LICENCIATURA EN FISICA MEDICA

BIOFISICA

CAPITULO 11 – Parte 1

La Luz. La Electromagnética. La Optica. La Fotónica. Los Ojos y la Visión Humana

CLASIFICACIONES DE LA ÓPTICA

Clásica

Rayos de luz. Frentes de ondas. Propagación. Efecto Doppler. Reflexión. Refracción. Sistemas ópticos formadores de imágenes. Aberraciones ópticas. Polarización. Interferencia. Difracción. Fotografía. Fotometría. Colorimetría. Etc.

Electromagnética

Sustento electromagnético de casi todos los temas de la Óptica Clásica. Sensores de radiación. Radiometría. Etc.

Cuántica o Fotónica

Interacción de la radiación con la materia. Efecto fotoeléctrico. Emisión y absorción de radiación por átomos, moléculas, cristales, semiconductores, tejidos, etc. Emisión estimulada de radiación. Amplificación de la luz. Láser. Etc.

OTRAS CLASIFICACIONES

Óptica Pasiva

Fotosíntesis en las plantas. Absorción por el pigmento macular en la retina. Fototropismos de orientación lenta o rápida en las plantas. Etc.

Óptica Activa

Objetivos. Microscopios. Telescopios. Cámaras fotográficas. Prismáticos. Fibras ópticas, Etc.

Óptica Adaptiva

Función pupilar de adaptación a la intensidad de la luz. Función de acomodación del cristalino para el enfoque cercano o lejano. Corrección de aberraciones de orden superior. Corrección de las perturbaciones atmosféricas en grandes telescopios astronómicos. Etc.

EL SISTEMA VISUAL HUMANO

Subsistema óptico:

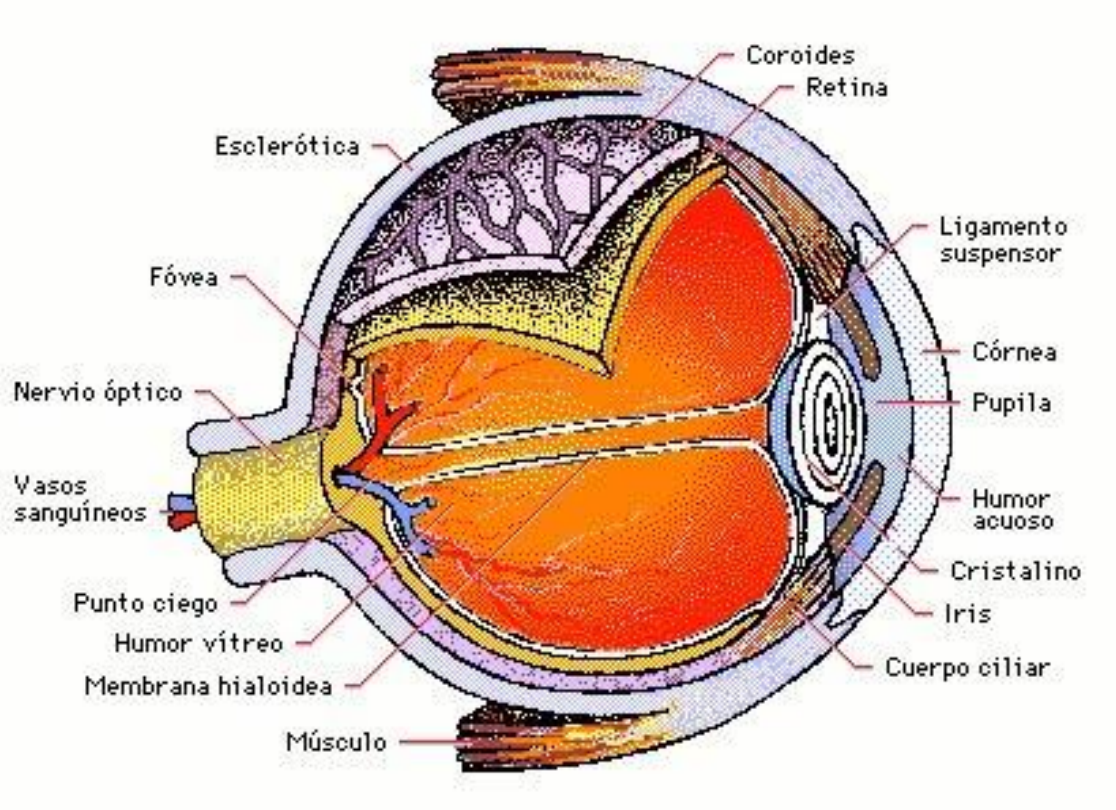
- Córnea
- Pupila
- Humor acuoso
- Cristalino
- Humor vítreo

Subsistema fotónico:

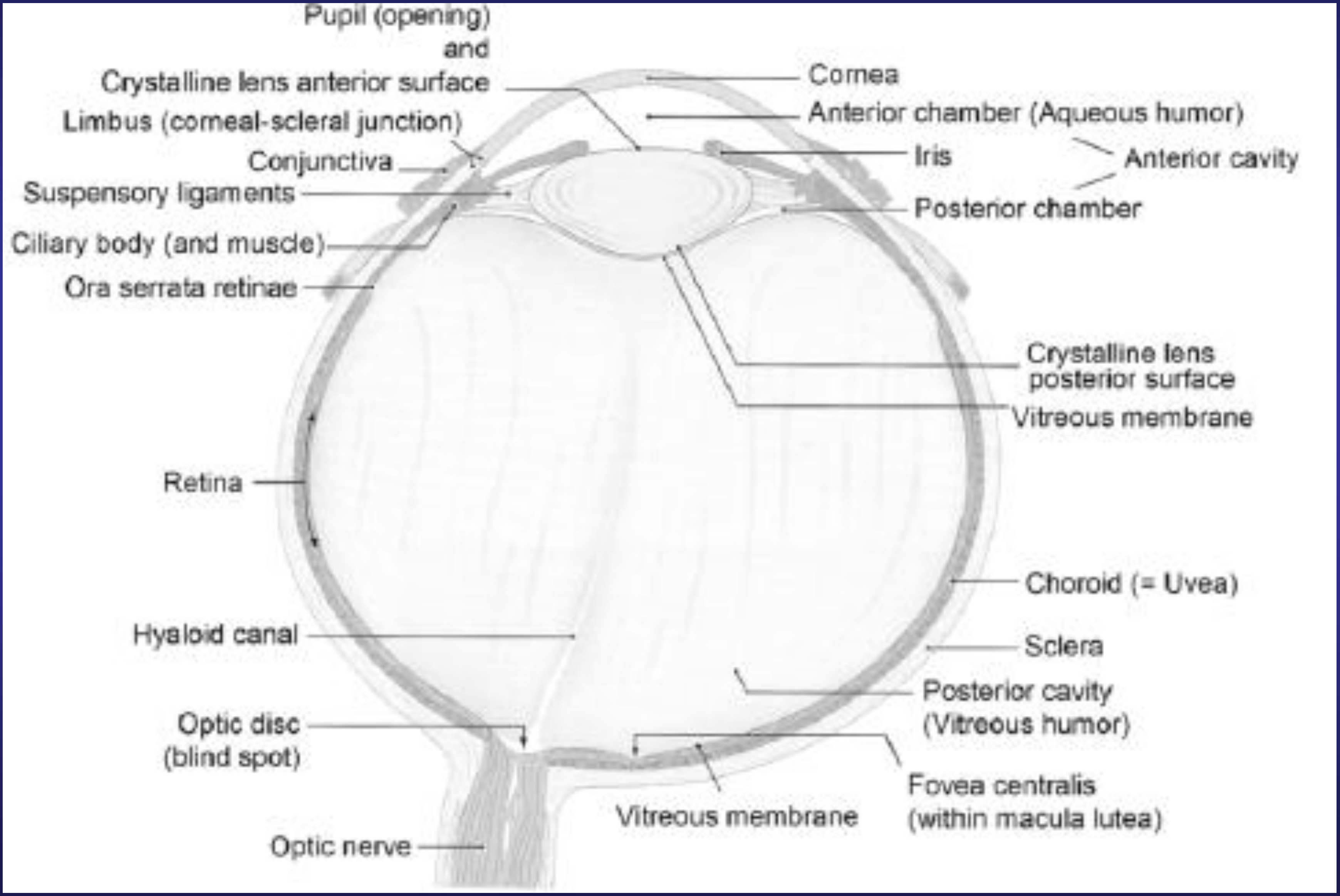
- Retina (Conos y bastones)

Sistema neural:

- Retina (Completa)
- Nervio óptico
- Cerebro
- Cerebelo



EL SISTEMA VISUAL HUMANO



OJO DERECHO ANATOMICO

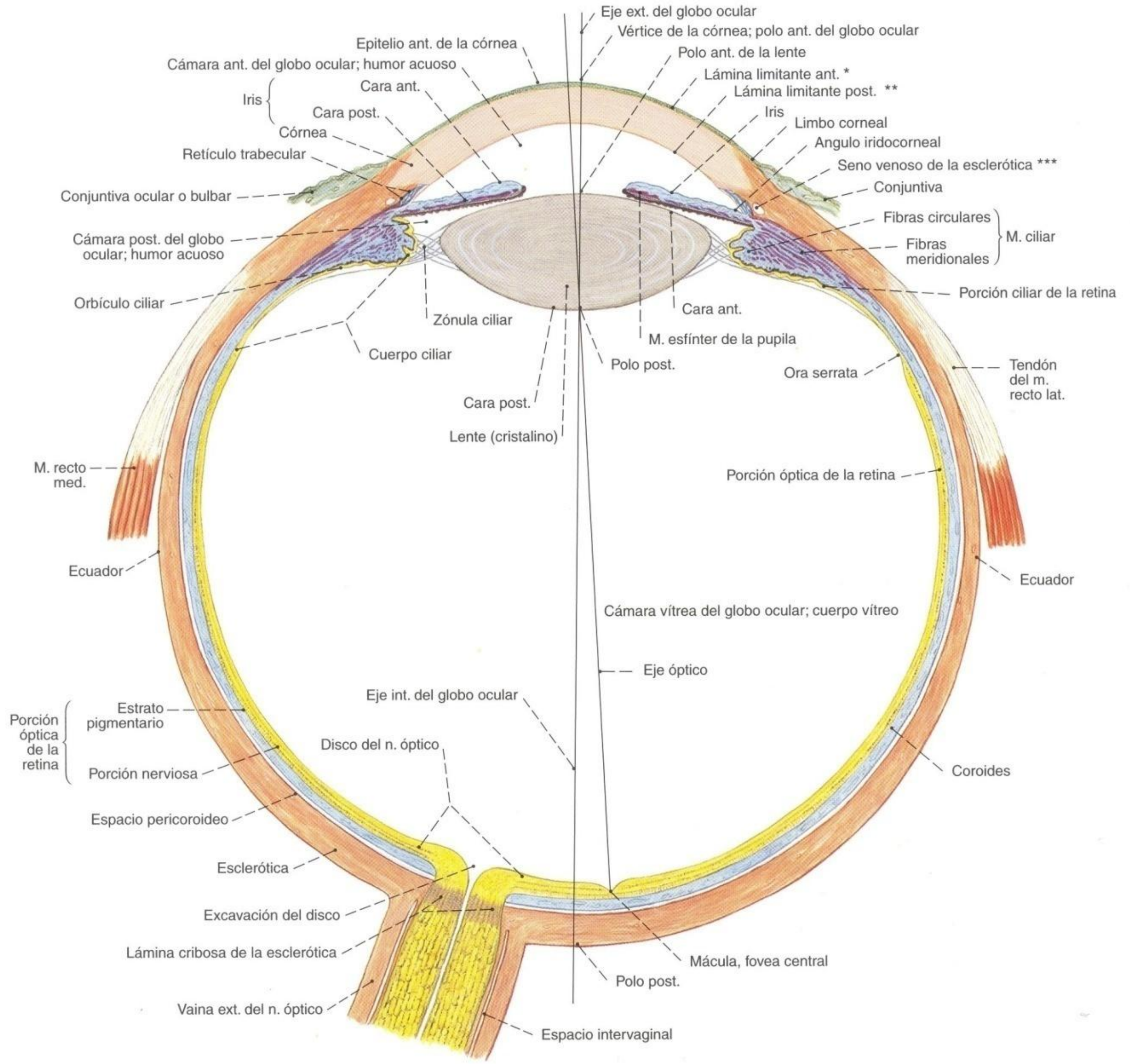


Fig. 633 Corte horizontal esquemático del globo ocular al nivel de la salida del nervio óptico.

* Epónimo clínico: membrana de Bowman
** Epónimo clínico: membrana de Descemet
*** Epónimo clínico: conducto de Schlemm

LOS OJOS Y EL CEREBRO

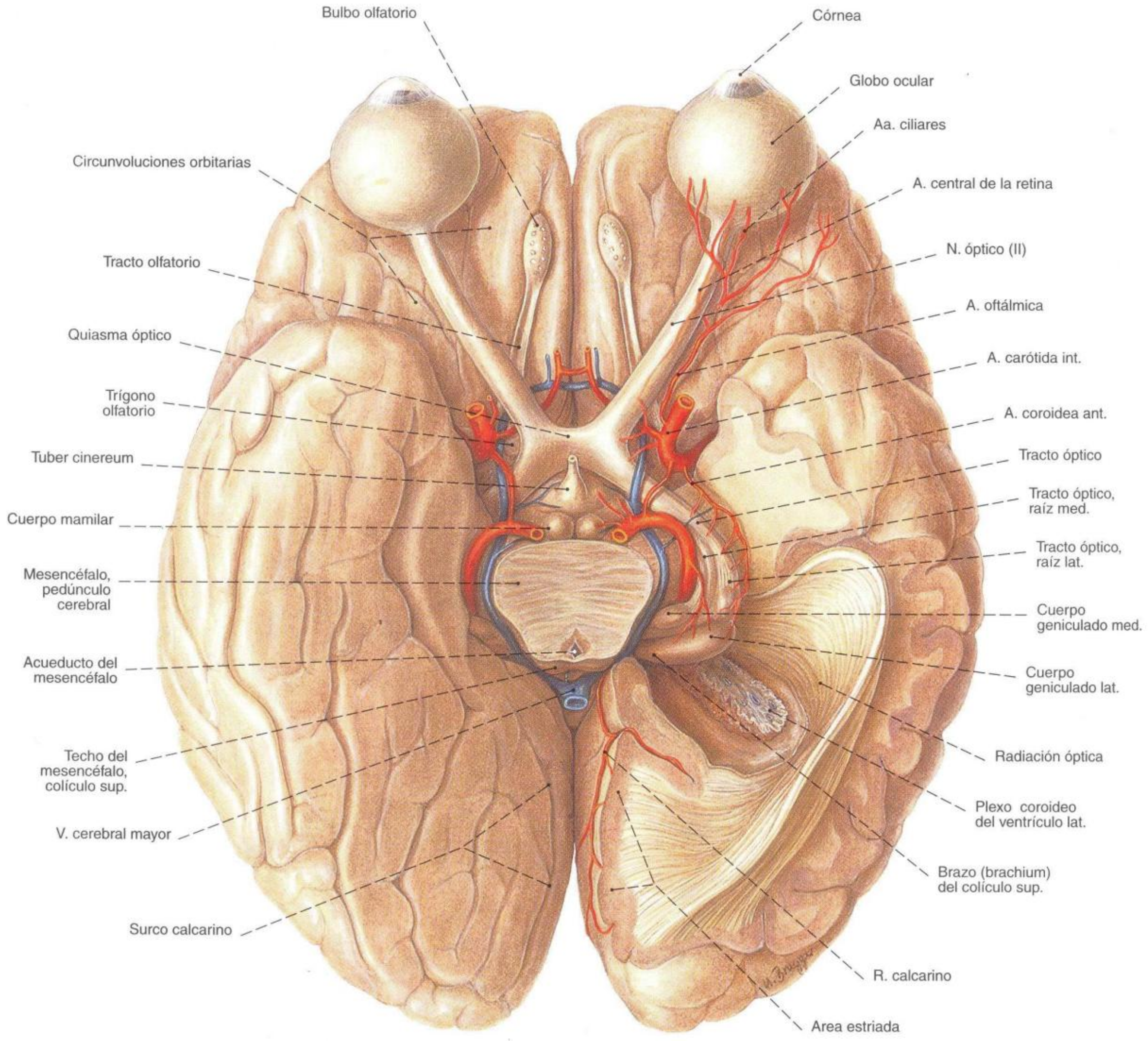


Fig. 651 Visión inferior del cerebro y de las vías visuales; se ha seccionado oblicuamente el mesencéfalo y el puente y se ha extirpado parte de los lóbulos temporal y occipital izquierdos.

DIFERENCIAS DIMENSIONALES DE OJOS HUMANO Y MONO RHESUS

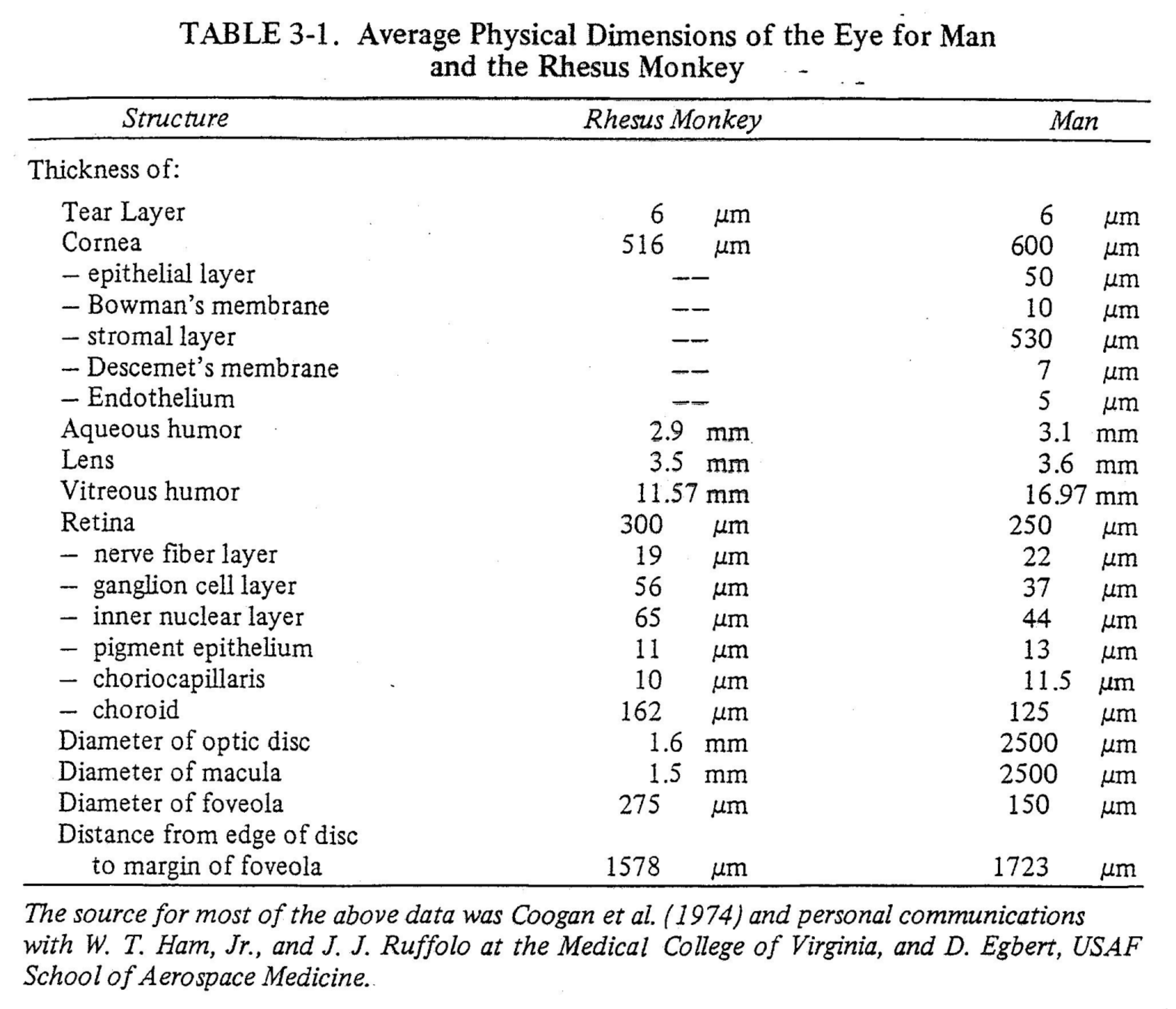
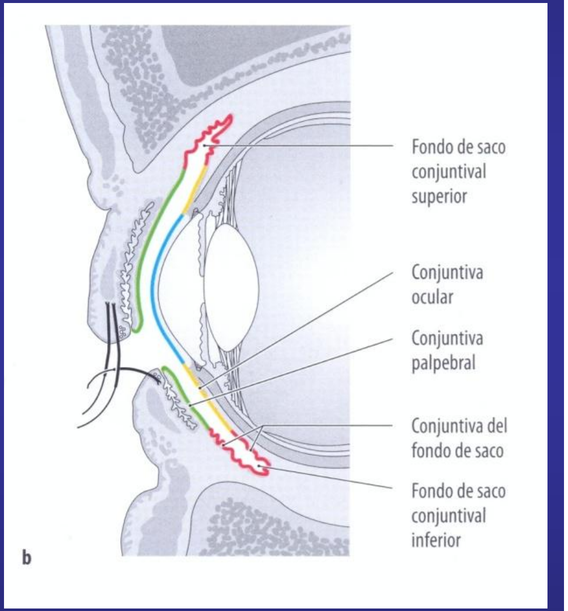


TABLE 3-1. Average Physical Dimensions of the Eye for Man and the Rhesus Monkey

Structure	*Rhesus Monkey*	*Man*
Thickness of:		
Tear Layer	6 μm	6 μm
Cornea	516 μm	600 μm
– epithelial layer	——	50 μm
– Bowman's membrane	——	10 μm
– stromal layer	——	530 μm
– Descemet's membrane	——	7 μm
– Endothelium	——	5 μm
Aqueous humor	2.9 mm	3.1 mm
Lens	3.5 mm	3.6 mm
Vitreous humor	11.57 mm	16.97 mm
Retina	300 μm	250 μm
– nerve fiber layer	19 μm	22 μm
– ganglion cell layer	56 μm	37 μm
– inner nuclear layer	65 μm	44 μm
– pigment epithelium	11 μm	13 μm
– choriocapillaris	10 μm	11.5 μm
– choroid	162 μm	125 μm
Diameter of optic disc	1.6 mm	2500 μm
Diameter of macula	1.5 mm	2500 μm
Diameter of foveola	275 μm	150 μm
Distance from edge of disc to margin of foveola	1578 μm	1723 μm

The source for most of the above data was Coogan et al. (1974) and personal communications with W. T. Ham, Jr., and J. J. Ruffolo at the Medical College of Virginia, and D. Egbert, USAF School of Aerospace Medicine.

CORNEA I



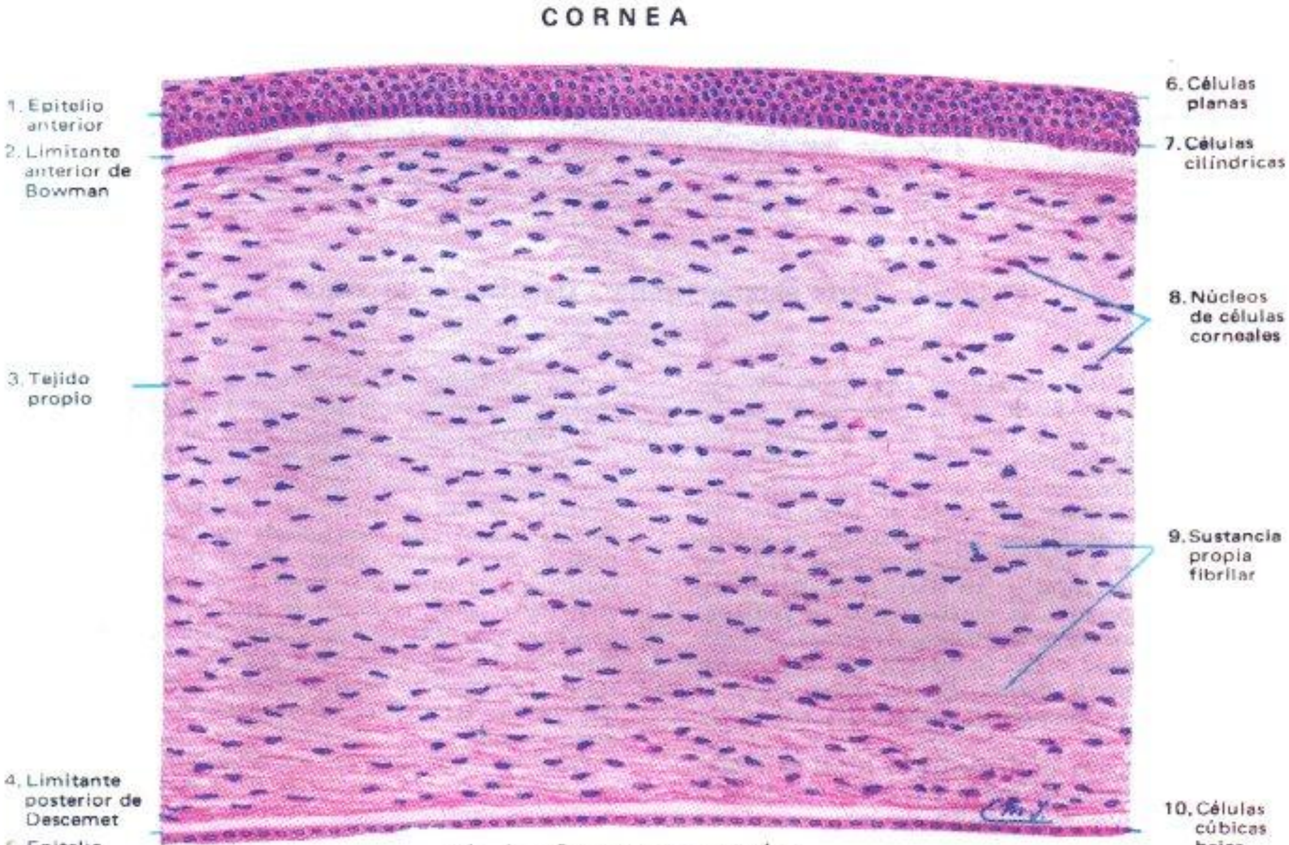


Fig. 2.– *Corte anteroposterior*

(Coloración: hematoxilina-eosina. 180 X.)

