by anterior surface of cornea (1st Purkinje image) – radius of curvature of cornea can be calculated

Principle



Therefore ,

B'P/A'B' = BP/AB

F/i = u/o

r/2 i = u/o (since F = r/2)

r = 2 ui/o

u (BP) → constant for any instrument

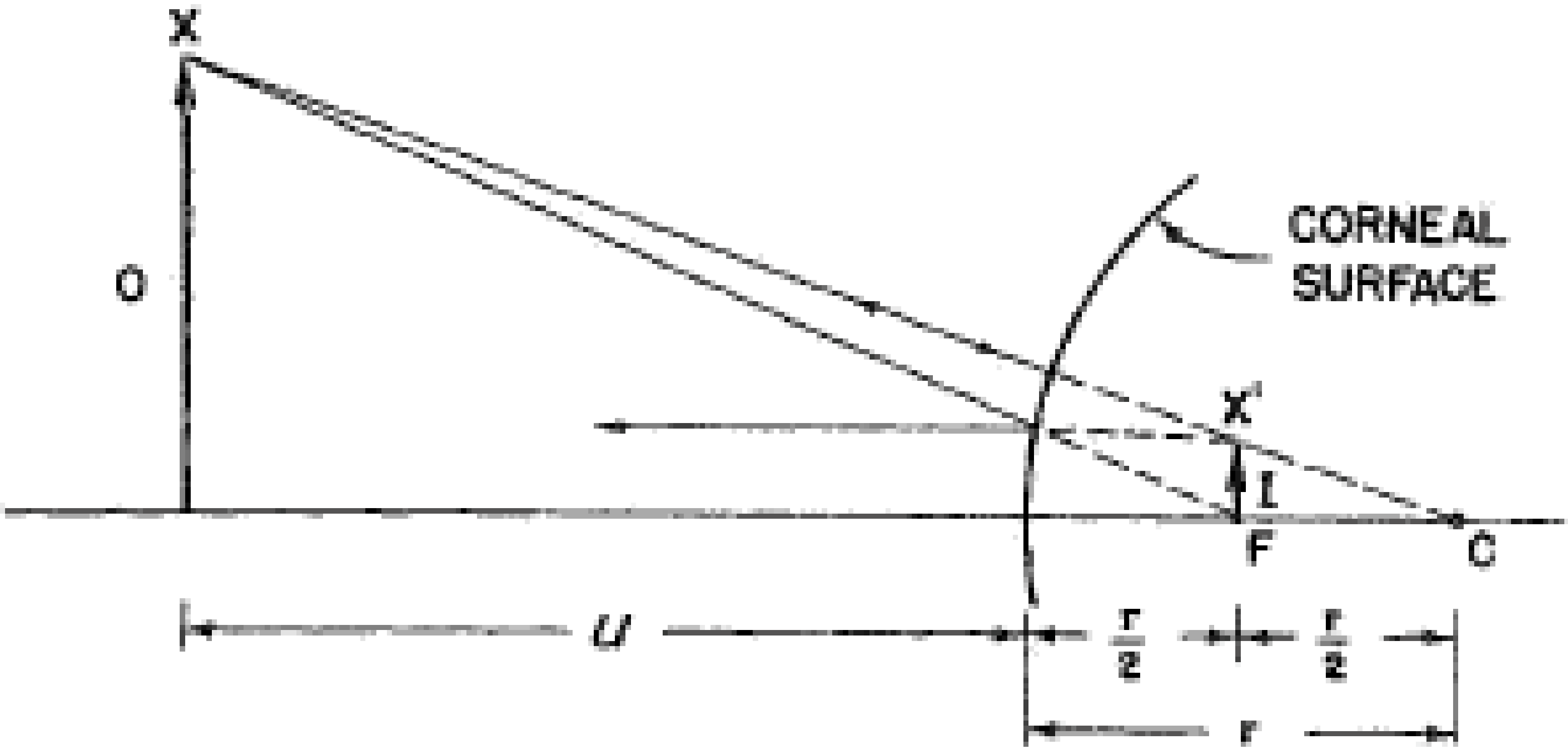
Surface Power Formula

- The keratometer usually shows the curvature in diopters of power or in ***<u>millimeters and diopters</u>***

- If a millimeter scale is not given, it can be found from tables or by using the surface power formula using the refractive index 1.3375

- Surface Power Formula: $$D = \frac{n-1}{R}$$

    - D = the dioptric power of the Cornea
    - n = the refractive index of the keratometer used (1.3375)
    - R = the radius of curvature of the cornea in meters


X
O
CORNEAL
SURFACE
X'
I
F
C
U
r
2
r
2
r

Doubling Principle

Miniature involuntary eye movements during fixation of eye

→

Image formed by anterior surface of cornea also moves (impossible to measure)

→

DOUBLING PRINCIPLE

Doubling Principle

- Biprism
- 2 images
- Move equally as eye moves

Depending on the position of prism – if distance↓, doubling ↑

What is the reflecting power of a cornea whose radius of curvature is 8 mm?

- A. +125 D
- B. +250 D
- C. -125 D
- D. -250 D

Explanation:

The **reflecting power** of a mirror is the amount of vergence produced by the mirror. A **convex** mirror adds **negative** vergence, thus acting like a minus lens. A **concave** mirror adds **positive** vergence, thus acting like a plus lens. The relationship of the reflecting power of a mirror and its focal length is similar to the same relationship for a lens:

Reflecting power of mirror = 1 / (focal length of mirror)

However, mirrors are often specified, not by focal length, but by **radius of curvature**. The relationship between radius of curvature and focal length is:

focal length of mirror = radius of curvature / 2

Thus,

Reflecting power of mirror = 2 / (radius of curvature of mirror)

Radius of curvature and focal length are both specified in meters. Thus, this cornea has a reflecting power of:

-2 / 0.008 = -250 D (negative since the cornea is a convex mirror)

A standard manual keratometer measures central corneal power at what approximate diameter?

- A. 1.65
- B. 2.5
- C. 3.2
- D. 5.0

Explanation:

A standard **manual keratometer** (e.g. one seen in the photo below) measures the power of the central cornea at a diameter of **3.2 mm**. Optical biometry with the IOL Master measures the power of the central cornea at a diameter of 2.5 mm. Optical biometry using the Lenstar measures central corneal power at diameters of 1.65 and 2.3 mm.

In other words, **none of these devices measure the "true" central power of the cornea**. This concept is important to understand especially in cases of IOL power calculations for eyes that have undergone refractive surgery. For post-refractive eyes, the measured corneal power may be significantly different from the actual central corneal power, which may lead to unpleasant surprises in post-cataract surgery refractive outcomes.