CORNEA II

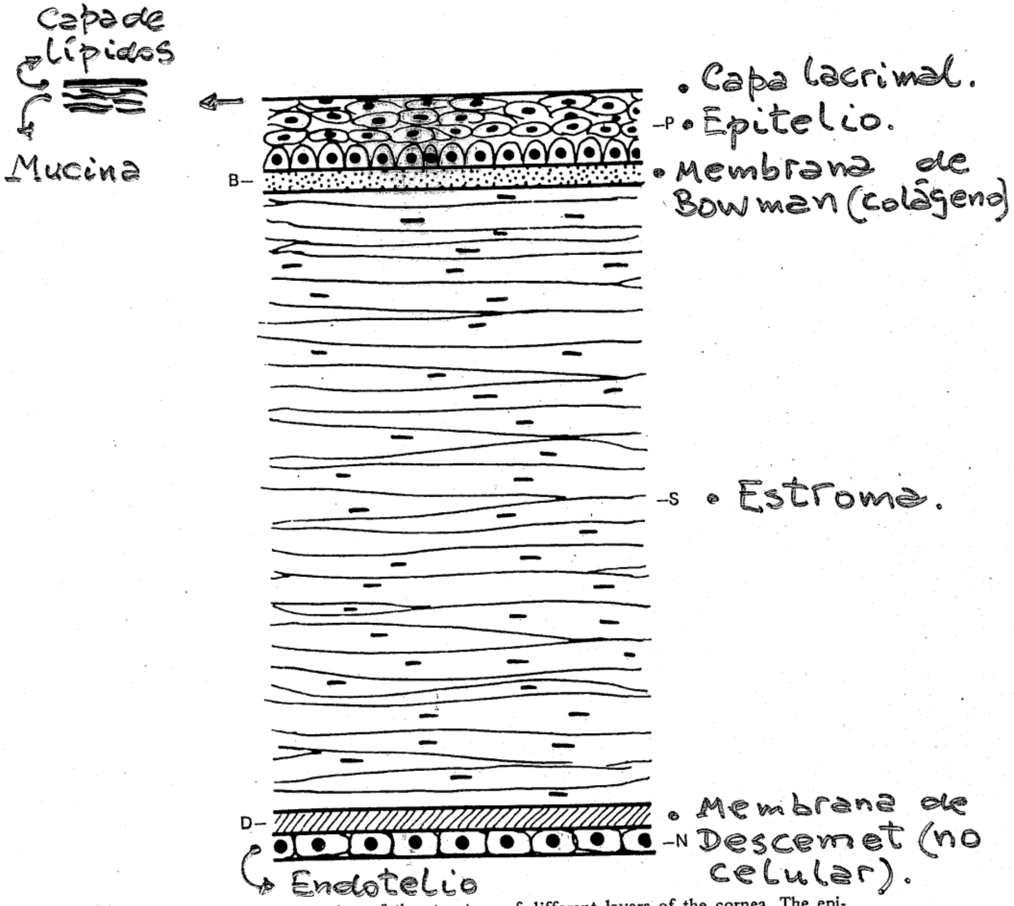


Figure 3-2. An artist's conception of the structure of different layers of the cornea. The epithelium (50-100 μm thick) is the structure facing the environment (P); Bowman's membrane (B) is 8-14 μm thick; stroma (S) is about 500 μm in thickness near the visual axis; Descemet's membrane (D) is 5-10 μm thick and the corneal endothelium (N) is about 5 μm thick. Adapted from Duke-Elder (1937).

-Capa lacrimal (6-10μm).

CRISTALINO I

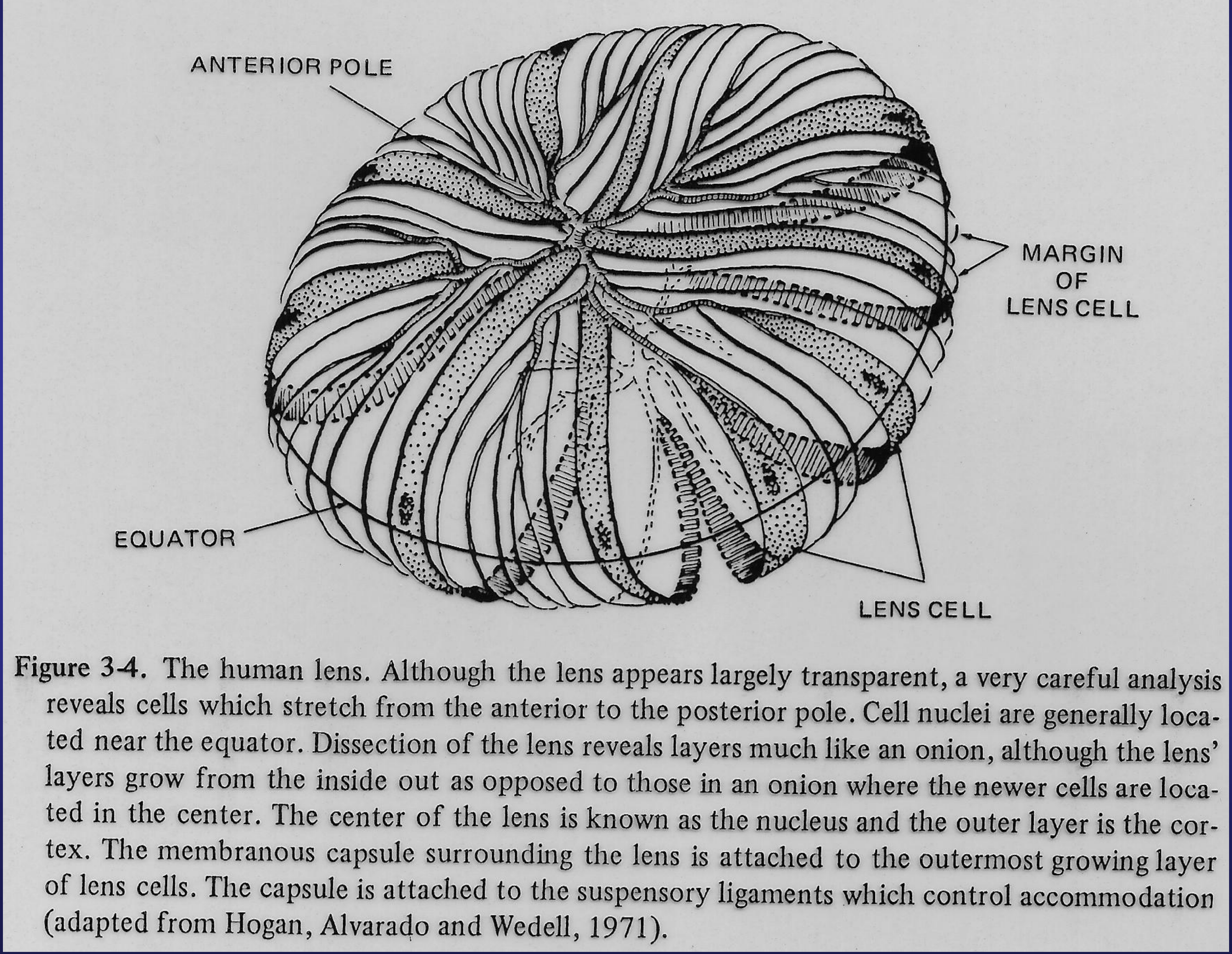
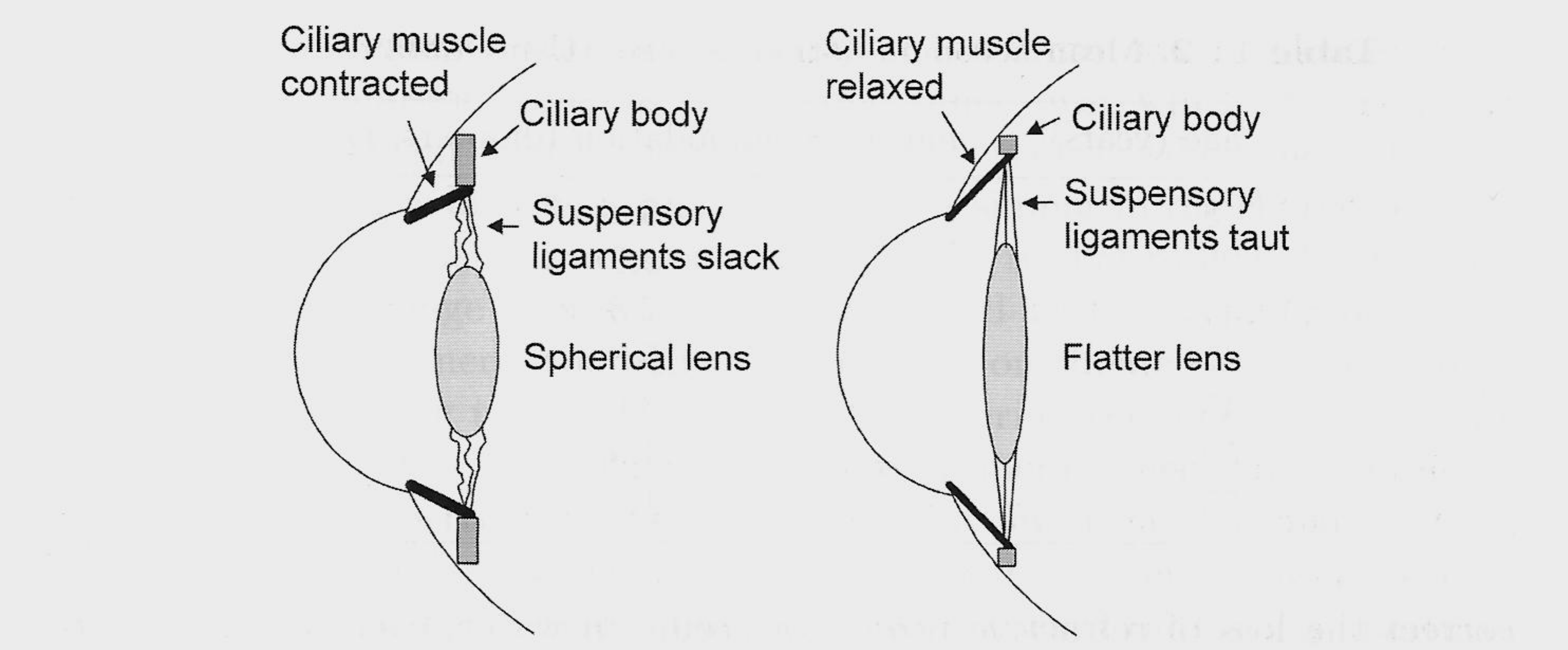
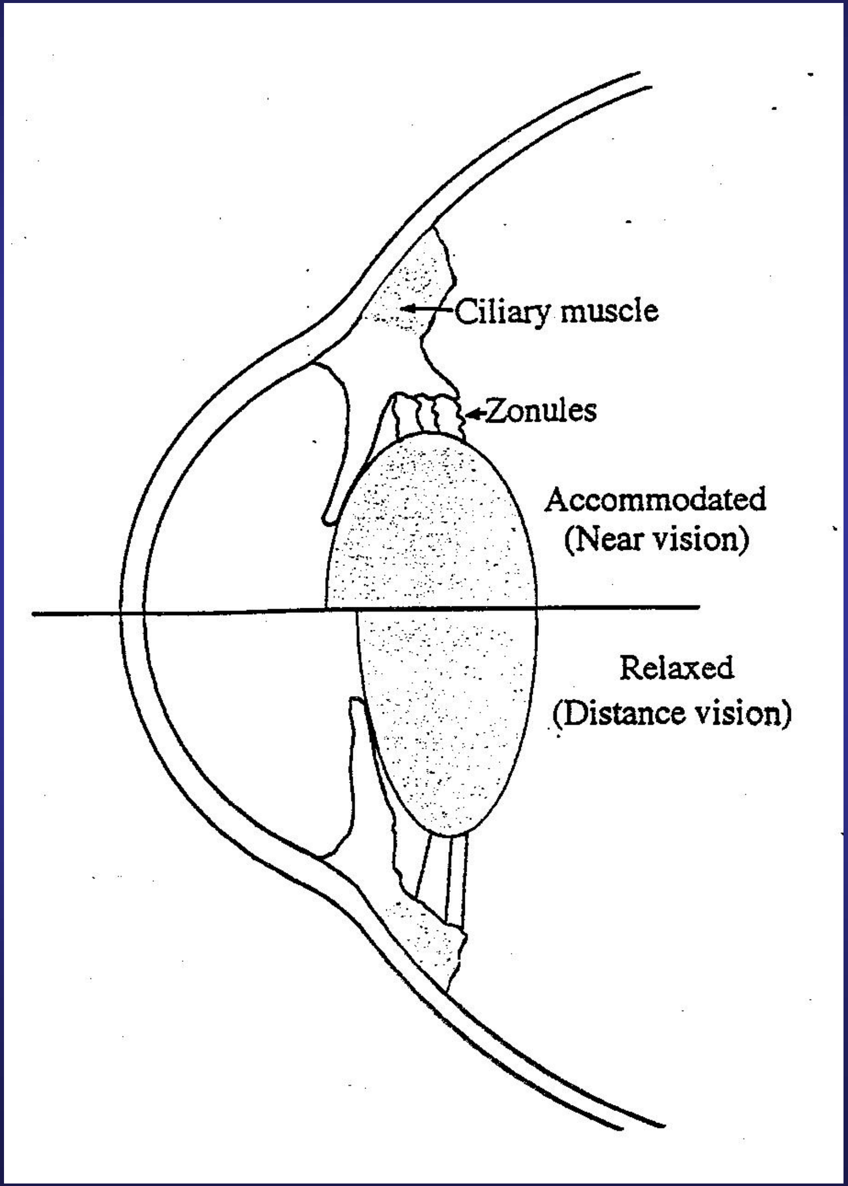


Figure 3-4. The human lens. Although the lens appears largely transparent, a very careful analysis reveals cells which stretch from the anterior to the posterior pole. Cell nuclei are generally located near the equator. Dissection of the lens reveals layers much like an onion, although the lens' layers grow from the inside out as opposed to those in an onion where the newer cells are located in the center. The center of the lens is known as the nucleus and the outer layer is the cortex. The membranous capsule surrounding the lens is attached to the outermost growing layer of lens cells. The capsule is attached to the suspensory ligaments which control accommodation (adapted from Hogan, Alvarado and Wedell, 1971).

CRISTALINO II



CRISTALINO III



CRISTALINO IV

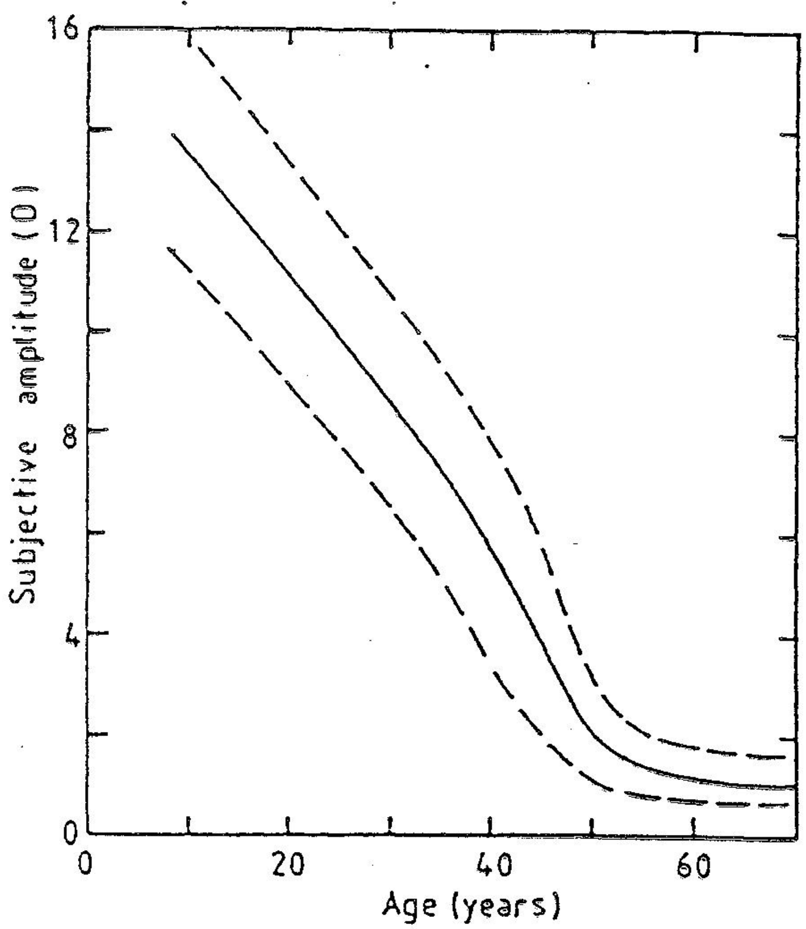


FIGURE 22 Changes in the subjective amplitude of accommodation with age (*after Duane*[315]): the dashed curves indicate the limits of the range found at each age. The data refer to 4200 eyes, amplitudes being measured at the spectacle point 14 mm anterior to the cornea.

CRISTALINO V

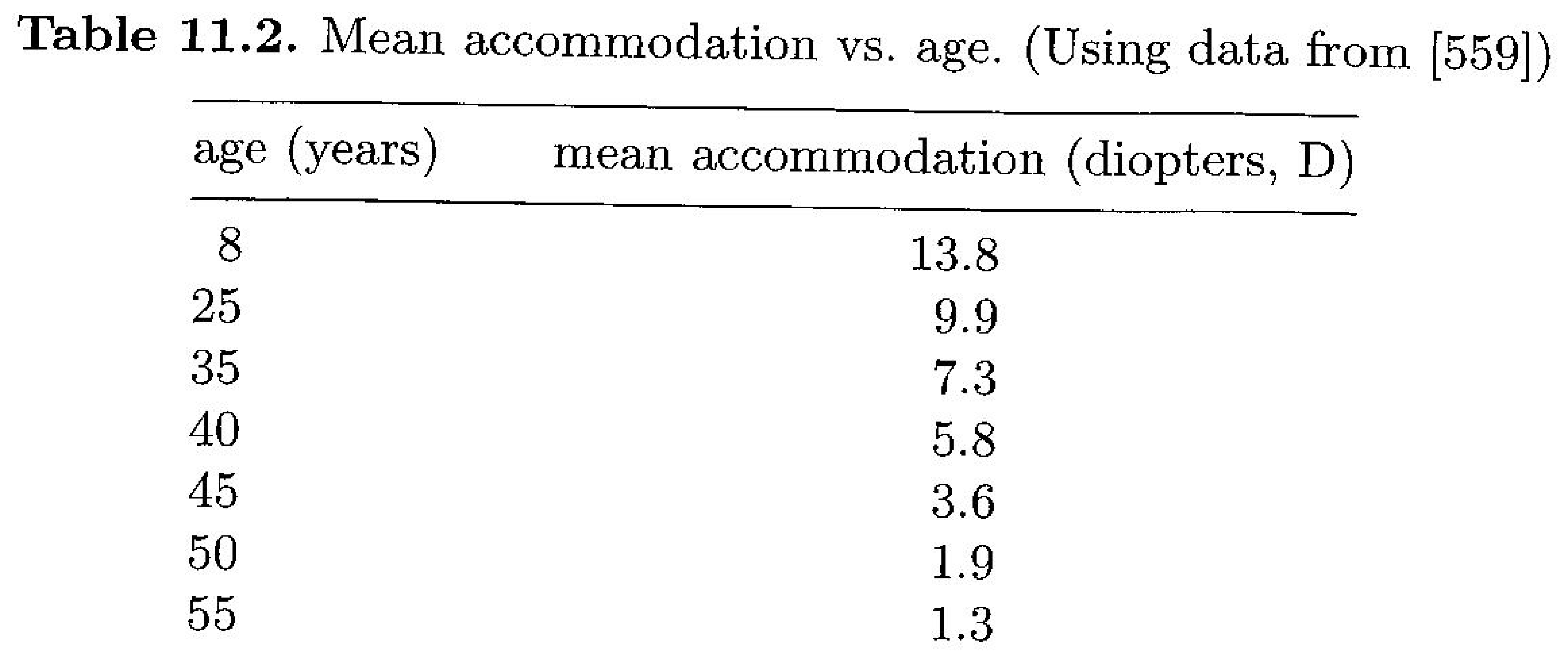


Table 11.2. Mean accommodation vs. age. (Using data from [559])

age (years)	mean accommodation (diopters, D)
8	13.8
25	9.9
35	7.3
40	5.8
45	3.6
50	1.9
55	1.3

EL SISTEMA VISUAL HUMANO

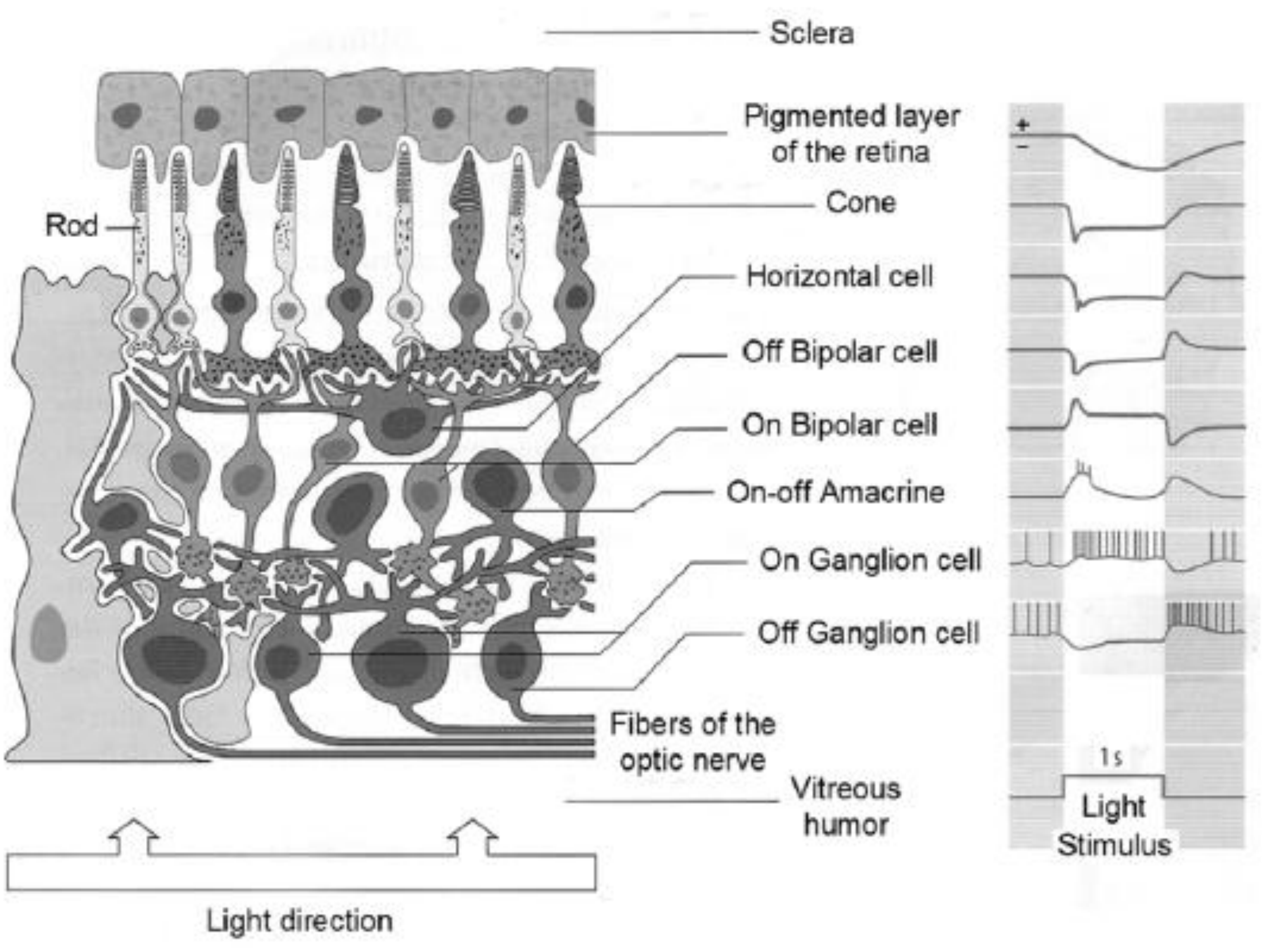
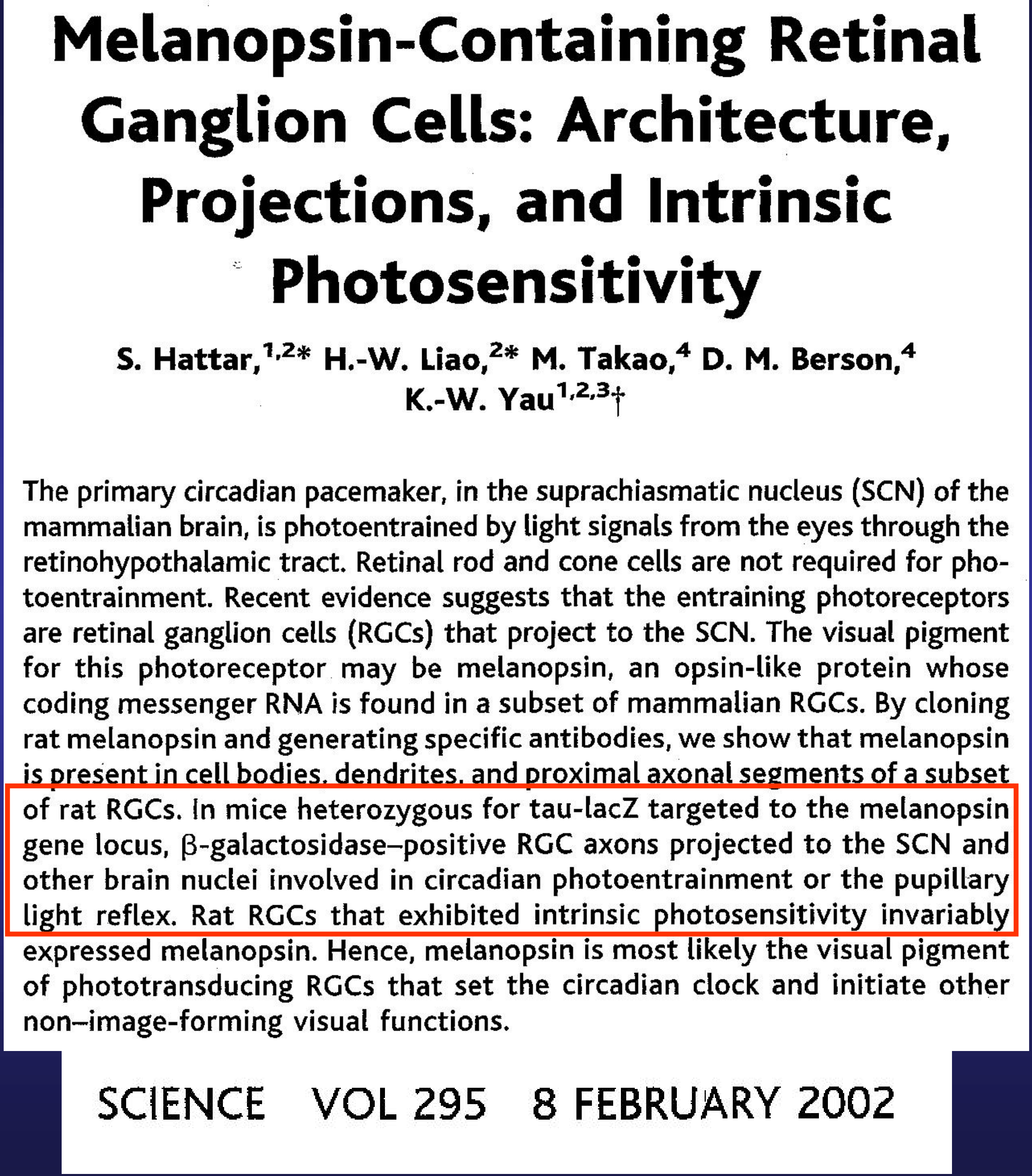


Fig. 11.2. Schematic of the retina in the eye, with the arrangement of rods and cones and other neurons, along with electrical excitation by the shown light stimulus. (From [551])



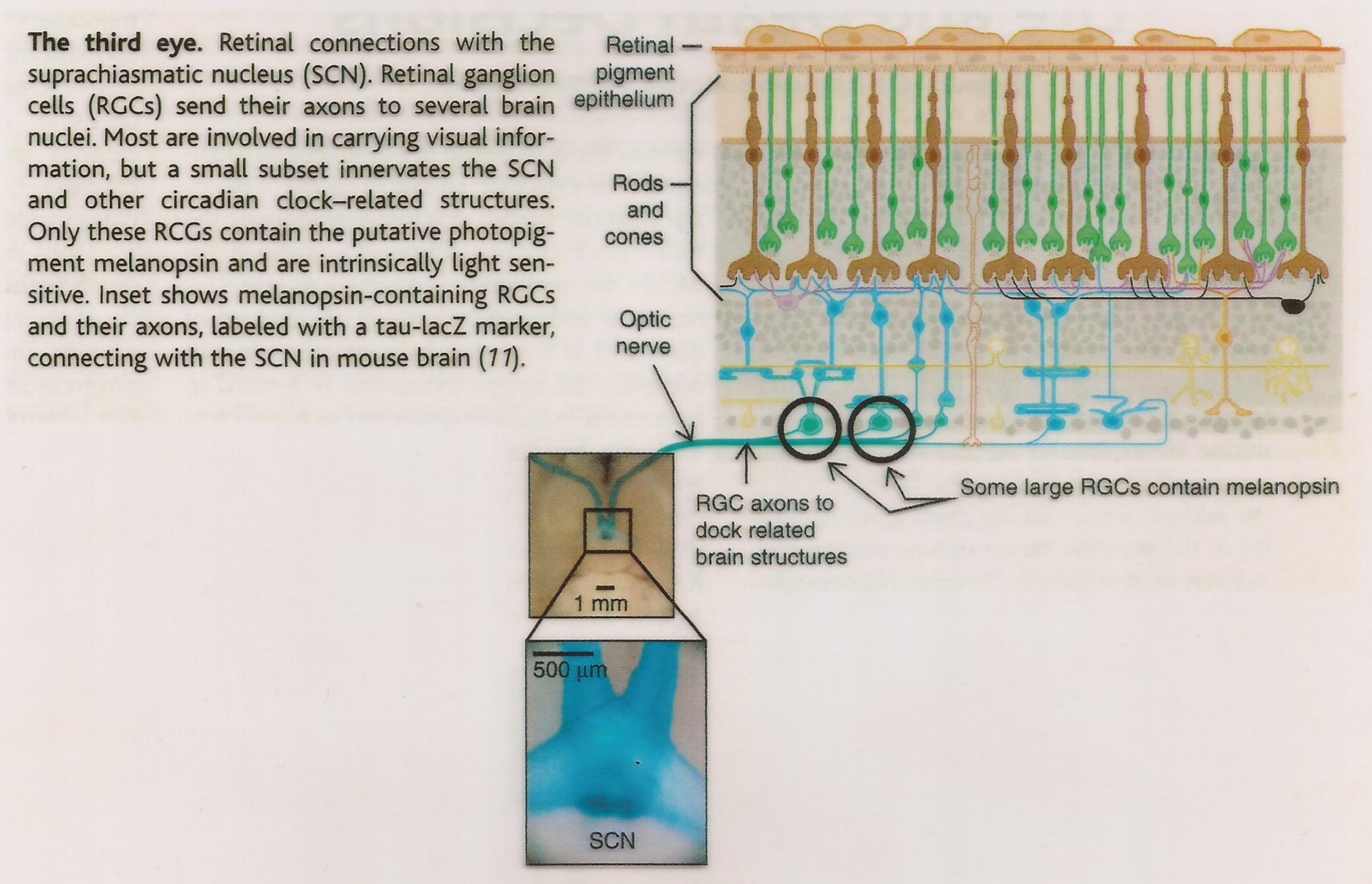
Melanopsin-Containing Retinal Ganglion Cells: Architecture, Projections, and Intrinsic Photosensitivity

S. Hattar,[1,2]* H.-W. Liao,[2]* M. Takao,[4] D. M. Berson,[4]
K.-W. Yau[1,2,3]†

The primary circadian pacemaker, in the suprachiasmatic nucleus (SCN) of the mammalian brain, is photoentrained by light signals from the eyes through the retinohypothalamic tract. Retinal rod and cone cells are not required for photoentrainment. Recent evidence suggests that the entraining photoreceptors are retinal ganglion cells (RGCs) that project to the SCN. The visual pigment for this photoreceptor may be melanopsin, an opsin-like protein whose coding messenger RNA is found in a subset of mammalian RGCs. By cloning rat melanopsin and generating specific antibodies, we show that melanopsin is present in cell bodies, dendrites, and proximal axonal segments of a subset of rat RGCs. In mice heterozygous for tau-lacZ targeted to the melanopsin gene locus, β-galactosidase–positive RGC axons projected to the SCN and other brain nuclei involved in circadian photoentrainment or the pupillary light reflex. Rat RGCs that exhibited intrinsic photosensitivity invariably expressed melanopsin. Hence, melanopsin is most likely the visual pigment of phototransducing RGCs that set the circadian clock and initiate other non–image-forming visual functions.

SCIENCE VOL 295 8 FEBRUARY 2002

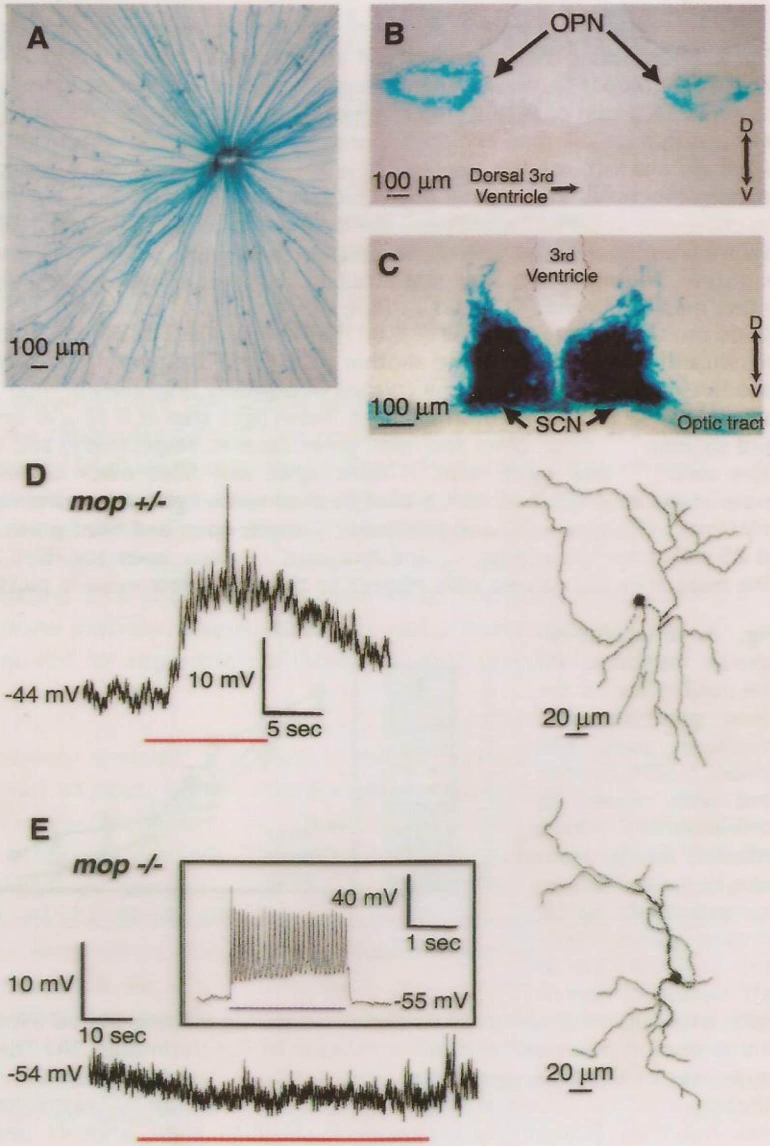
CELULAS GANGLIONARES CON MELANOPSINA I



The third eye. Retinal connections with the suprachiasmatic nucleus (SCN). Retinal ganglion cells (RGCs) send their axons to several brain nuclei. Most are involved in carrying visual information, but a small subset innervates the SCN and other circadian clock–related structures. Only these RCGs contain the putative photopigment melanopsin and are intrinsically light sensitive. Inset shows melanopsin-containing RGCs and their axons, labeled with a tau-lacZ marker, connecting with the SCN in mouse brain (*11*).

CELULAS GANGLIONARES CON MELANOPSINA II

Fig. 1. RGCs that would normally express melanopsin in wild-type and $mop^{+/-}$ mice are still present in $mop^{-/-}$ mice and project to the OPN and SCN but have lost their intrinsic photosensitivity. (**A**) Flat-mount view of a $mop^{-/-}$ retina stained with X-Gal (blue labeling). (**B** and **C**) Coronal sections of $mop^{-/-}$ mouse brains showing normal innervation of the OPN and the SCN by X-Gal–labeled axons. D, dorsal; V, ventral. (**D** and **E**) Intrinsic photosensitivity of SCN-projecting RGCs of $mop^{+/-}$ (D) but not $mop^{-/-}$ (E) mice. Left: Voltage responses to light stimuli (red line) of RGCs retrograde-labeled from the SCN. Recordings were made from an isolated, flat-mount retina in the presence of 2 mM $CoCl_2$ to block synaptic transmission. Right: Camera-lucida drawings of the cells recorded. Inset in (E): Depolarization and action potentials evoked by current injection (50 pA; blue line), demonstrating functional viability of this cell.



VARIACION DEL DIAMETRO PUPILAR I

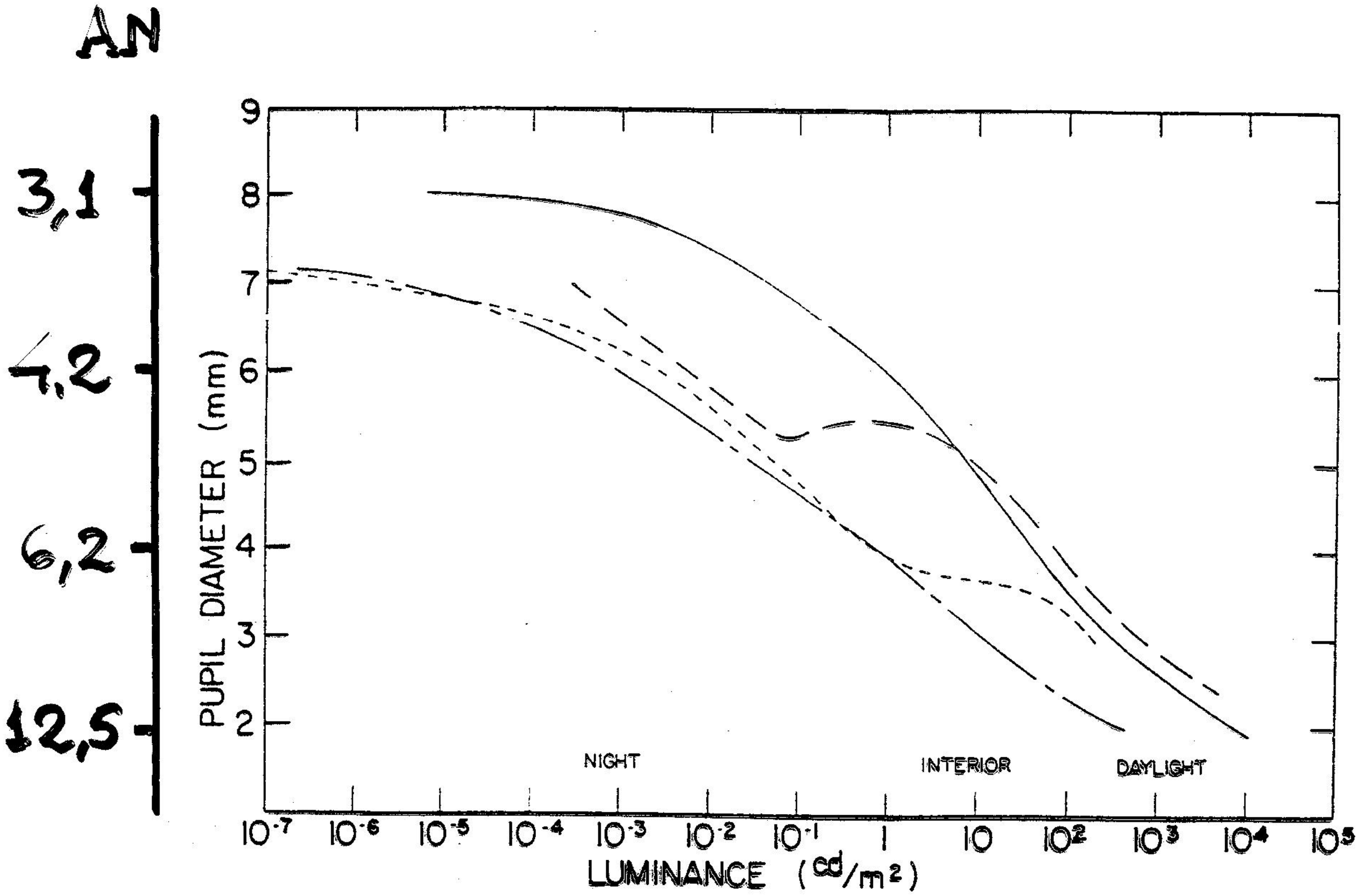


Figure 3-3. Variation of human pupil size with ambient light conditions. The abscissa provides the luminance of the adapting field with pupil diameter measured in 4 studies from Crawford (1936), ---; Reeves (1921), ——; Flamant (1948), – – –; and the average of 8 studies by de Groot and Gebhard (1952), ——— - ——— -, (from Sliney, 1971, with permission).

VARIACION DEL DIAMETRO PUPILAR II

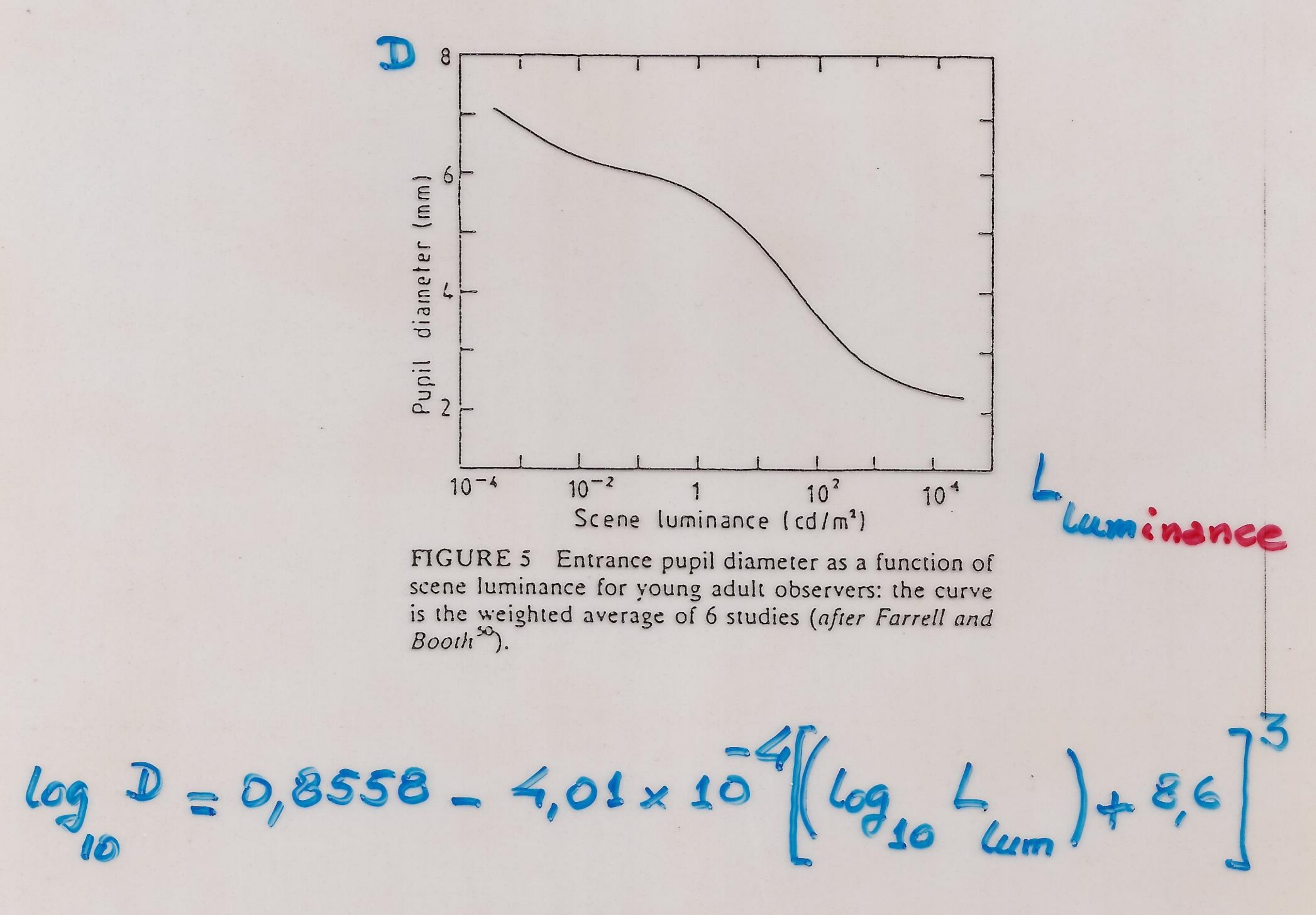
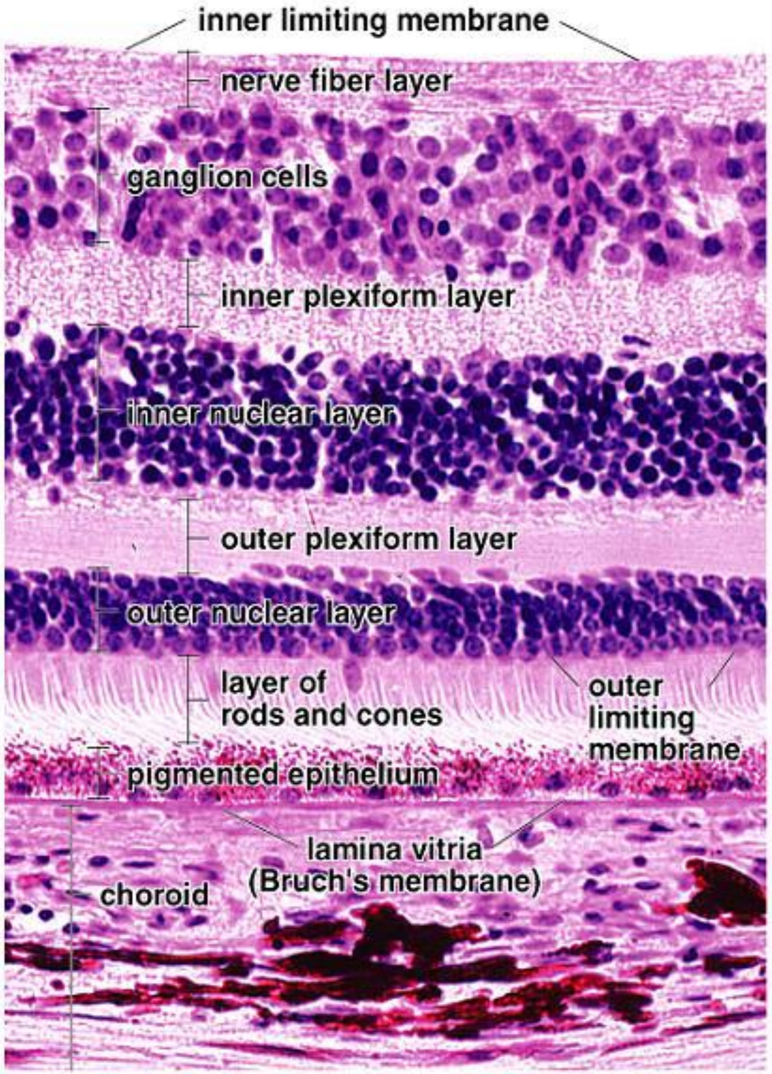
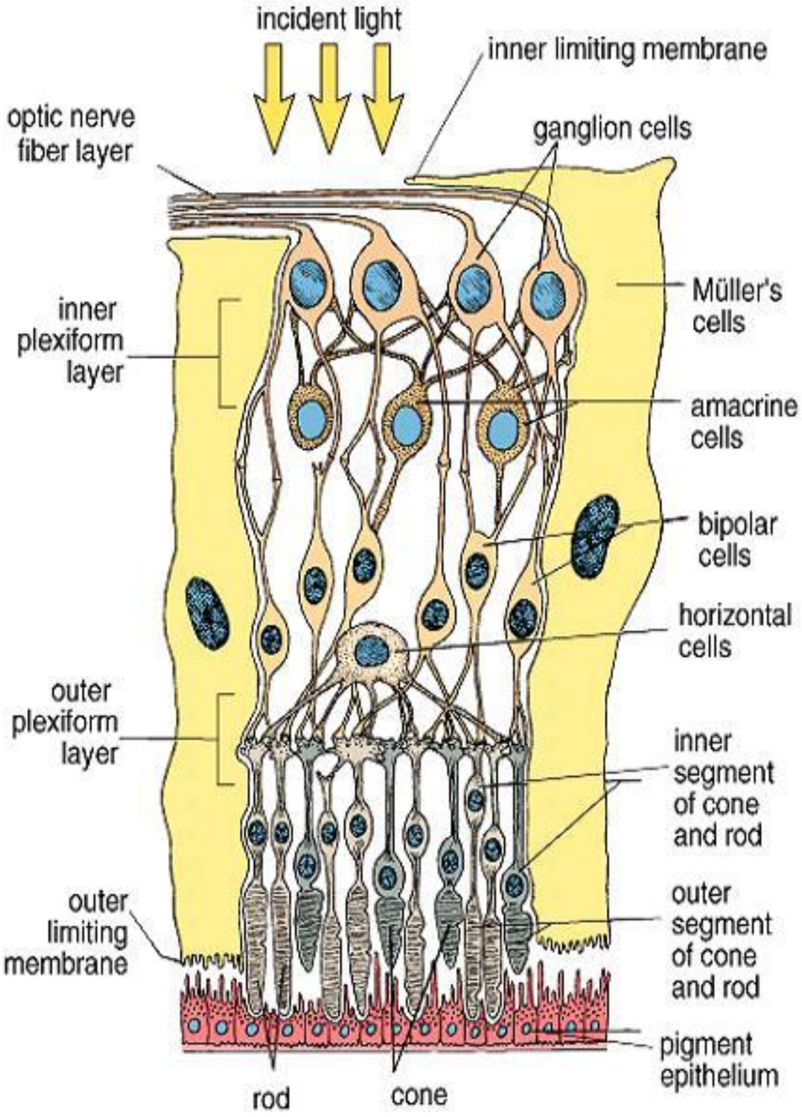


FIGURE 5 Entrance pupil diameter as a function of scene luminance for young adult observers: the curve is the weighted average of 6 studies (*after Farrell and Booth*[50]).

$$\log_{10} D = 0{,}8558 - 4{,}01 \times 10^{-4}\left[\left(\log_{10} L_{lum}\right) + 8{,}6\right]^{3}$$

ESTRUCTURA DE LA RETINA





EL SISTEMA VISUAL HUMANO

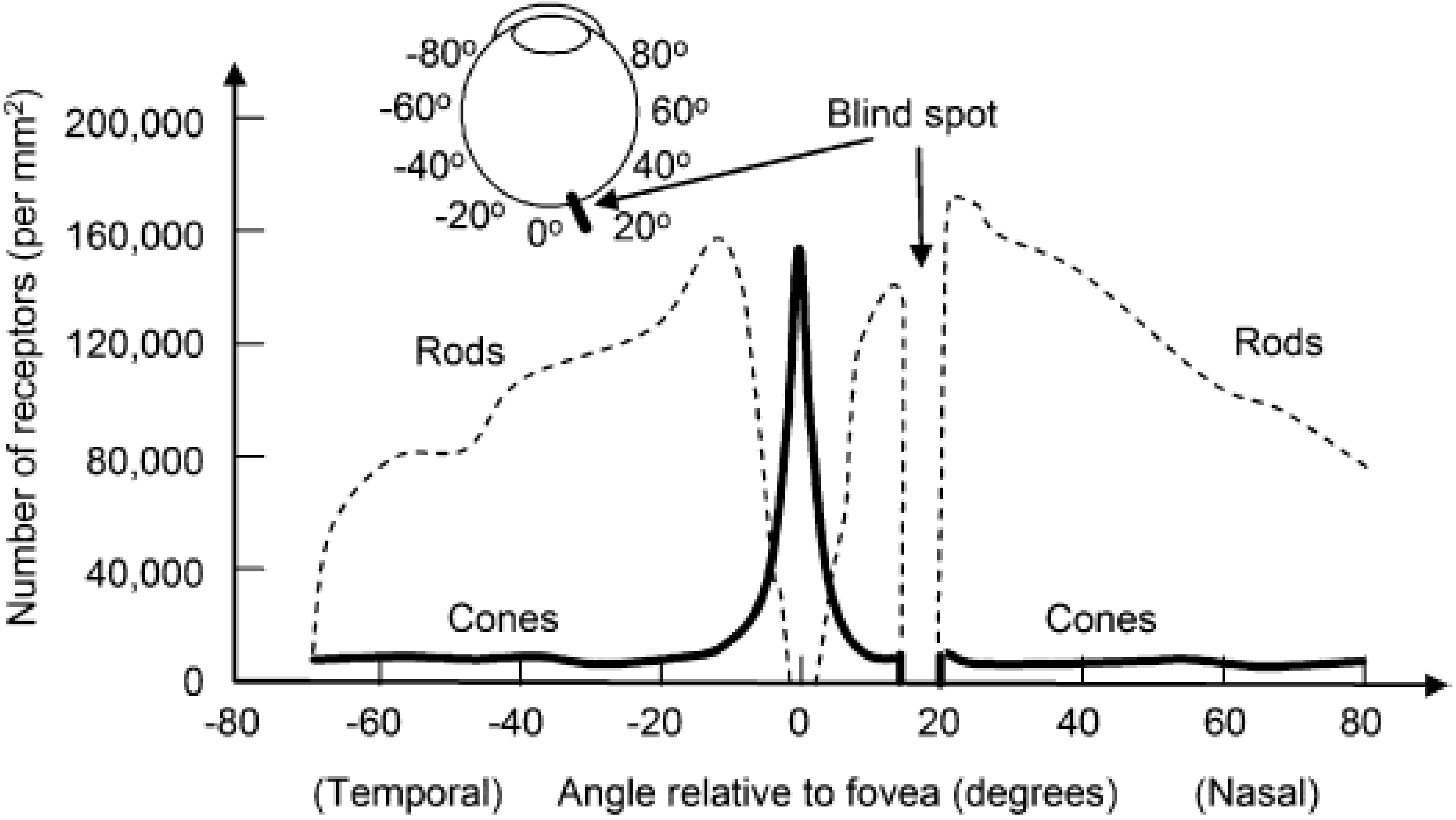
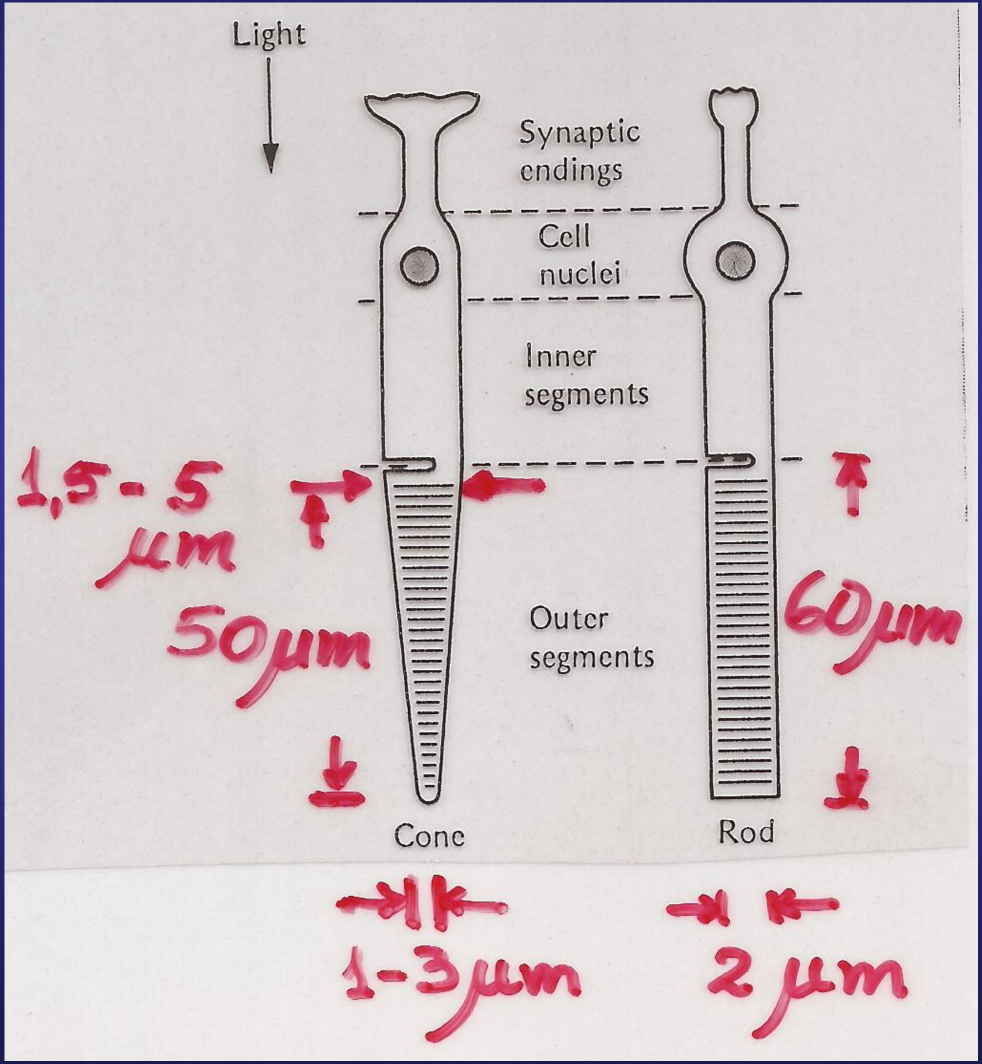


Fig. 11.3. Distribution of rods and cones on the retina, and the location of the blind spot. (Based on [523] and [560])

DIMENSIONES TIPICAS DE CONOS Y BASTONES I



DIMENSIONES TIPICAS DE CONOS Y BASTONES II

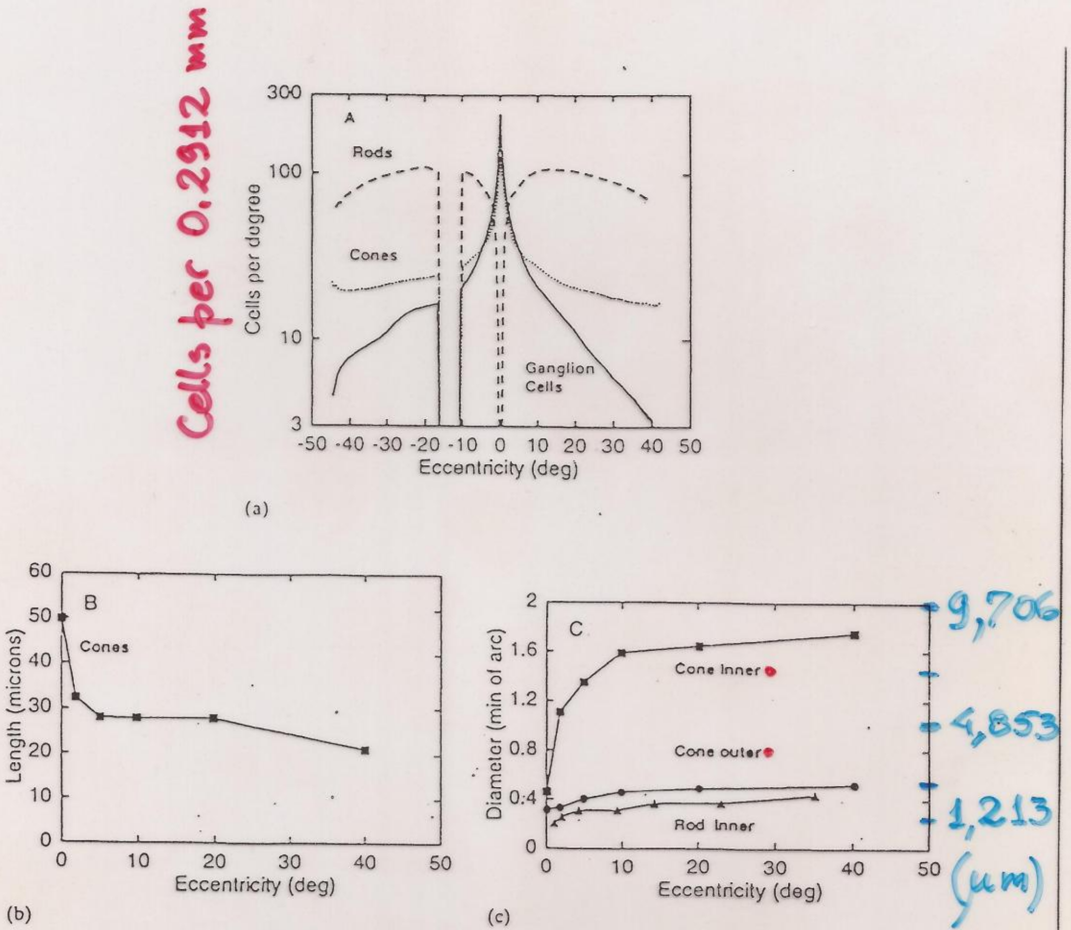


FIGURE 2 (*a*) Linear density of cones, rods, and ganglion cells as a function of eccentricity in the human retina. (The data were modified from Refs. 6 and 32.) Conversion from cells/mm^2 to cells/deg^2 was computed assuming a posterior nodal point 16.68 mm from the retina, and a retinal radius of curvature of 12.1 mm. Conversion to cells/deg was obtained by taking the square root of areal density. Ganglion cell density in the central 10 deg was derived assuming a 3:1 ratio of ganglion cells to cones in the fovea.[32] (*b*) Human cone outer segment length. (Modified from Ref. 125.) (*c*) Human cone inner segment, cone outer segment and rod diameter as a function of eccentricity. (Modified from Ref. 125.)

TIPO Y CANTIDAD DE COMPONENTES EN LA RETINA

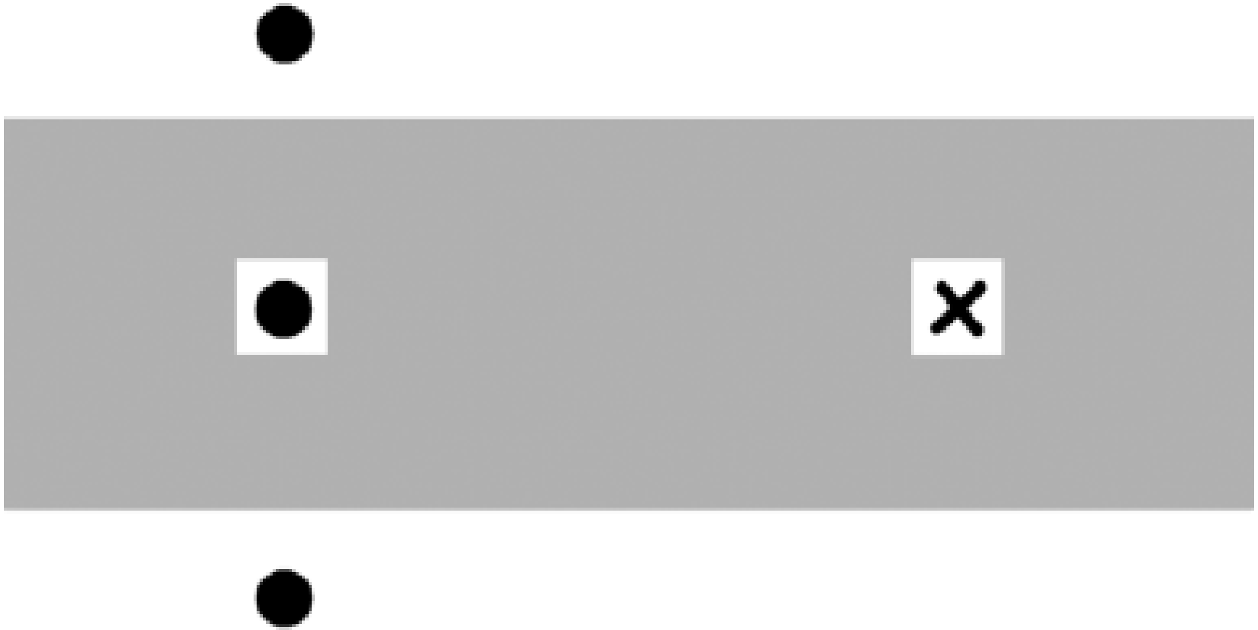


Fig. 11.4. Fixate on the x using your left eye, with your right eye closed. Keep the book about 10 cm from your left eye, and then move it back and forth until you do not see the central spot. This spot is then on the blind spot. The spots above and below it are still visible, but fuzzy because of the lower visual acuity outside the fovea. (Based on [560])

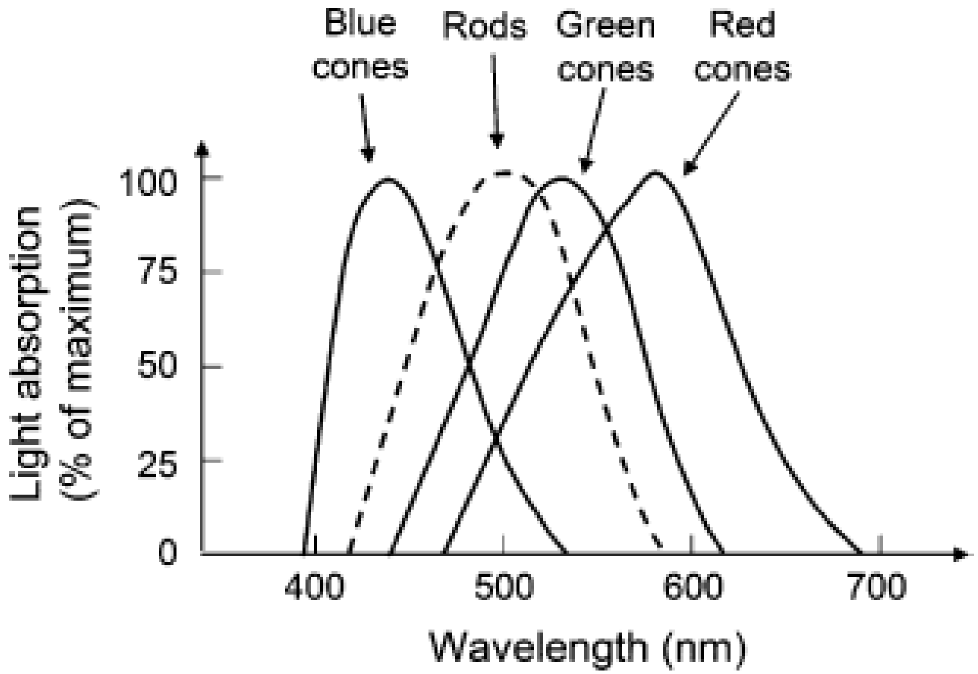
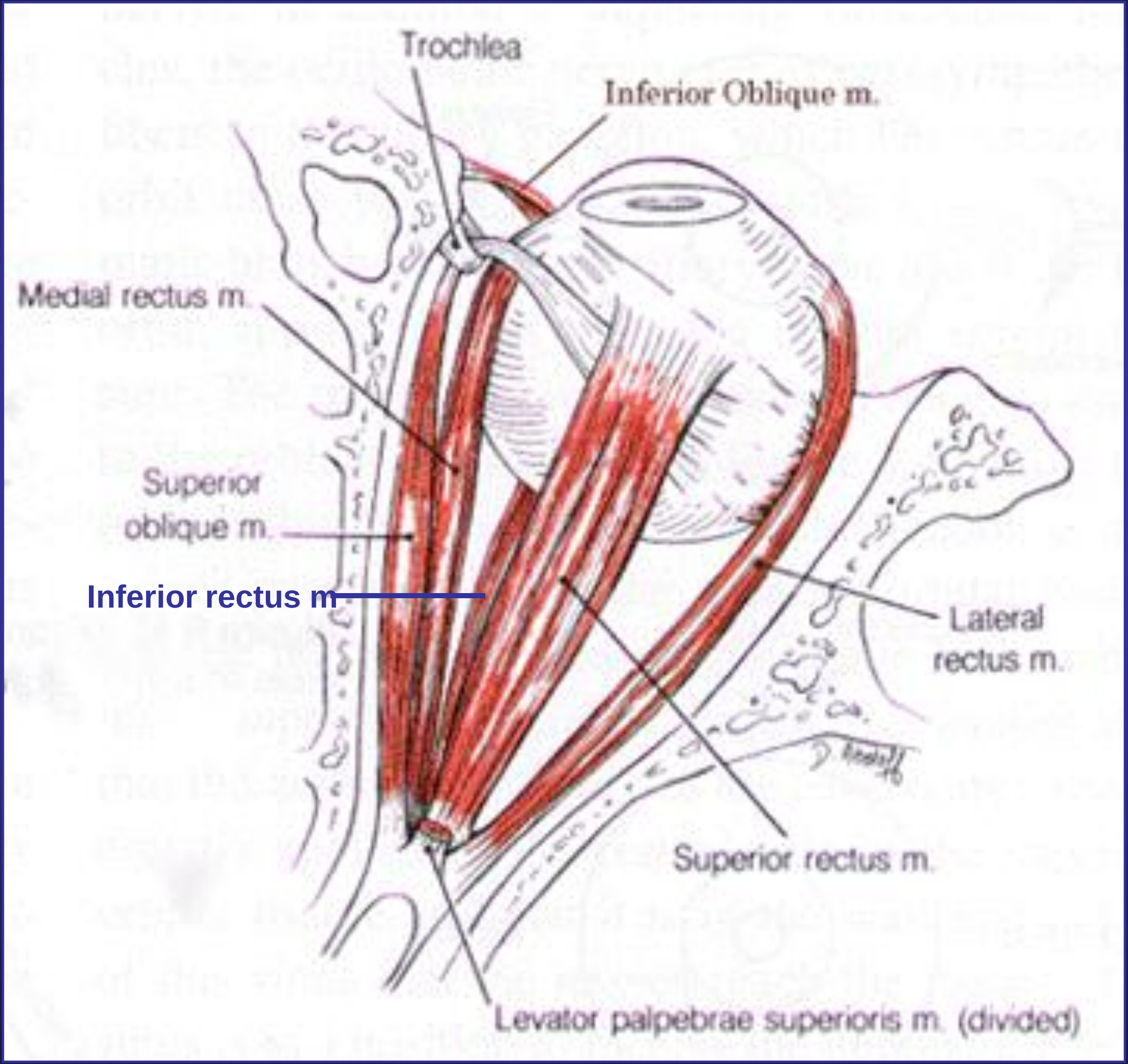
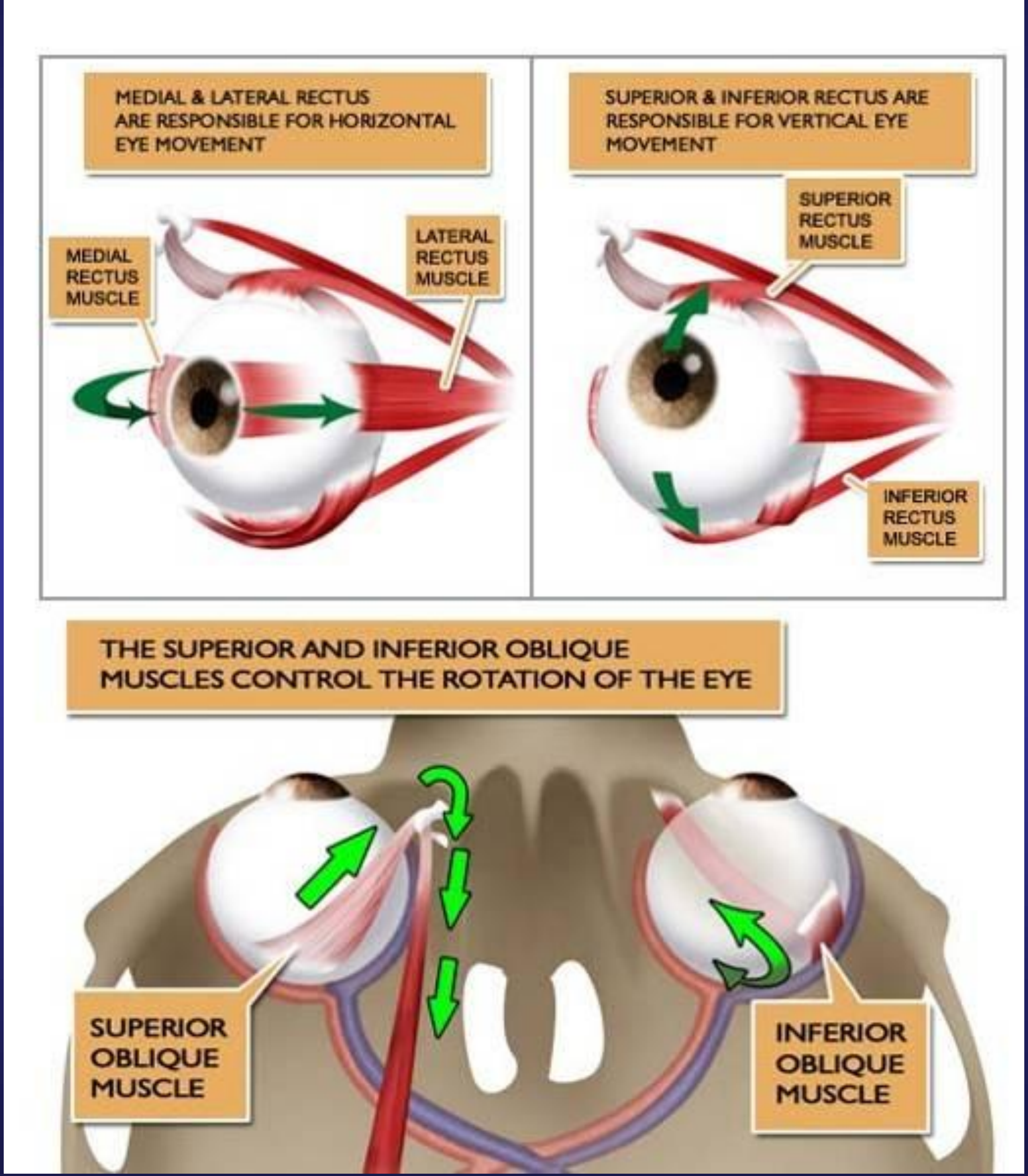


Fig. 11.6. Relative spectral sensitivity of rods and cones. The absolute sensitivity of rods is 1,000× larger those of the cones. (Based on [515], [526], and [540])

MUSCULOS OCULARES II



MOVIMIENTOS DEL OJO HUMANO



ONDAS ELECTROMAGNÉTICAS I

Ecuaciones de Maxwell

$$\nabla \bullet \vec{E} = \rho / \varepsilon$$

$$\nabla \bullet \vec{B} = 0$$

$$\nabla \otimes \vec{E} = -\frac{\partial \vec{B}}{\partial t}$$

$$\nabla \otimes \vec{B} = \mu \sigma \vec{E} + \mu \varepsilon \frac{\partial \vec{E}}{\partial t}$$

Ecuaciones de onda en el vacío

$$\nabla^2 E = -\mu_0 \varepsilon_0 \frac{\partial^2 E}{\partial t^2}$$

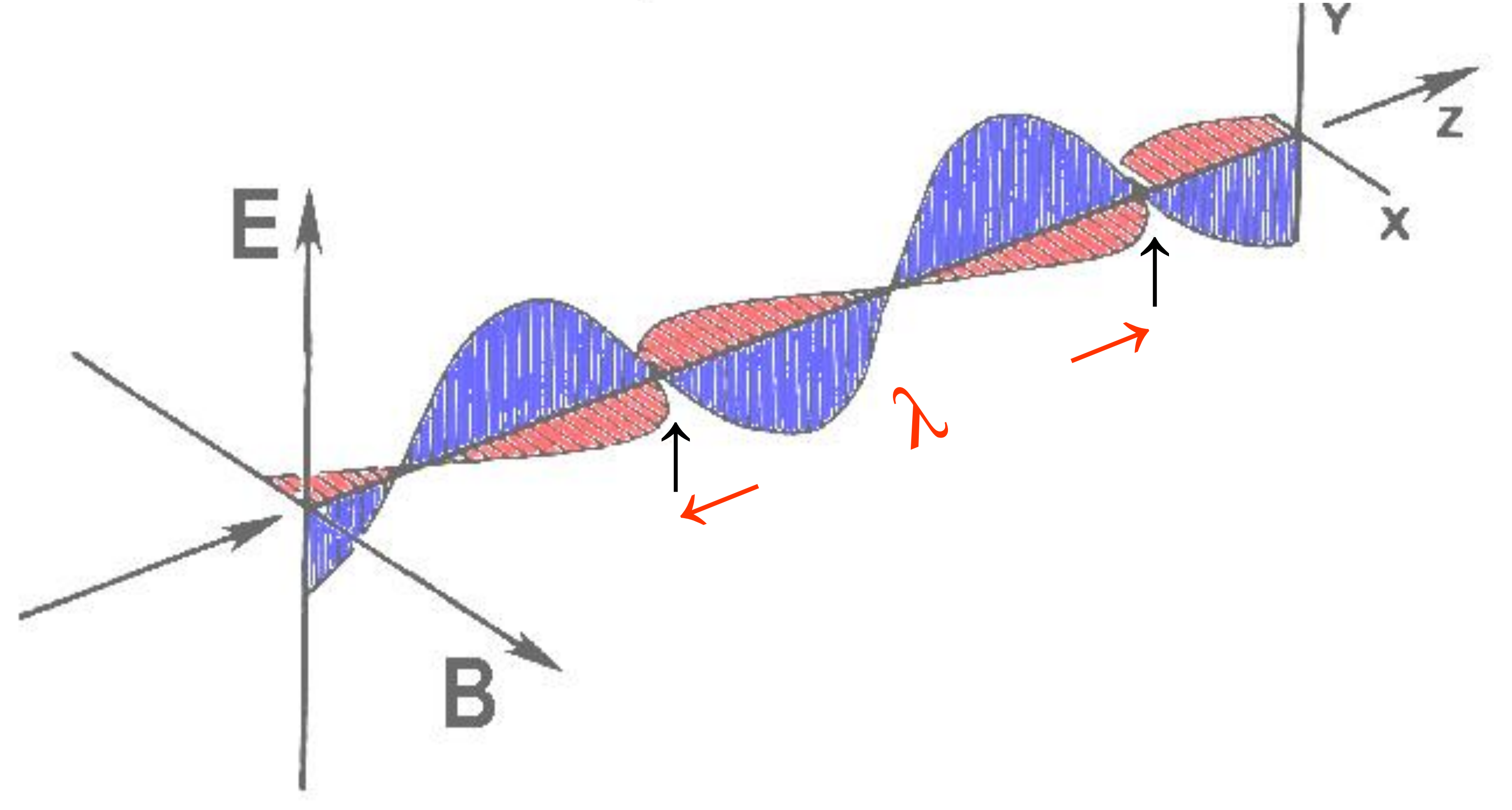
$$\nabla^2 B = -\mu_0 \varepsilon_0 \frac{\partial^2 B}{\partial t^2}$$

ONDAS ELECTROMAGNÉTICAS II

Ondas planas:

$$E_y(z,t) = E_{0y}\cos\left[\omega\left(t-\frac{z}{c}\right)+\varphi\right]$$

$$E_y = cB_x$$



ONDAS ELECTROMAGNÉTICAS III

Ecuación diferencial escalar de onda:

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}+\frac{\partial^2\psi}{\partial z^2}=\frac{1}{v^2}\frac{\partial^2\psi}{\partial t^2}$$

Velocidad en el vacío: $v=1/\sqrt{\mu_0\varepsilon_0}$

$$\mu_0\varepsilon_0\approx\left(8{,}85\times10^{-12}\,\frac{s^2C^2}{m^3kg}\right)\left(4\pi\times10^{-7}\,\frac{mkg}{C^2}\right)$$

Valor adoptado: $\boxed{c=299792458\,\frac{m}{s},\ \text{sin incertidumbre.}}$

(XVII Conferencia General de Pesas y Medidas el 21 de octubre de 1983)

EL METRO (1960) Y EL SEGUNDO (1967)

El metro es igual a 1 650 763,73 longitudes de onda en el vacío de la radiación λ = 605,780 211 nm emitida por el ^{86}Kr ($^{36p\,+\,50n}$Kr), con calidad $\Delta\lambda / \lambda = \pm\, 4 \times 10^{-9}$, o $\Delta\lambda / \lambda = 4{:}10^{9}$. (XI CGPM, 1960).

El segundo es igual a la duración de 9 192 631 770 períodos de la radiación correspondiente a la transición entre dos niveles hiperfinos del estado fundamental del átomo de ^{133}Cs ($^{55p\,+\,78n}$Cs), con calidad $\Delta t / t = 1{:}10^{14}$. (XIII CGPM, 1967).

XVII CONFERENCIA GENERAL DE PESAS Y MEDIDAS (21-10-1983) I

Definición:

El metro es la longitud del camino recorrido en el vacío por la luz durante el intervalo de tiempo de 1/299 792 458 de segundo.

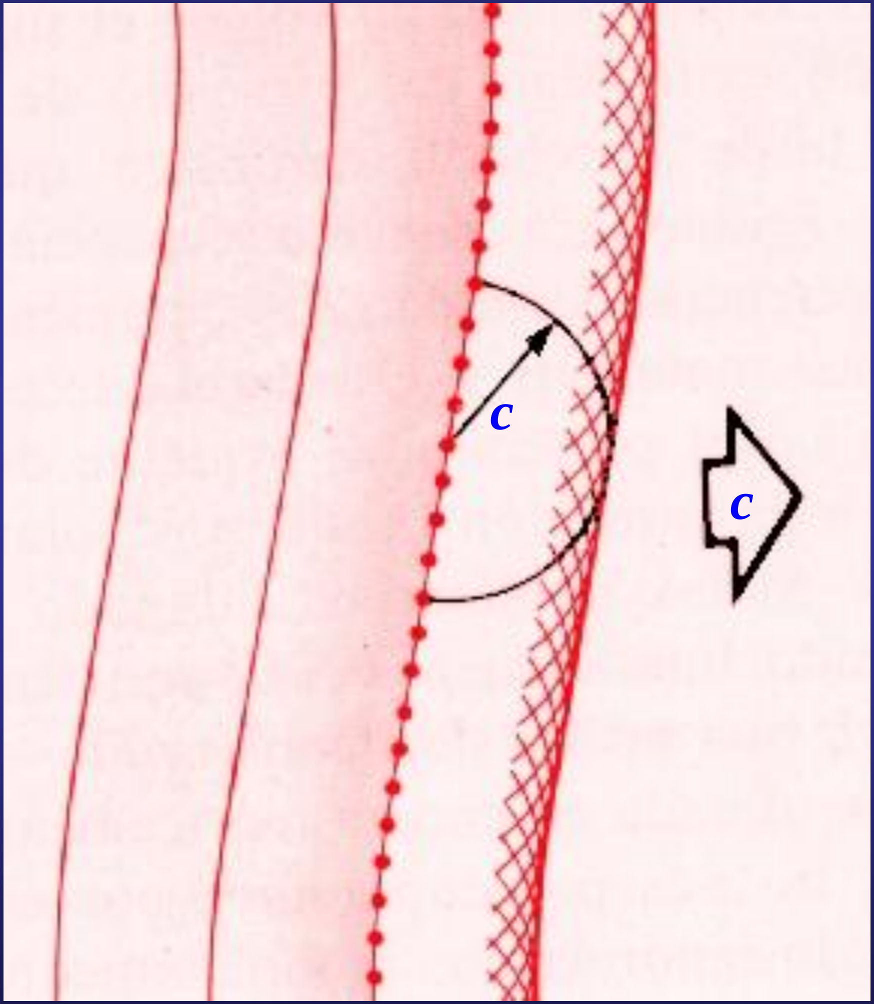
Realización 1: Láser de He-Ne:CH_4

λ_{CH_4} = 3 392 231 397,0 fm ($\Delta\lambda / \lambda = \pm 1,3 \times 10^{-10}$)

ν_{CH_4} = 88 376 181 608 kHz ($\Delta\nu/\nu = \pm 1,3 \times 10^{-10}$)

$c = \lambda_{CH_4} \nu_{CH_4}$ = 299 792 457,997 63 m/s

ONDAS ELECTROMAGNÉTICAS IV



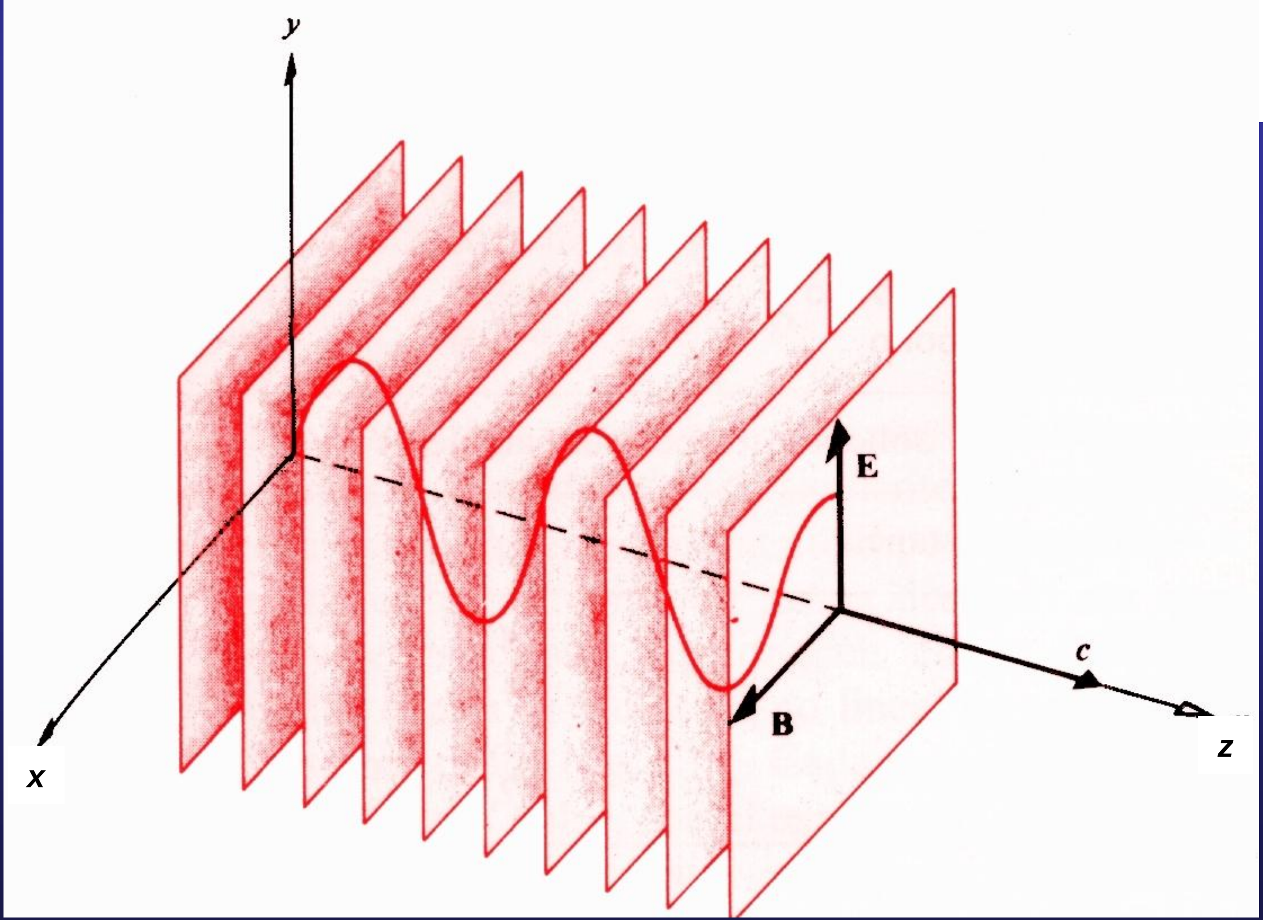
PROPAGACIÓN DE LA LUZ

Principio de Huygens (1678)

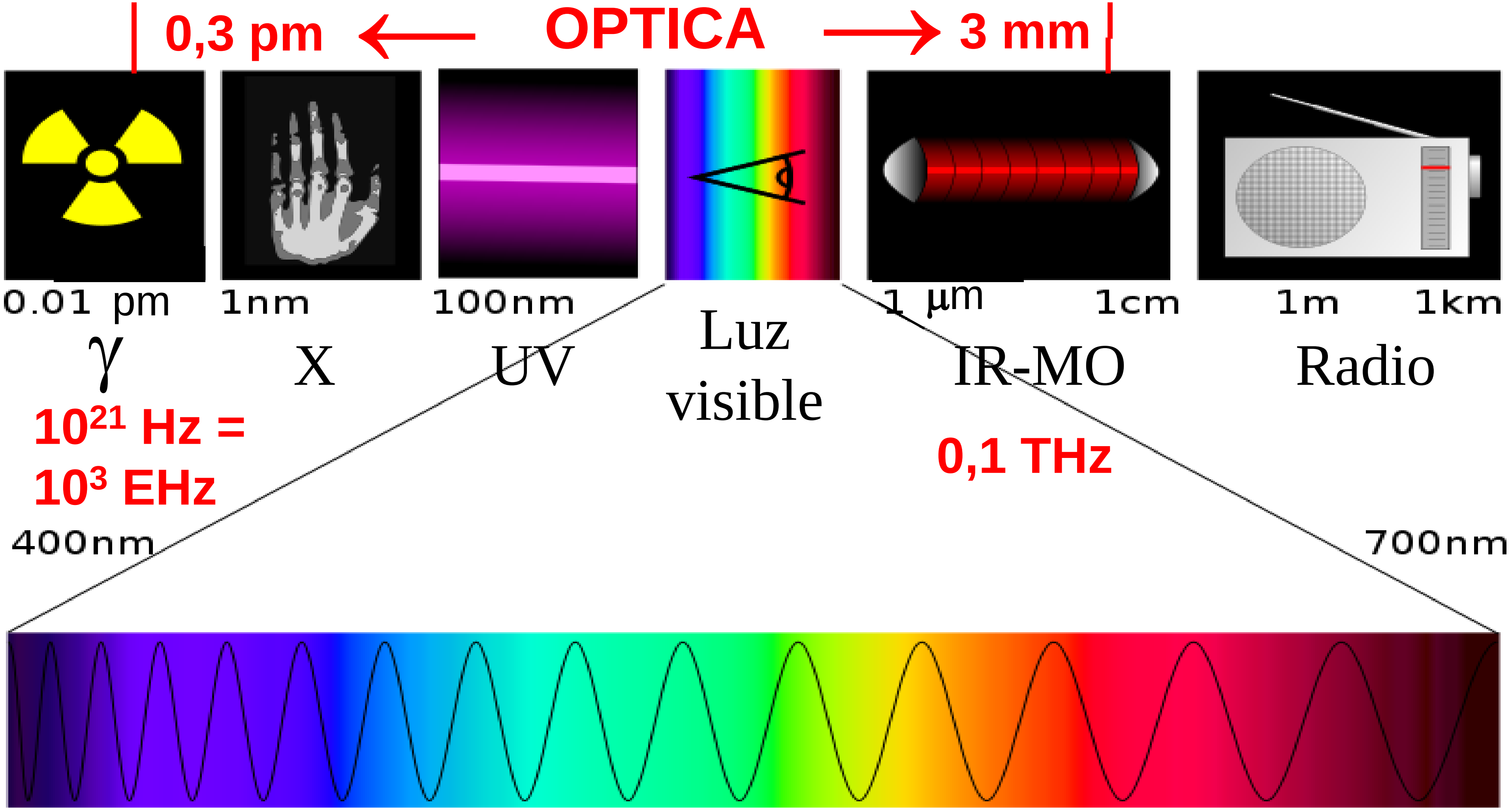
ONDAS ELECTROMAGNÉTICAS V

Ondas planas:

$$E_y(z,t) = E_{0y}\cos\left[\omega\left(t - \frac{z}{c}\right) + \varphi\right]$$



ESPECTRO ELECTROMAGNETICO I



10^{21} Hz = 10^{3} EHz

0,1 THz

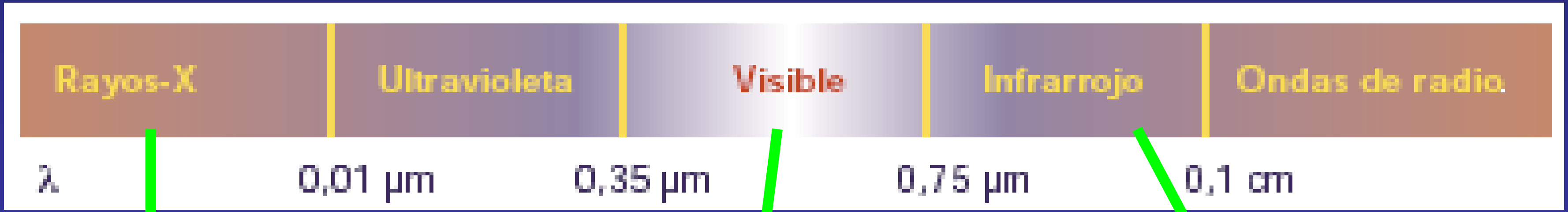
El prefijo **E** se lee Exa (6), y el **T**, Tera.

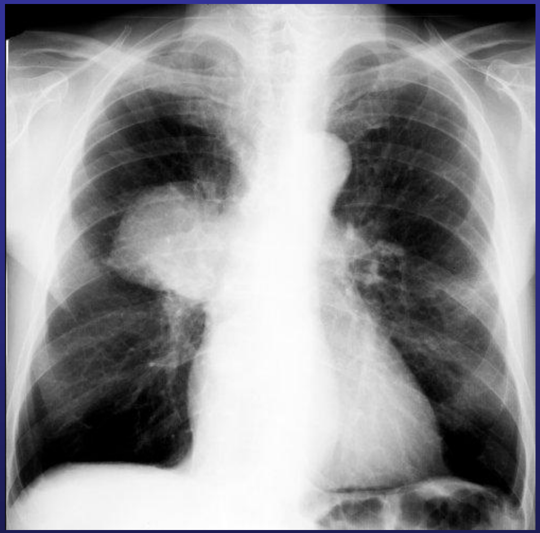
ESPECTRO ELECTROMAGNETICO II

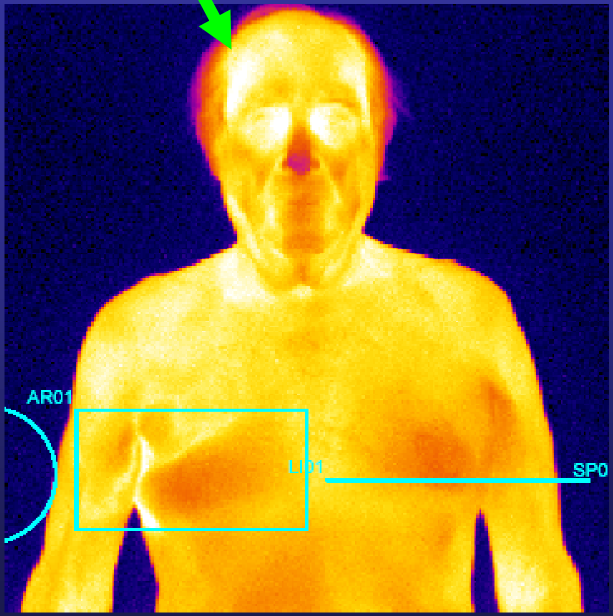
Totalmente Invasivo

No Invasivo, pero ¡cuidado!

No Invasivo







EL ESPECTRO ELECTROMAGNETICO III

Velocidad de la luz en el vacío

$$c = \nu \times \lambda$$

$$c = 299\ 792\ 458 \text{ m/s}$$

Energía de un fotón

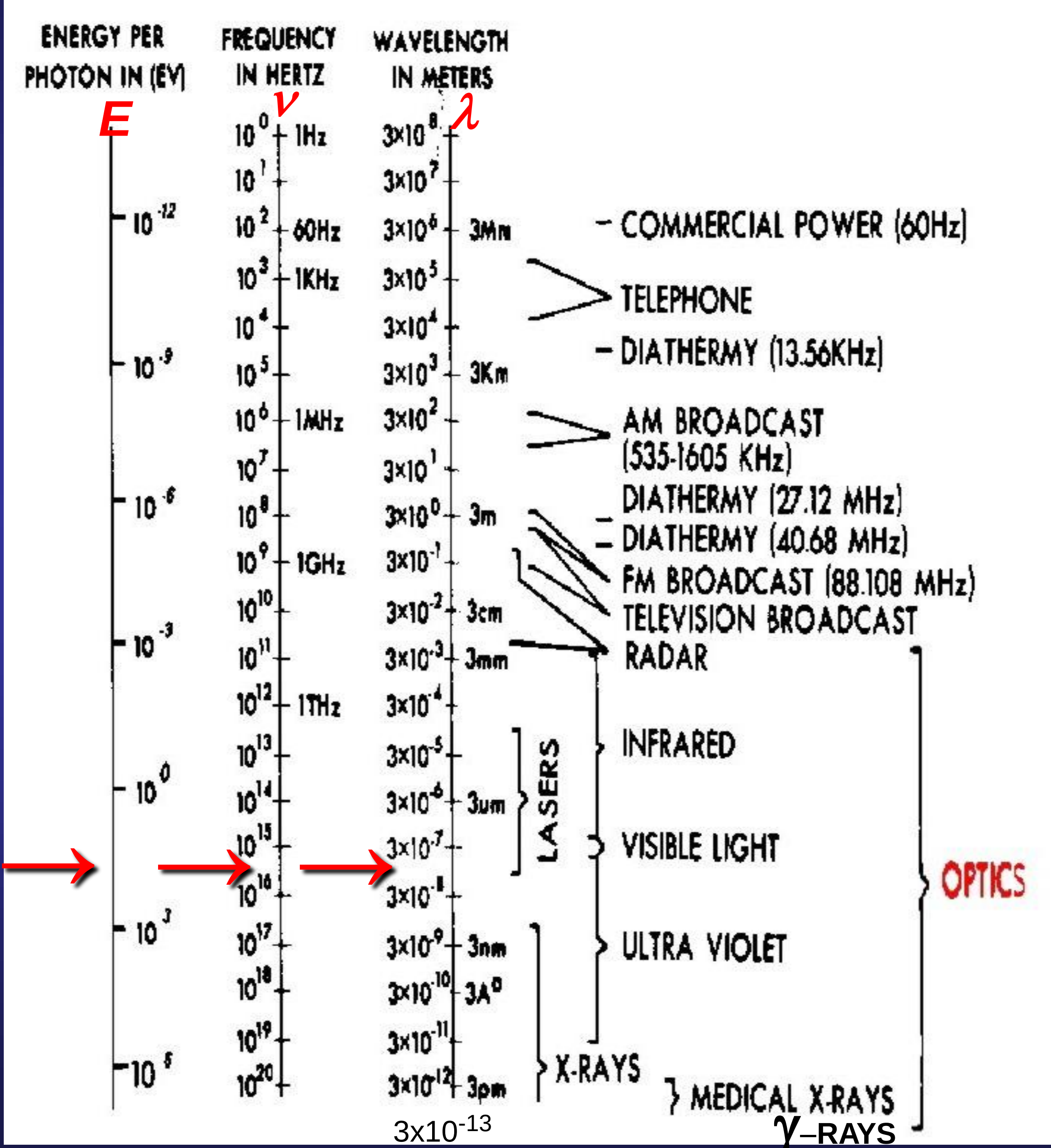
$$E = h \times \nu$$

Constante de Planck

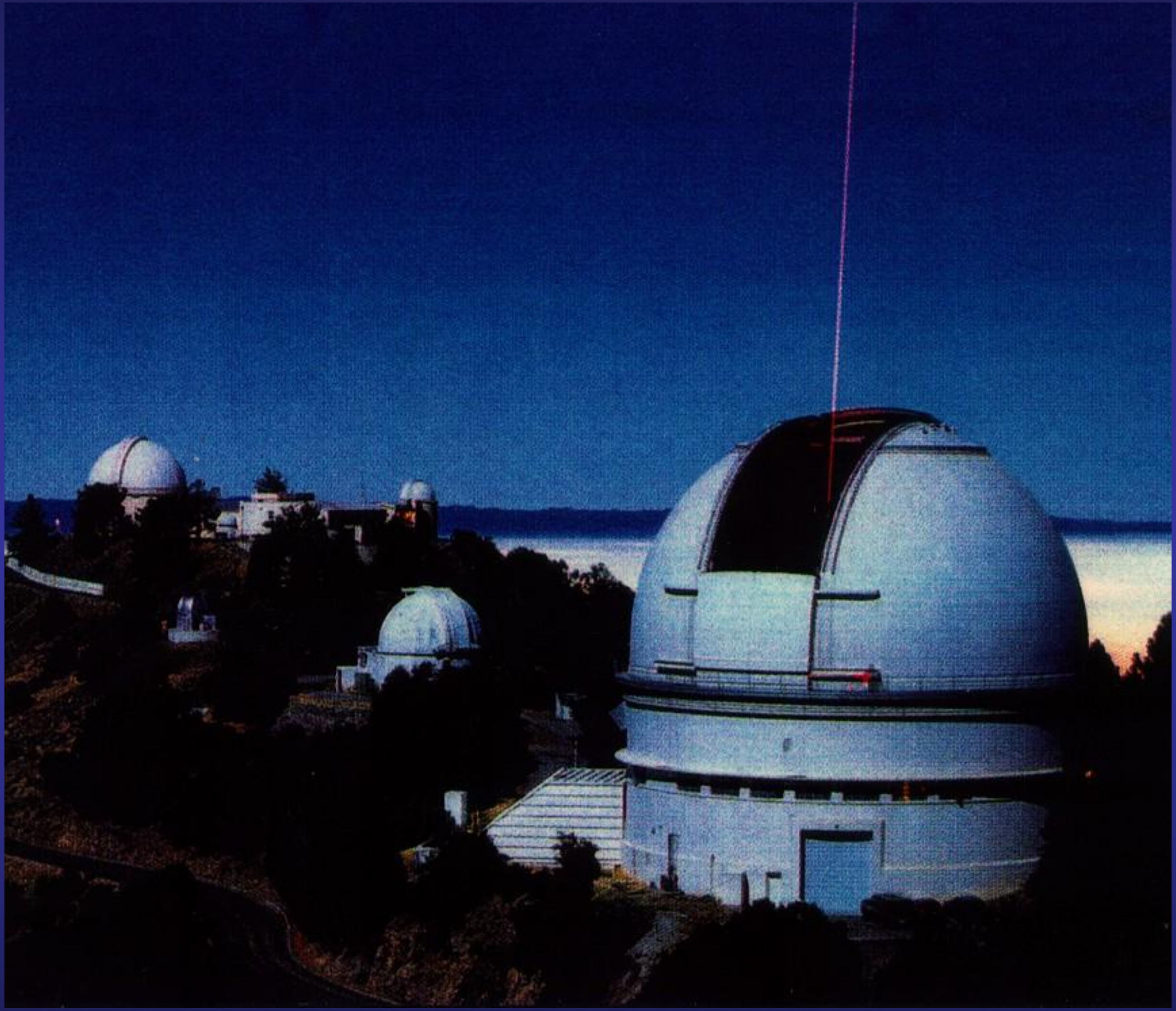
$$h = 6{,}6256 \times 10^{-34} \text{ Js}$$

EJEMPLO:
Láser de EXCIMERO (Ar-F).
λ **= 193 nm**
ν **= 1, 5 x 10^{15} Hz = 1, 5 PHz**
E_{ν} **= 1,03 x 10^{-15} mJ = 1,03 aJ**

P se lee Peta (5), y el **a**, atto (18).

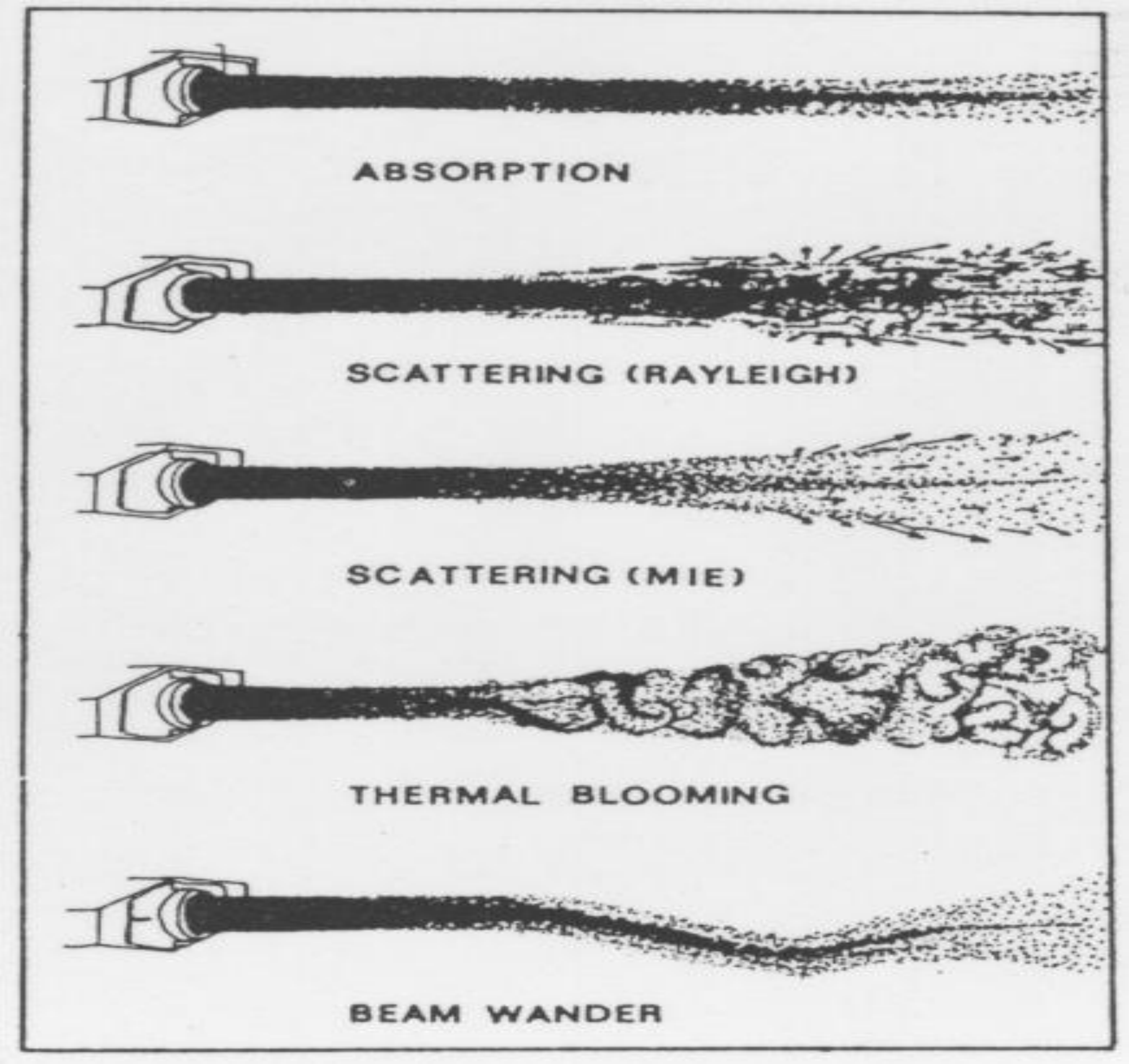


PROPAGACION RECTILINEA DE LA LUZ



Haz láser para adaptar el enfoque de un gran telescopio
(Lick Observatory, Estados Unidos de América del Norte).

PROPAGACION DE UN HAZ LASER EN AIRE ESTACIONARIO Y TURBULENTO



Atenuación del haz por absorción molecular

Dispersión del haz por moléculas

Dispersión del haz por partículas o aerosoles

Distorsión del haz por acción del calor

Bailoteo del haz por acción convectiva

INTENSIDAD DE LA LUZ DIVERGENTE DESDE UNA FUENTE PUNTUAL

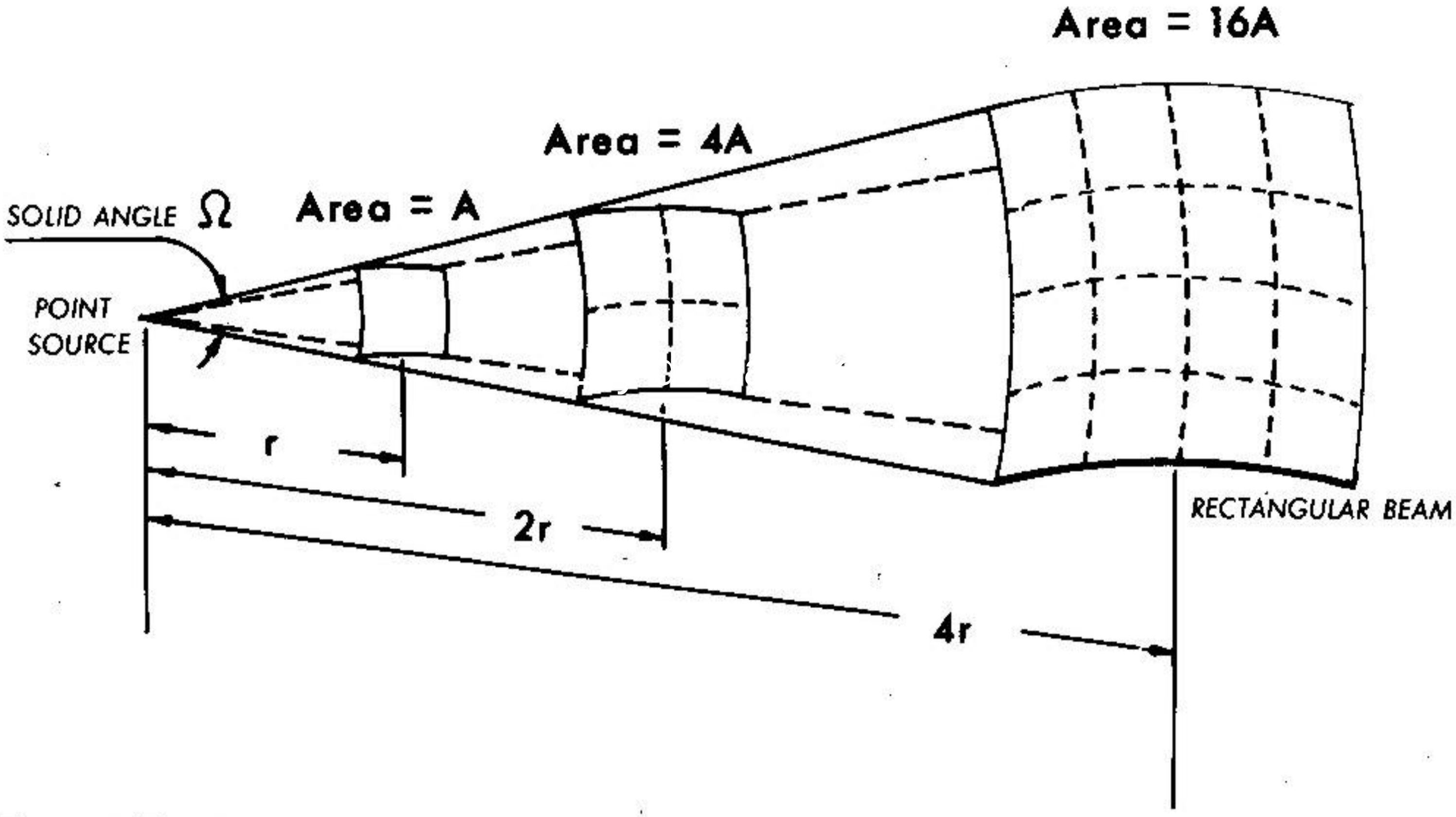


Figure 2-30. The inverse square law can be visualized best by imagining a square beam spreading out from a point source.

Ley de Johann Heinrich Lambert o del inverso del cuadrado de la distancia

SOMBRA Y PROYECCION DE FRANJAS O ILUMINACION ESTRUCTURADA

Proyección de franjas para caracterizar caras

DETERMINACION DE LAS TOPOGRAFÍAS CORNEALES I

Apice corneal: Está en el eje del topógrafo cuando el paciente mira el punto de fijación O.

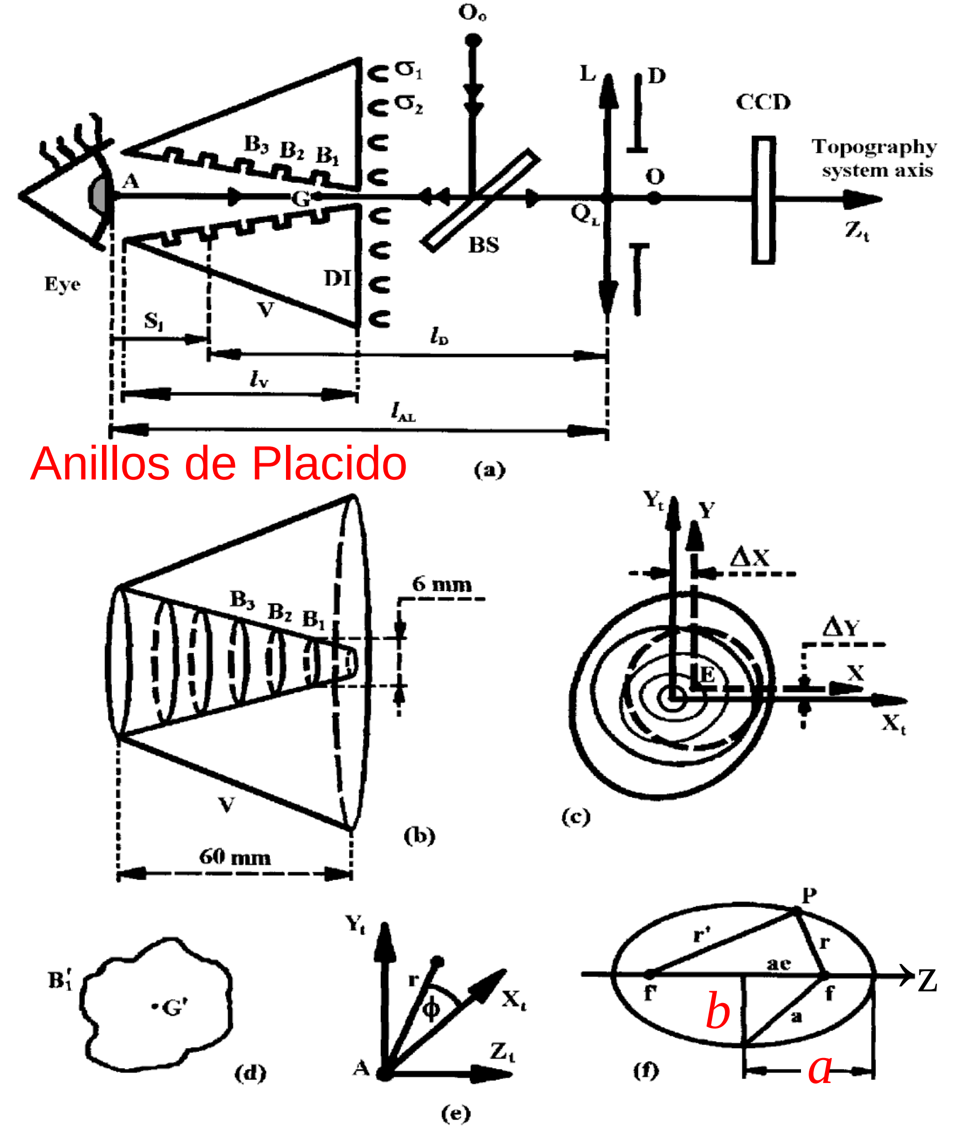
(ΔX, ΔY): Distancia entre el centro pupilar y el ápice.

(r,φ): Coordenadas polares en el topógrafo.

Elipsoide: La córnea puede aproximarse a un casquete elipsoidal de semieje mayor a según z y de semiejes menores b según x e y, tal que:

$$b/a = (1- e^2)^{1/2} ,$$

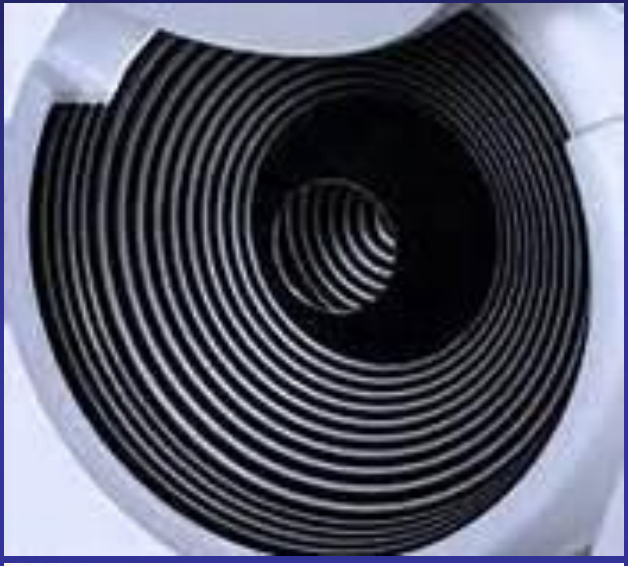
siendo e la excentricidad.

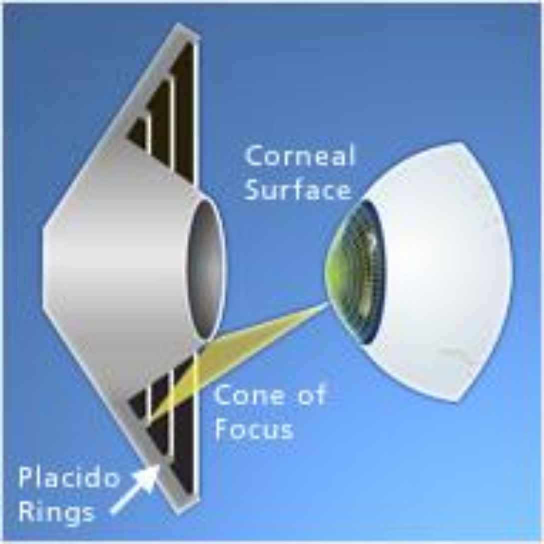


Anillos de Placido

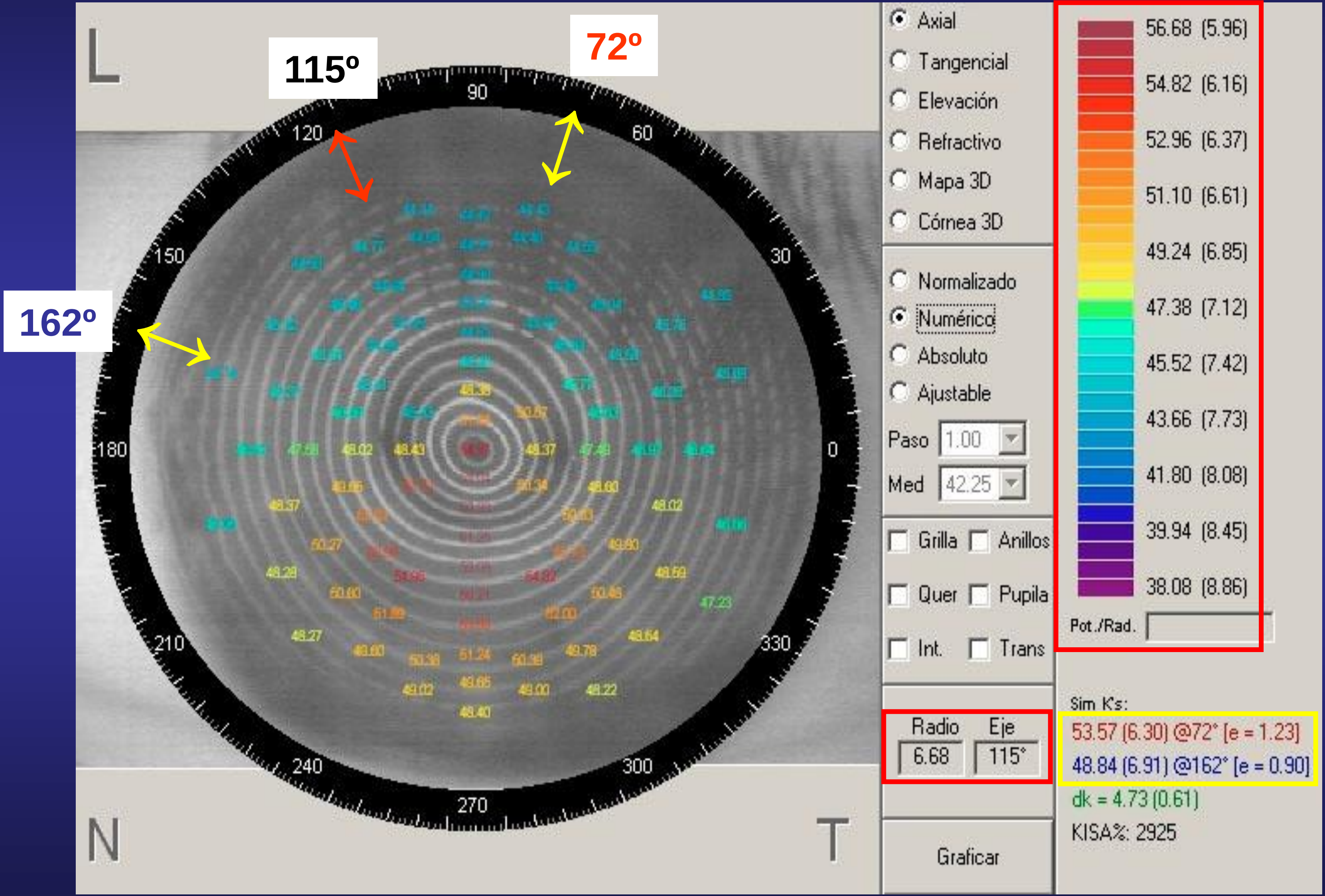
Figure 1 : Corneal Topographer

DETERMINACION DE LAS TOPOGRAFÍAS CORNEALES II





DETERMINACION DE LAS TOPOGRAFÍAS CORNEALES III



● Axial
○ Tangencial
○ Elevación
○ Refractivo
○ Mapa 3D
○ Córnea 3D

○ Normalizado
● Numérico
○ Absoluto
○ Ajustable

Paso 1.00
Med 42.25

☐ Grilla ☐ Anillos
☐ Quer ☐ Pupila
☐ Int. ☐ Trans

Radio	Eje
6.68	115°

Graficar

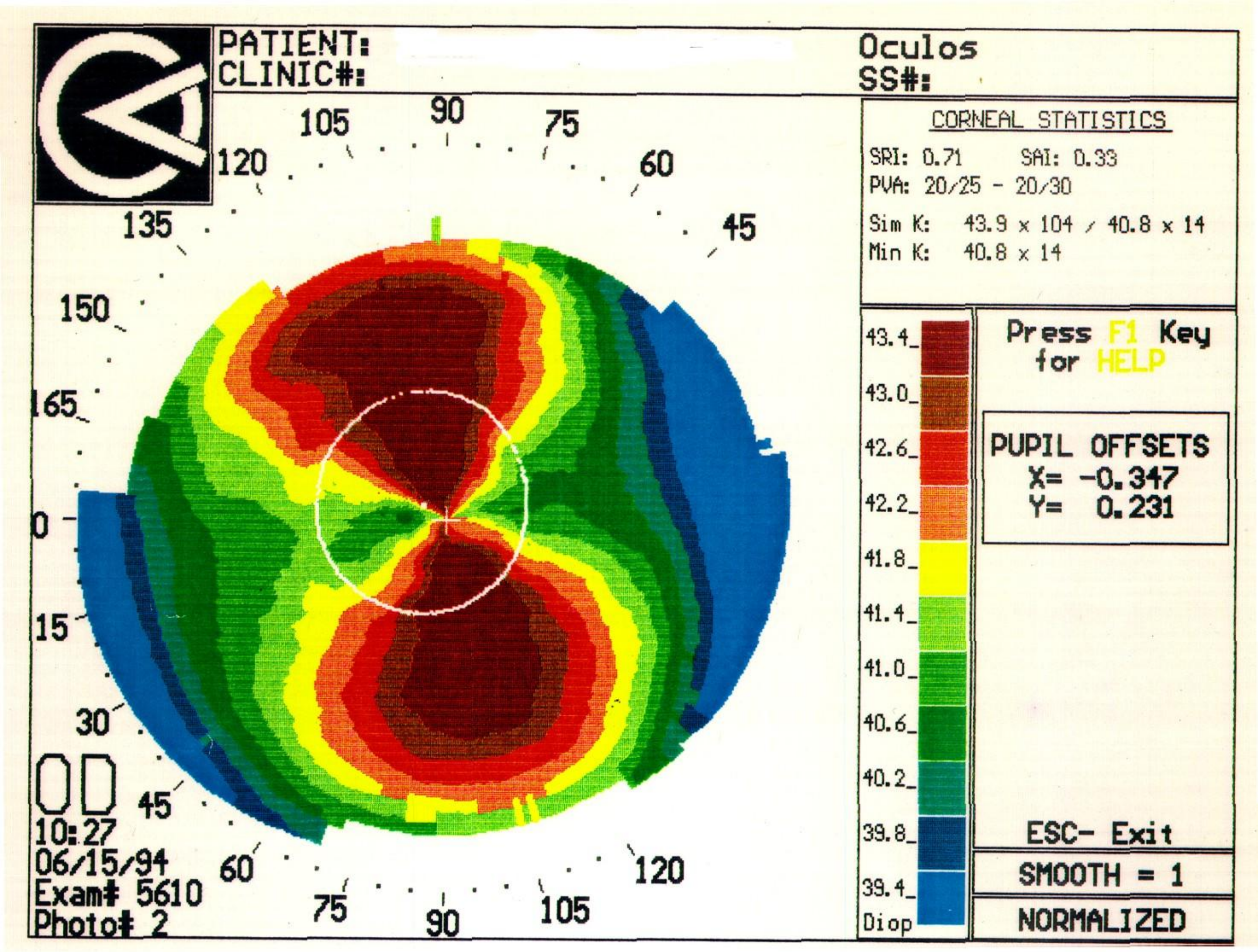
56.68 (5.96)
54.82 (6.16)
52.96 (6.37)
51.10 (6.61)
49.24 (6.85)
47.38 (7.12)
45.52 (7.42)
43.66 (7.73)
41.80 (8.08)
39.94 (8.45)
38.08 (8.86)

Pot./Rad.

Sim K's:
53.57 (6.30) @72° [e = 1.23]
48.84 (6.91) @162° [e = 0.90]
dk = 4.73 (0.61)
KISA%: 2925

Aplicación del Sistema de Anillos de Placido

DETERMINACION DE LAS TOPOGRAFÍAS CORNEALES IV



PATIENT: [redacted]
CLINIC#:

Oculos
SS#:

CORNEAL STATISTICS

SRI: 0.71 SAI: 0.33
PVA: 20/25 - 20/30
Sim K: 43.9 x 104 / 40.8 x 14
Min K: 40.8 x 14

43.4
43.0
42.6
42.2
41.8
41.4
41.0
40.6
40.2
39.8
39.4
Diop

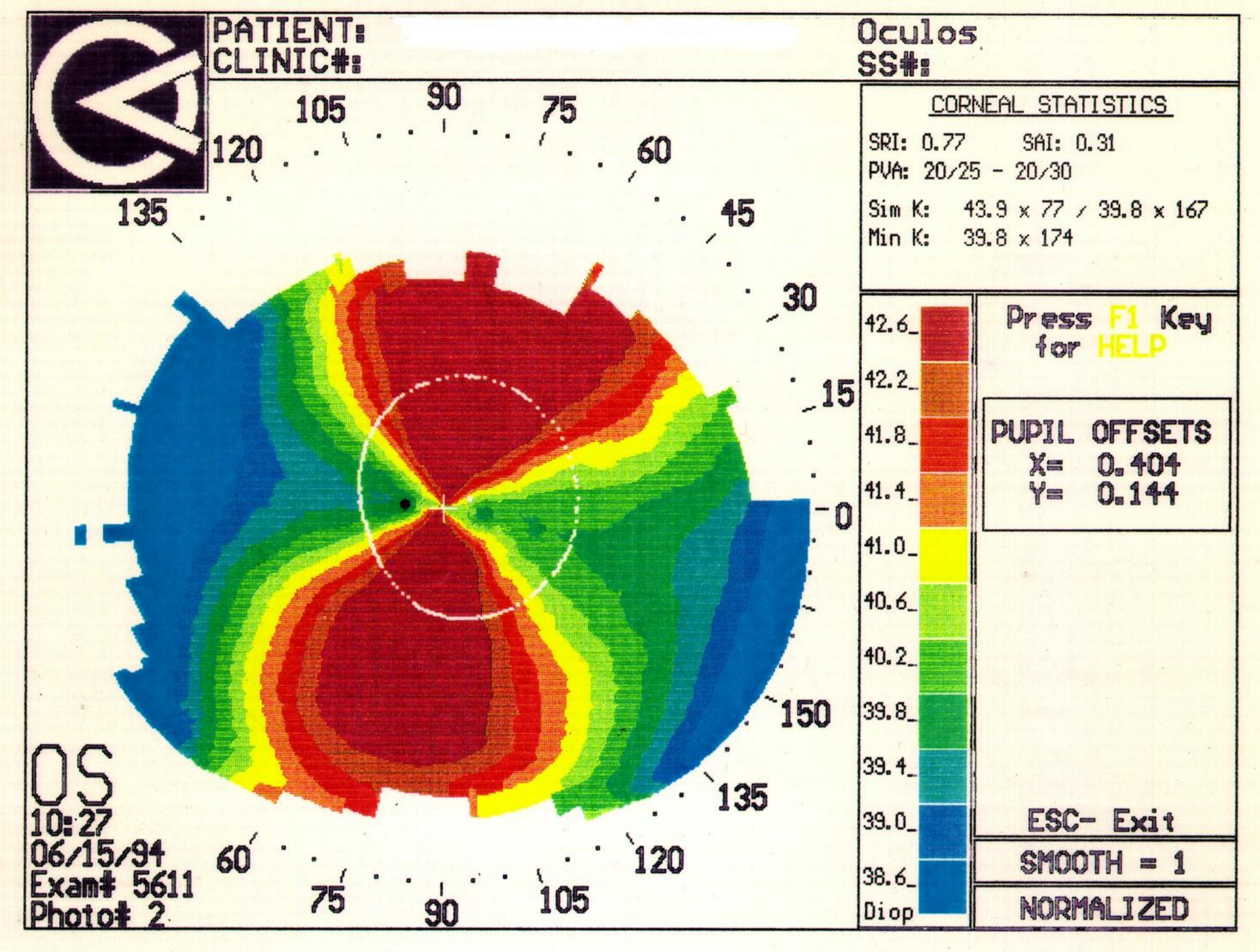
Press F1 Key
for HELP

PUPIL OFFSETS
X= -0.347
Y= 0.231

ESC- Exit
SMOOTH = 1
NORMALIZED

OD
10:27
06/15/94
Exam# 5610
Photo# 2

DETERMINACION DE LAS TOPOGRAFÍAS CORNEALES V



PATIENT: [redacted]
CLINIC#:

Oculos
SS#:

CORNEAL STATISTICS

SRI: 0.77 SAI: 0.31
PVA: 20/25 - 20/30
Sim K: 43.9 x 77 / 39.8 x 167
Min K: 39.8 x 174

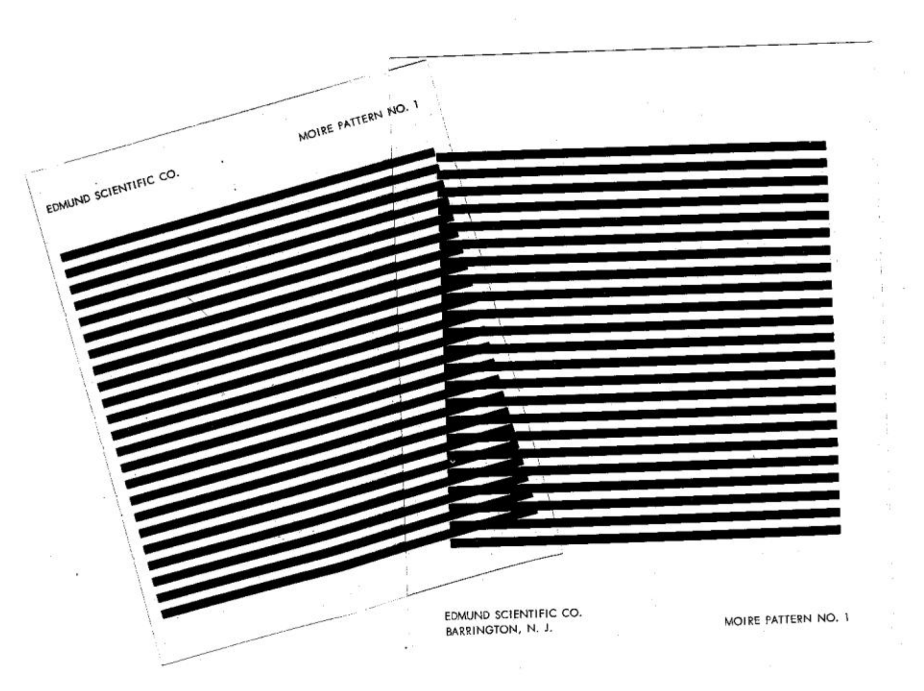
Press F1 Key for HELP

PUPIL OFFSETS
X= 0.404
Y= 0.144

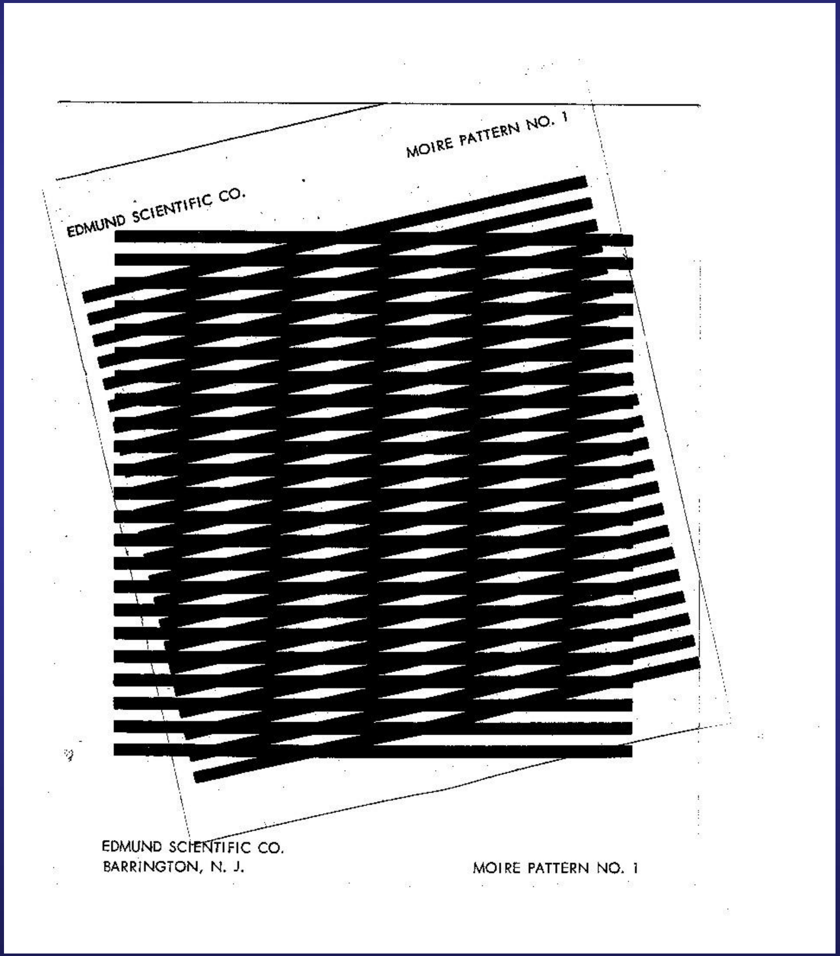
OS
10:27
06/15/94
Exam# 5611
Photo# 2

ESC- Exit
SMOOTH = 1
NORMALIZED

EFECTO *MOIRÉ* II

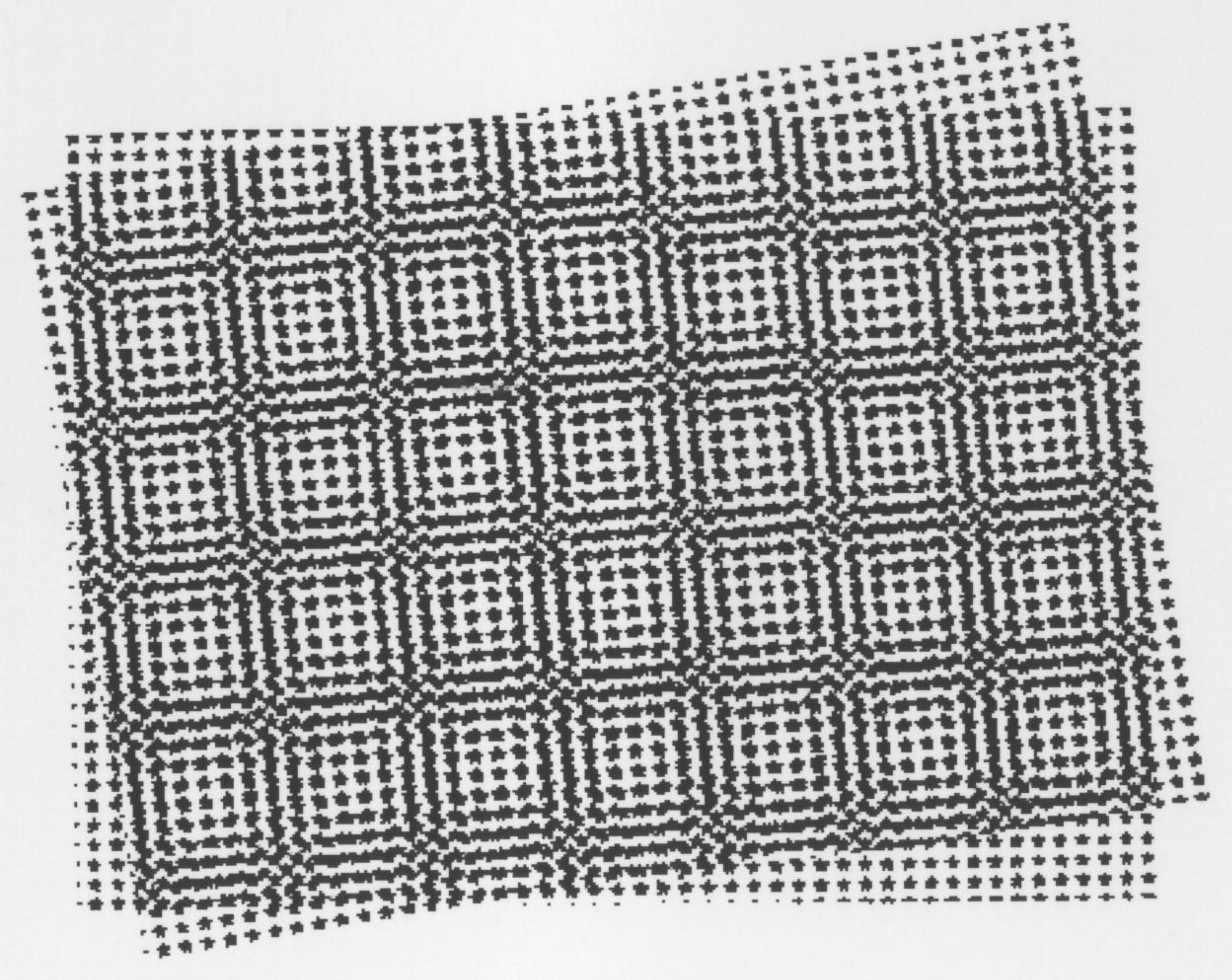


Grillas de Ronchi 1D de igual periodo superponiéndose



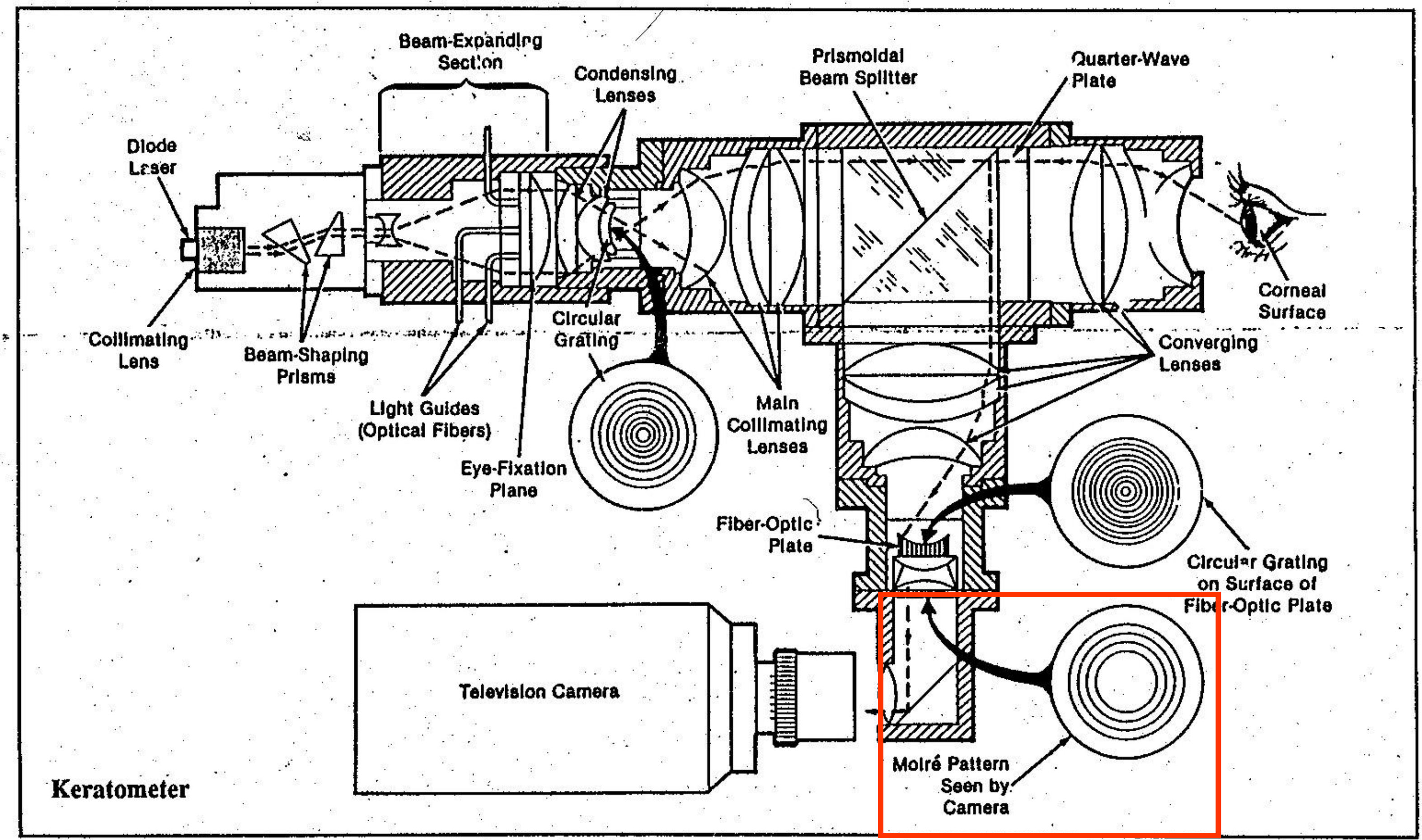
Franjas de *moiré* por superposición de grillas de Ronchi

EFECTO *MOIRÉ* III



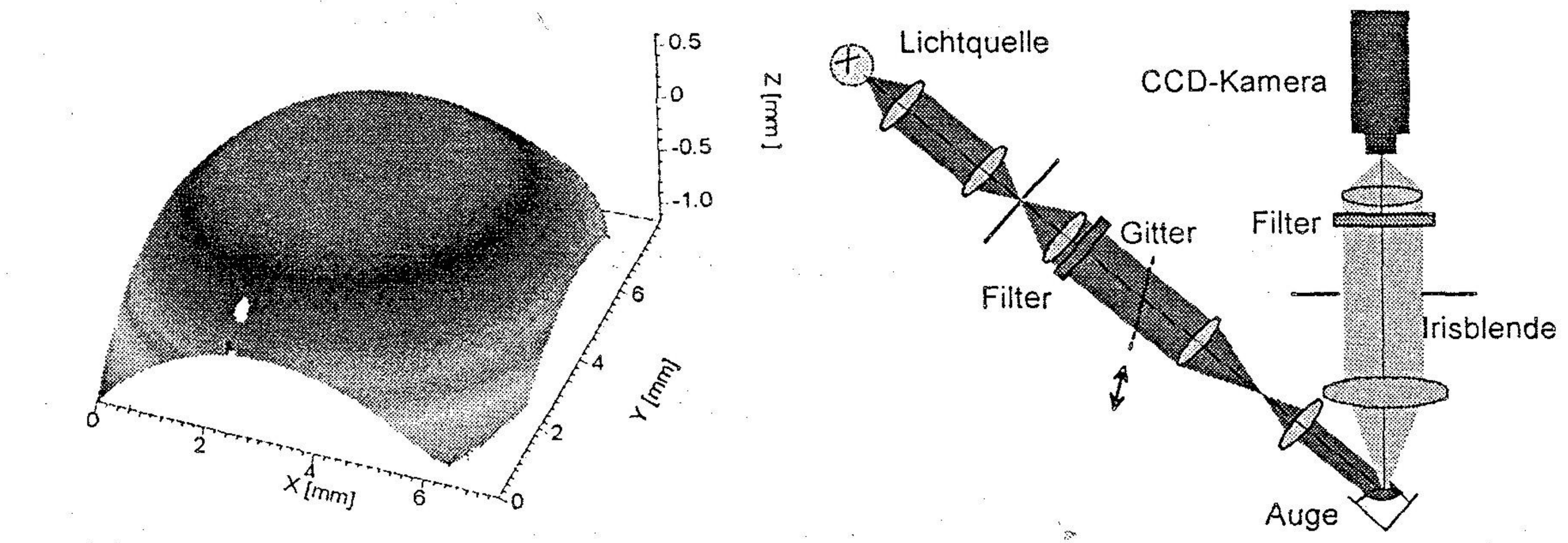
Dos arreglos 2D de puntos del mismo período p.

DETERMINACIÓN DE TOPOGRAFÍAS CORNEALES DE ASTRONAUTAS



J.P.L., Pasadena, 1.988.

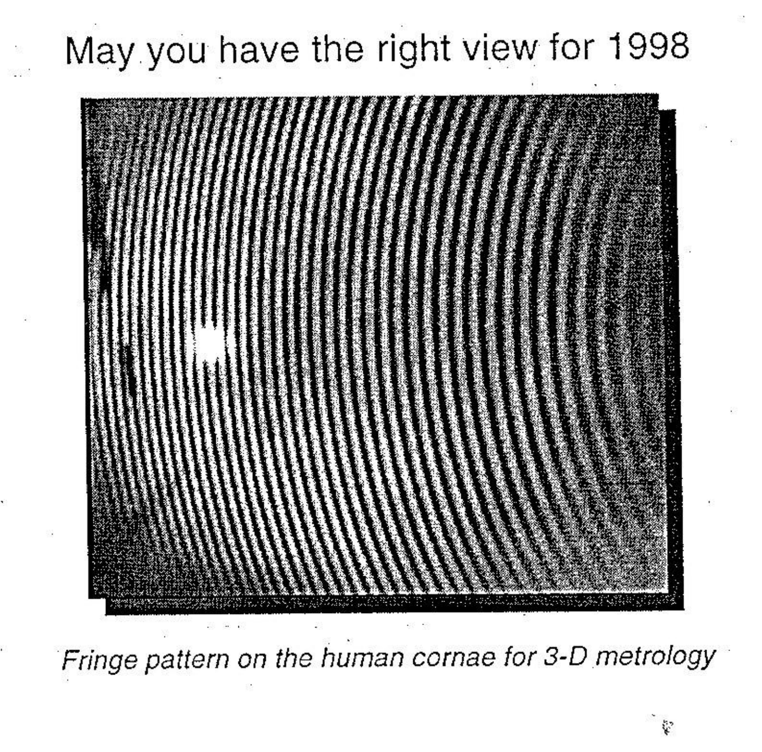
DETERMINACION CLINICA DE TOPOGRAFIAS CORNEALES I



Left: In vivo measured 3-D topography of the human cornea

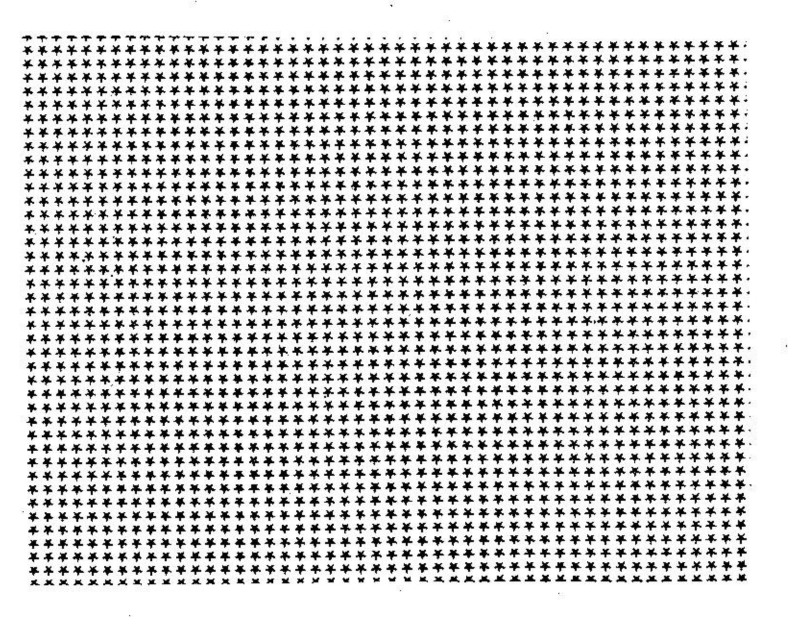
Right: Schematic experimental setup using fringe projection technique

DETERMINACION CLINICA DE TOPOGRAFIAS CORNEALES II


May you have the right view for 1998

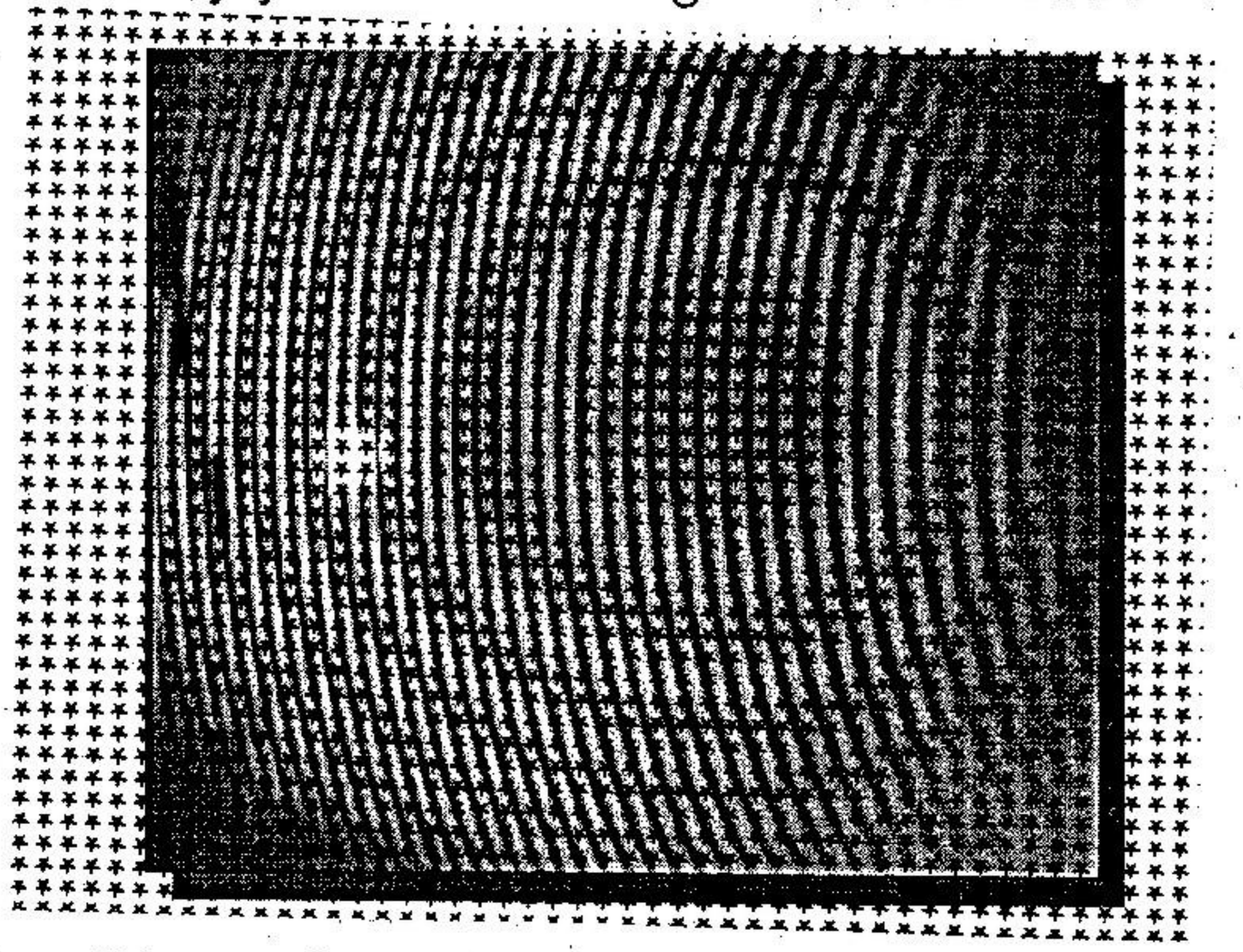
Fringe pattern on the human cornae for 3-D metrology

Observación de las franjas proyectadas sobre la superficie de la córnea


Grillas bidimensional de puntos

DETERMINACION CLINICA DE TOPOGRAFIAS CORNEALES III

May you have the right view for 1998



Fringe pattern on the human cornae for 3-D metrology

OJO DERECHO ANATOMICO

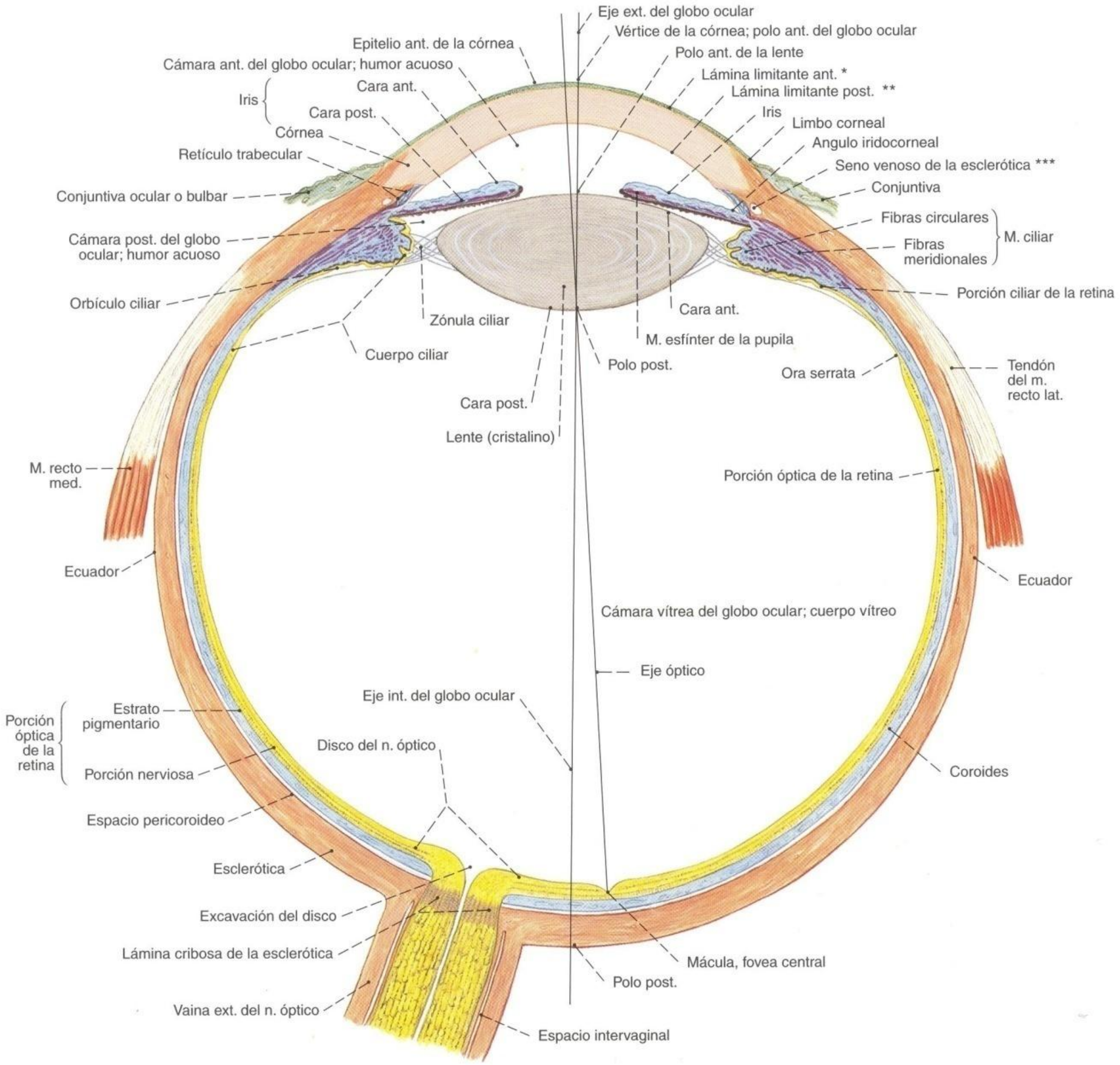
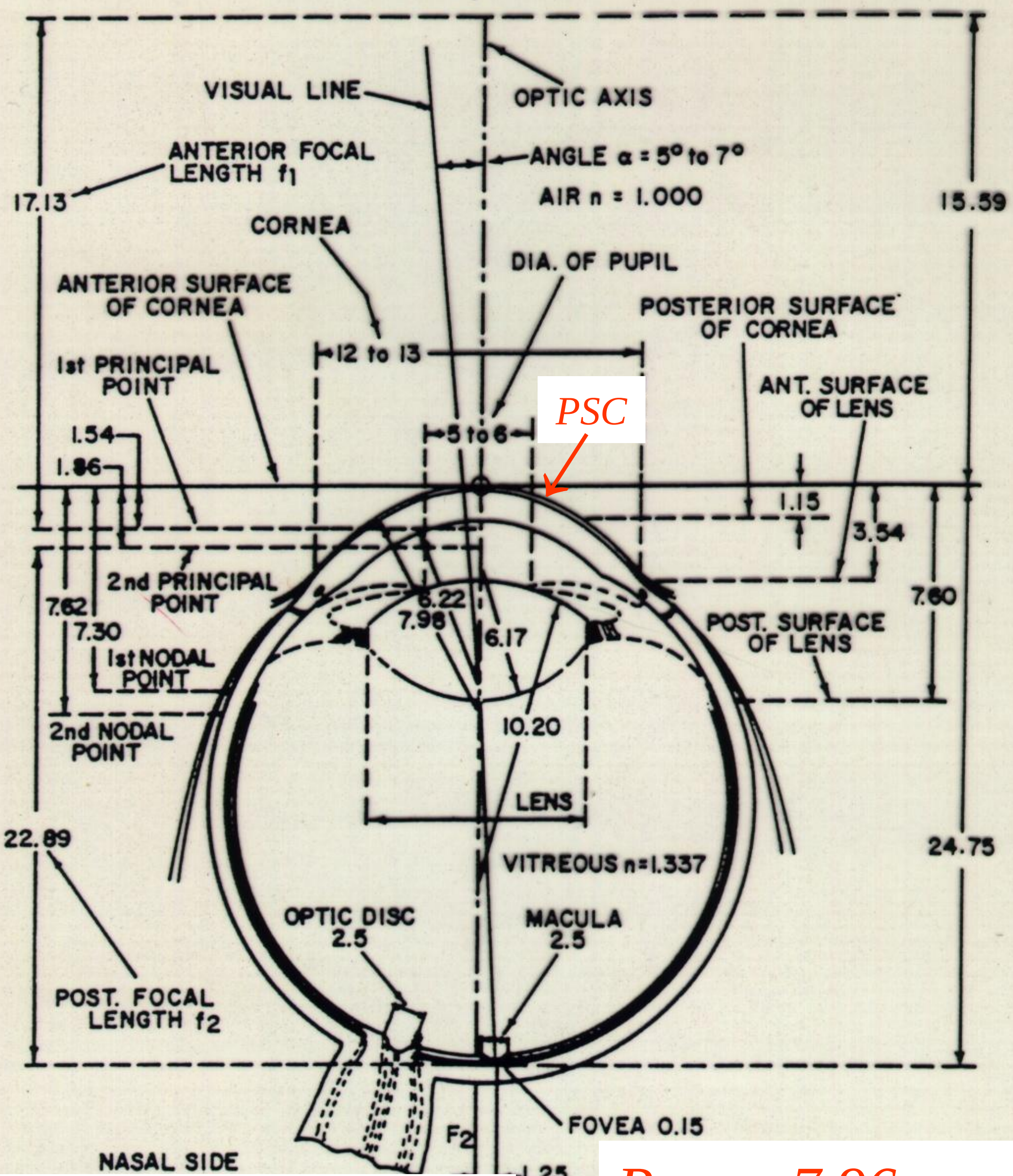


Fig. 633 Corte horizontal esquemático del globo ocular al nivel de la salida del nervio óptico.

* Epónimo clínico: membrana de Bowman
** Epónimo clínico: membrana de Descemet
*** Epónimo clínico: conducto de Schlemm

Ojo Derecho Standard



PSC : Primera Superficie de la Córnea

$R_{PSC} = 7{,}96$ mm

Figure B-1. Optical Constants For A "Standard Right Eye." Adapted from "Optical Design," MIL-HDBK-141, US Defense Department, 5 October 1962.

$n_{Aire} = 1{,}000$

$n_{Córnea} = 1{,}376$

$n_{H.\,A.} = 1{,}336$

$n_{C.\,Núcleo} = 1{,}406$

$n_{C.Polos} = 1{,}386$

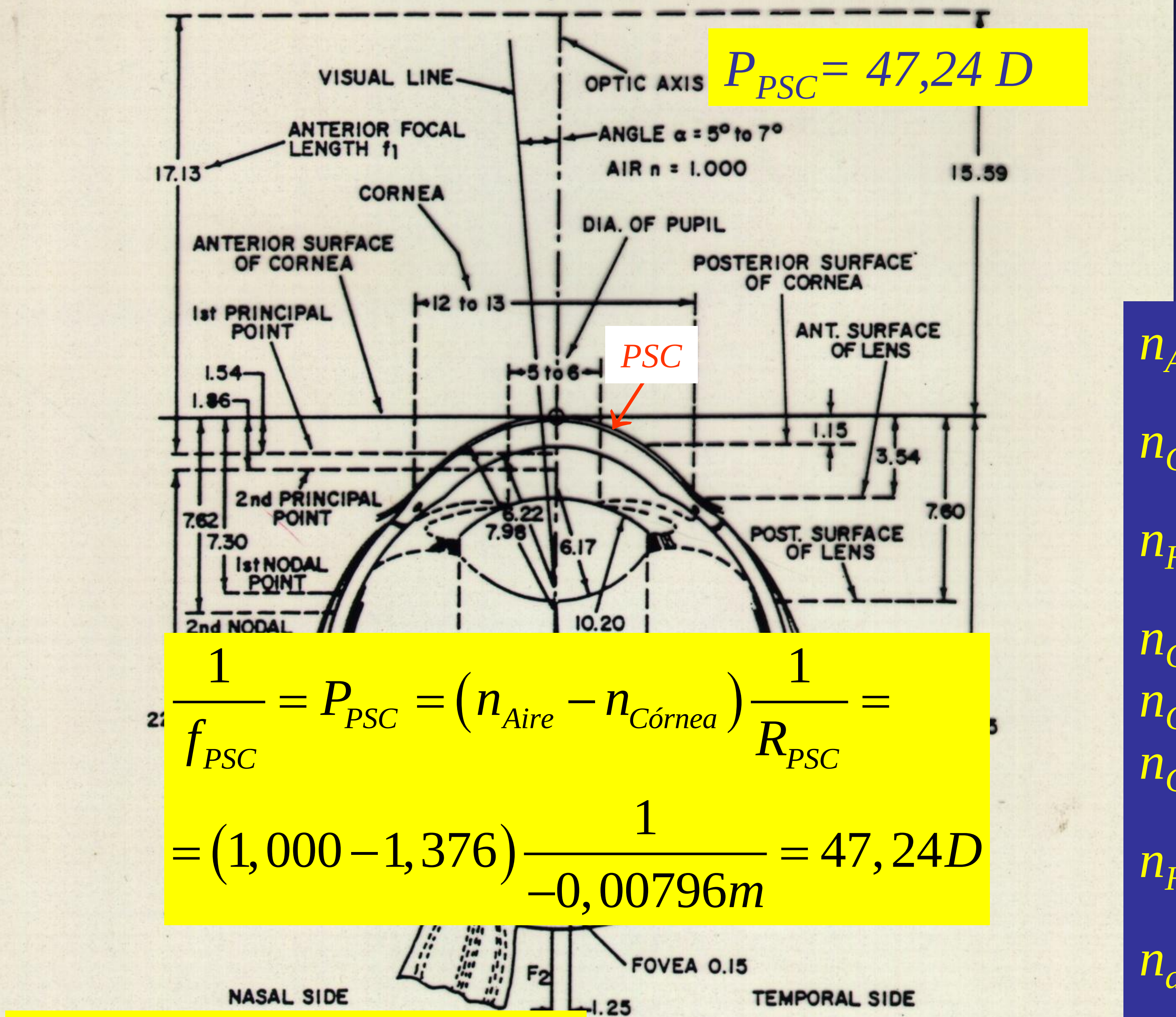
$n_{C.Ecuador} = 1{,}375$

$n_{C.Cápsula} = 1{,}360$

$n_{H.V.} = 1{,}337$

$n_{agua} = 1{,}333$

Ojo Derecho Standard



P_{PSC}= 47,24 D

PSC

$$\frac{1}{f_{PSC}} = P_{PSC} = \left(n_{Aire} - n_{\text{Córnea}}\right)\frac{1}{R_{PSC}} =$$

$$= (1,000 - 1,376)\frac{1}{-0,00796m} = 47,24D$$

PSC : Primera Superficie de la Córnea

Figure B-1. Optical Constants For A "Standard Right Eye." Adapted from "Optical Design," MIL-HDBK-141, US Defense Department, 5 October 1962.

n_{Aire} = 1,000

$n_{\text{Córnea}}$ = 1,376

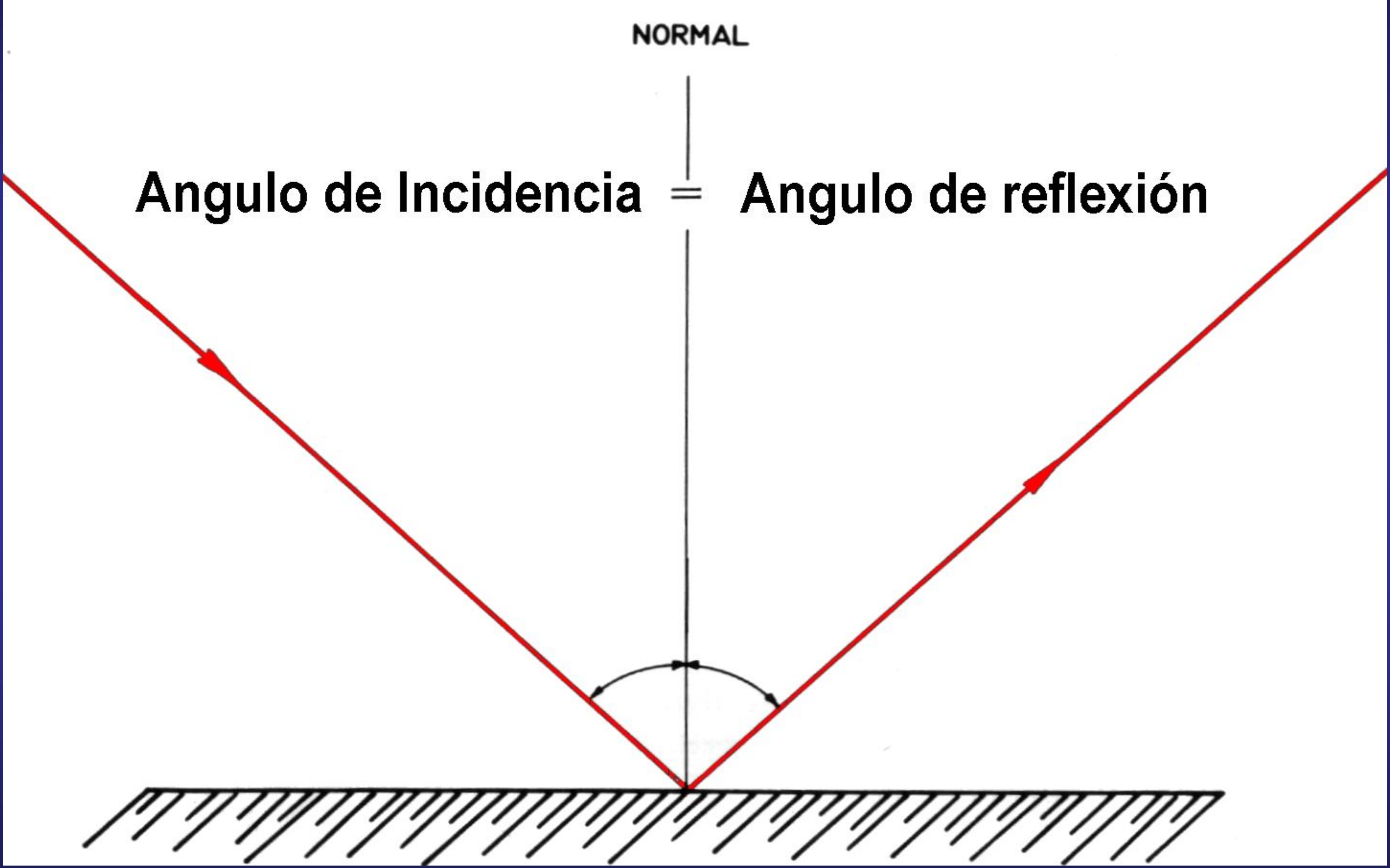
$n_{H.\ A.}$ = 1,336

$n_{C.\ \text{Núcleo}}$ = 1,406
$n_{C.Polos}$ = 1,386
$n_{C.Ecuador}$ = 1,375

$n_{H.V.}$ = 1,337

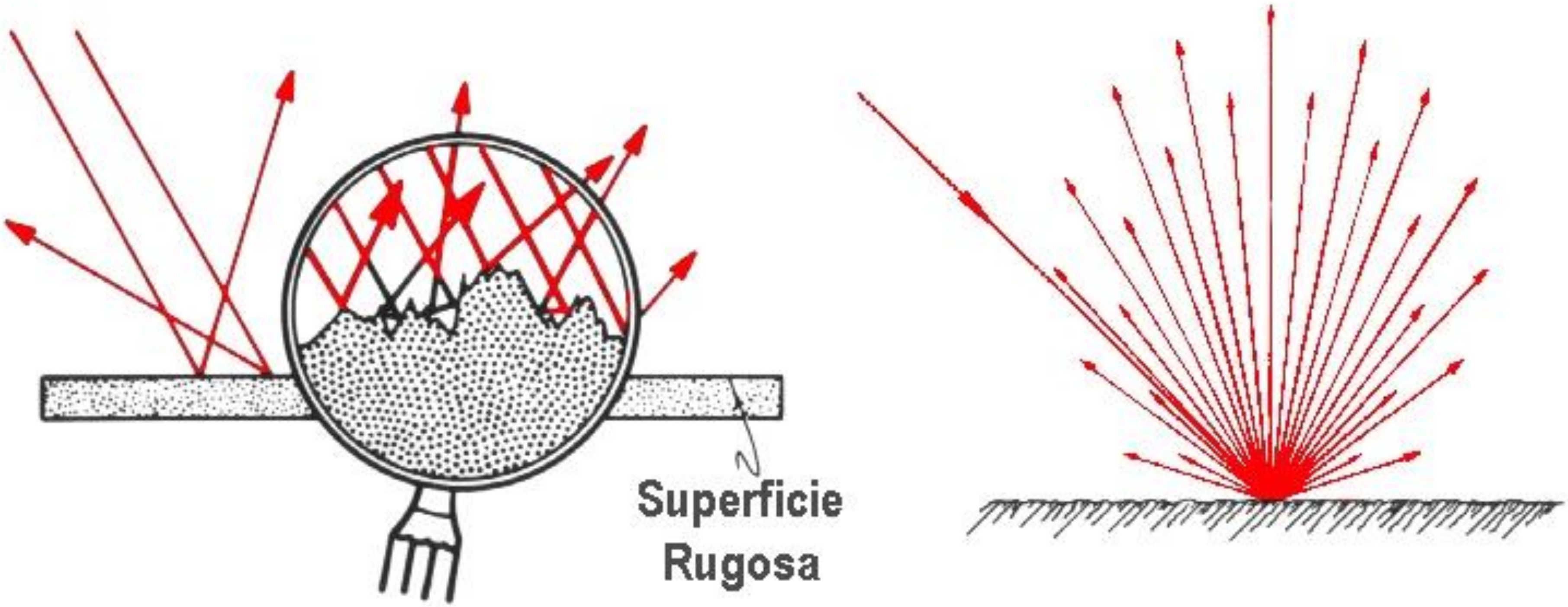
n_{agua} = 1,333

REFLEXION DE LA LUZ I



Ley de la Reflexión Especular

REFLEXION DE LA LUZ II



Ley de la Reflexión Difusa o de Reflexión Especular Local

SUPERFICIES NATURALES DE ALTÍSIMA CALIDAD

Ruby Mica de alta calidad (Rugosidad media 0,073 nm).

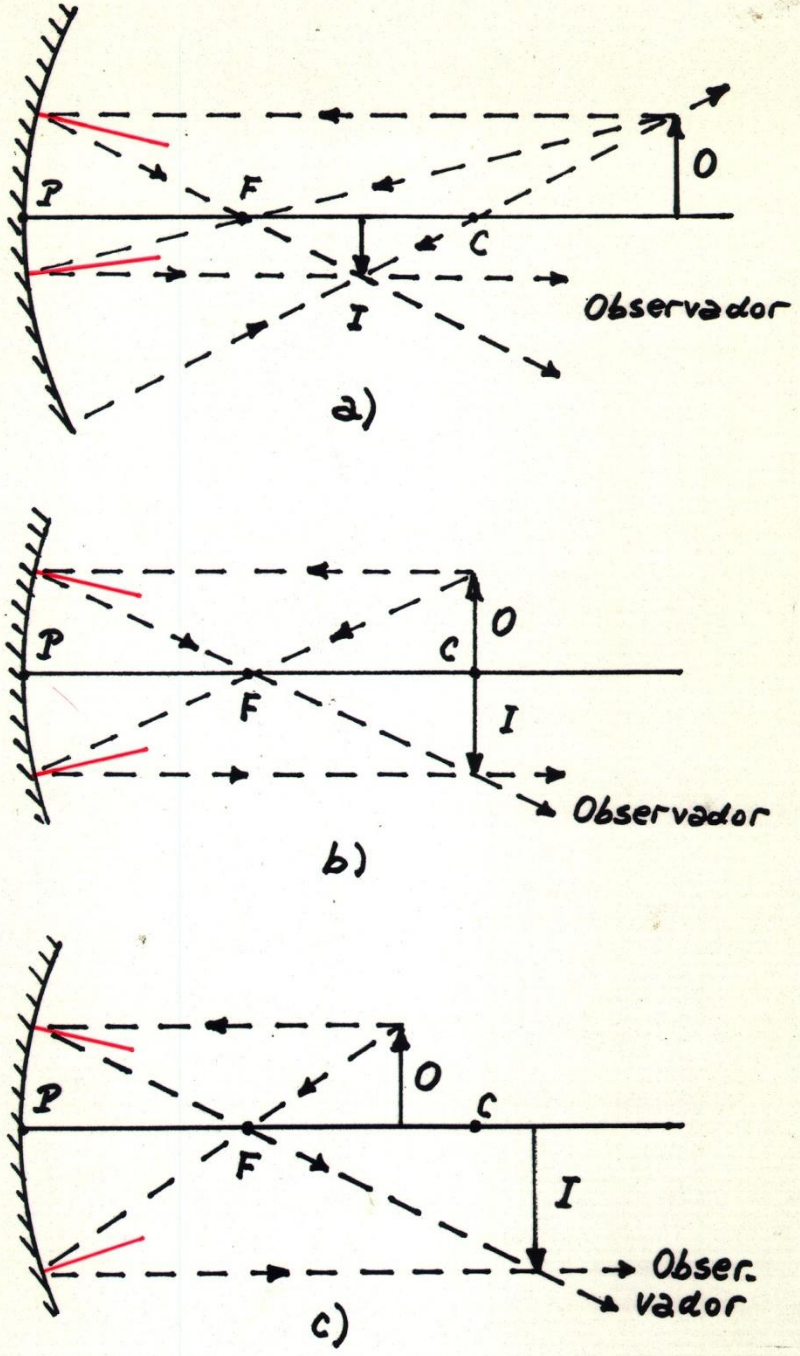


Figura 1

FORMACION DE IMAGENES POR UN ESPEJO CONCAVO. TODAS LAS IMAGENES SON REALES E INVERTIDAS.

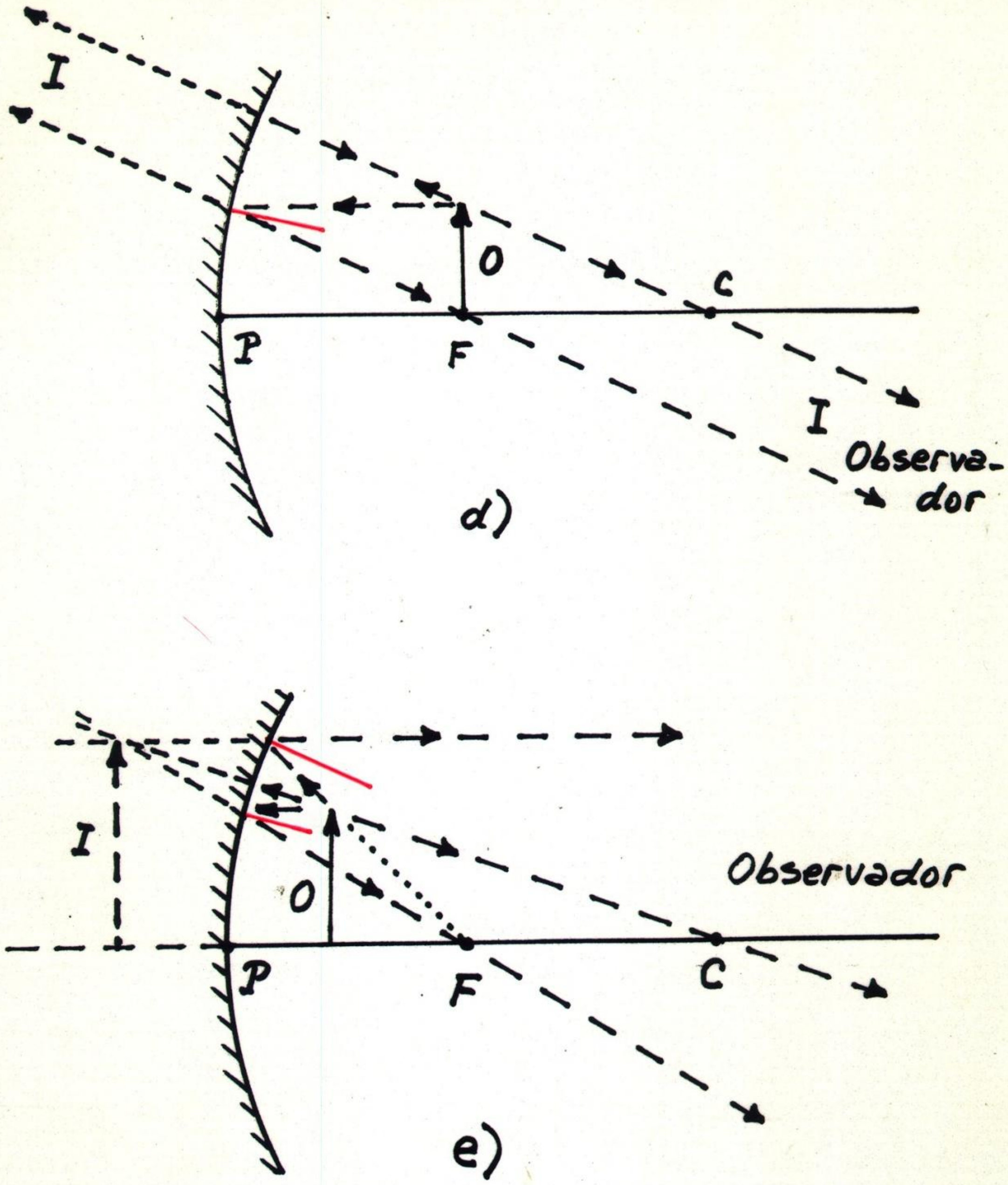
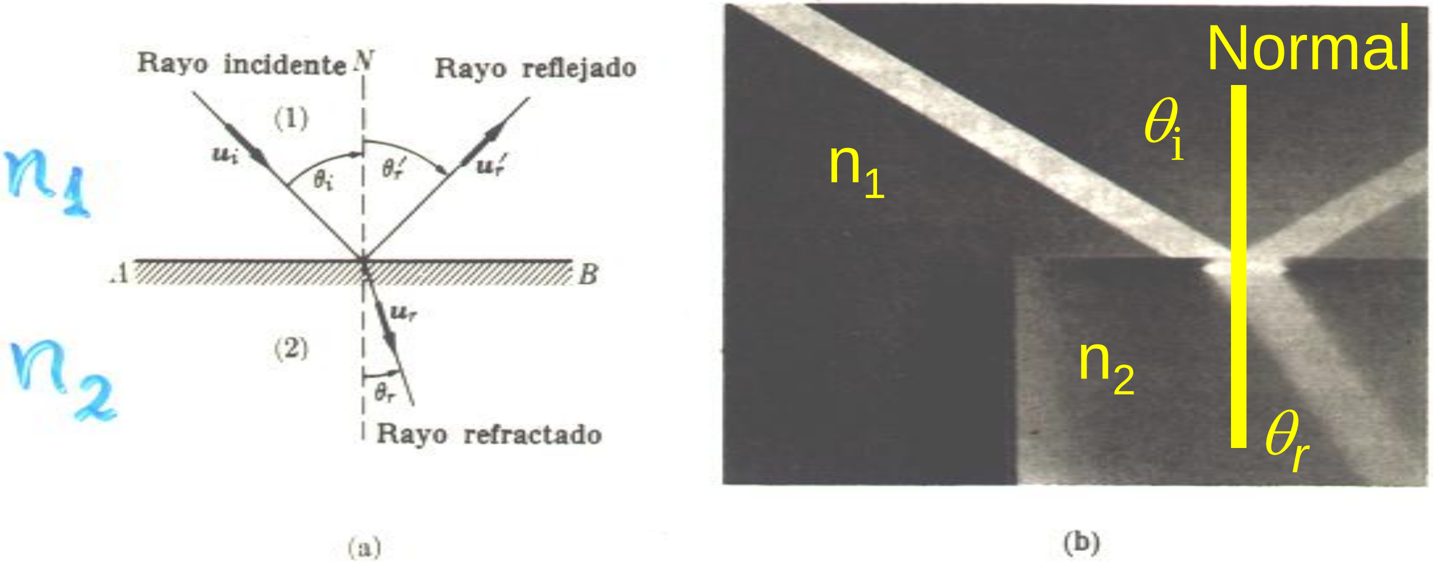


Figura 1

FORMACION DE IMAGENES POR UN ESPEJO CONCAVO.

EN *d)* SE SUPERPONE LA IMAGEN REAL E INVERTIDA CON LA VIRTUAL Y DERECHA. EN *e)* LA IMAGEN ES VIRTUAL Y DERECHA.

REFRACCION EN UNA INTERFAZ

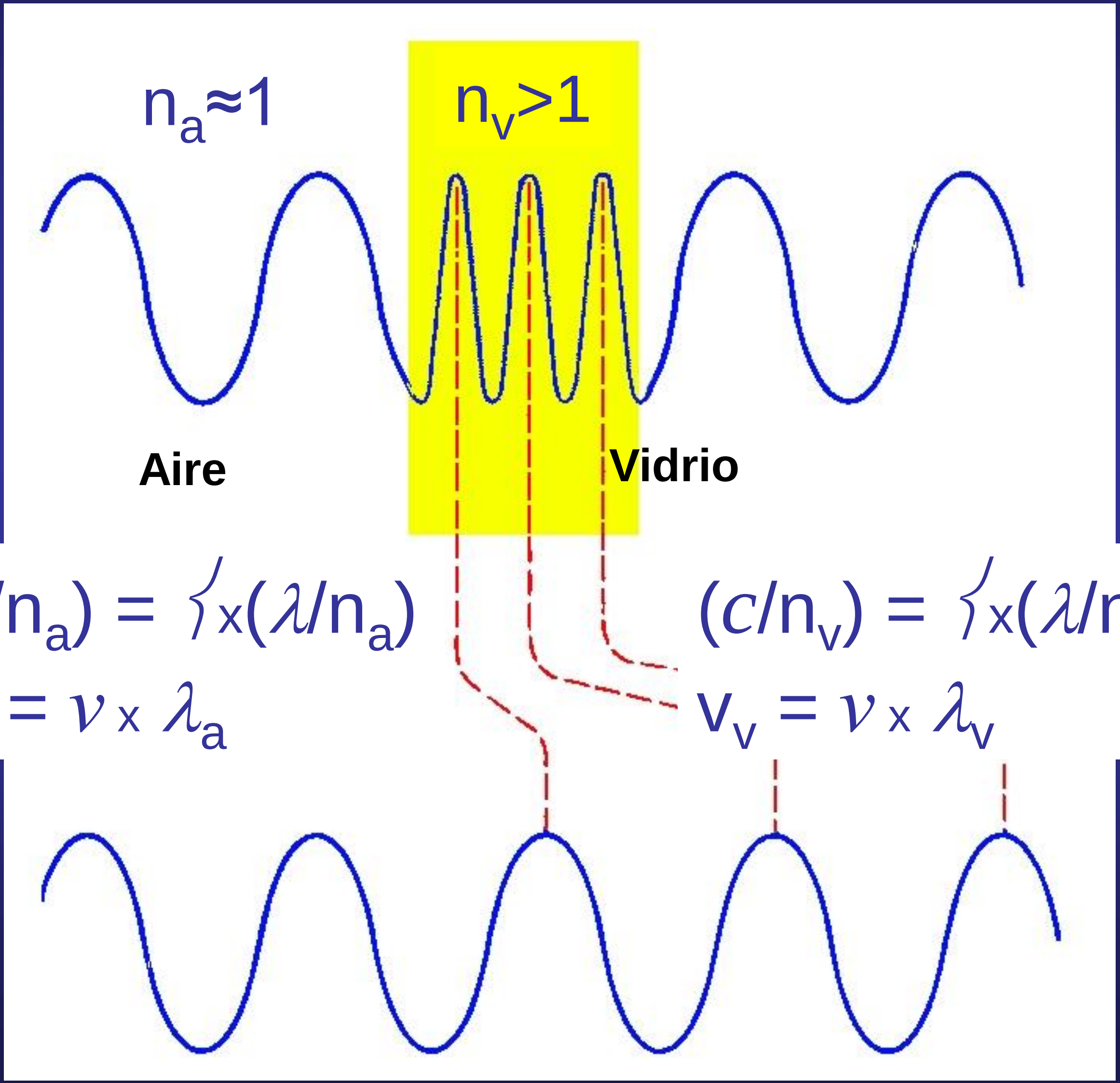


(a) Rayo incidente, reflejado y refractado. (b) Un haz de luz reflejado y refractado por un bloque de vidrio. (De: *Physics*, D.C. Heath, Boston, 1960.)

$$n_1 \operatorname{sen} \theta_i = n_2 \operatorname{sen} \theta_r$$

Ley de Snell

PROPAGACIÓN EN MEDIOS MATERIALES



$(c/n_a) = \nu \times (\lambda/n_a)$

$v_a = \nu \times \lambda_a$

$(c/n_v) = \nu \times (\lambda/n_v)$

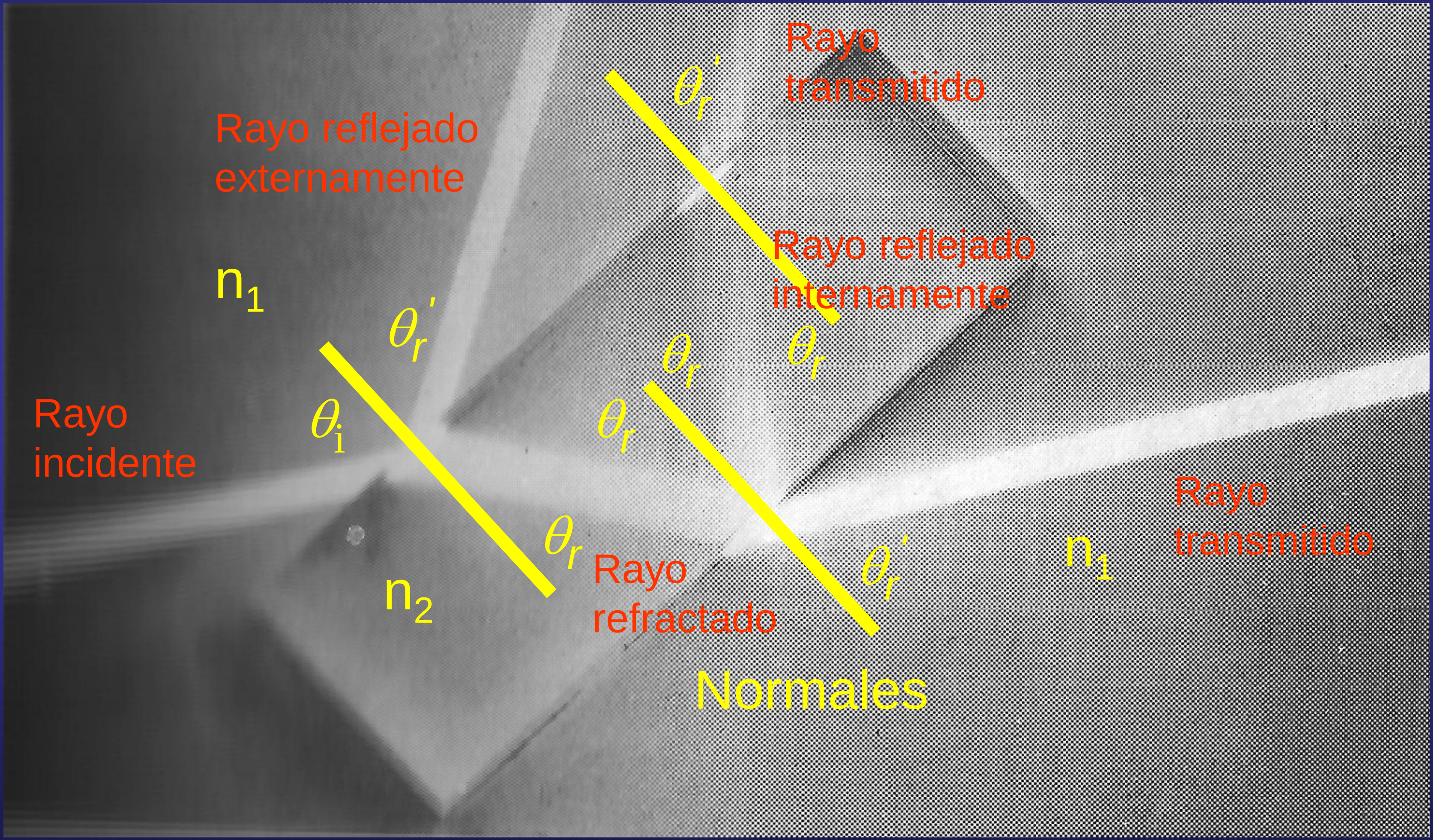
$v_v = \nu \times \lambda_v$

Velocidad
de la luz
en el vacío

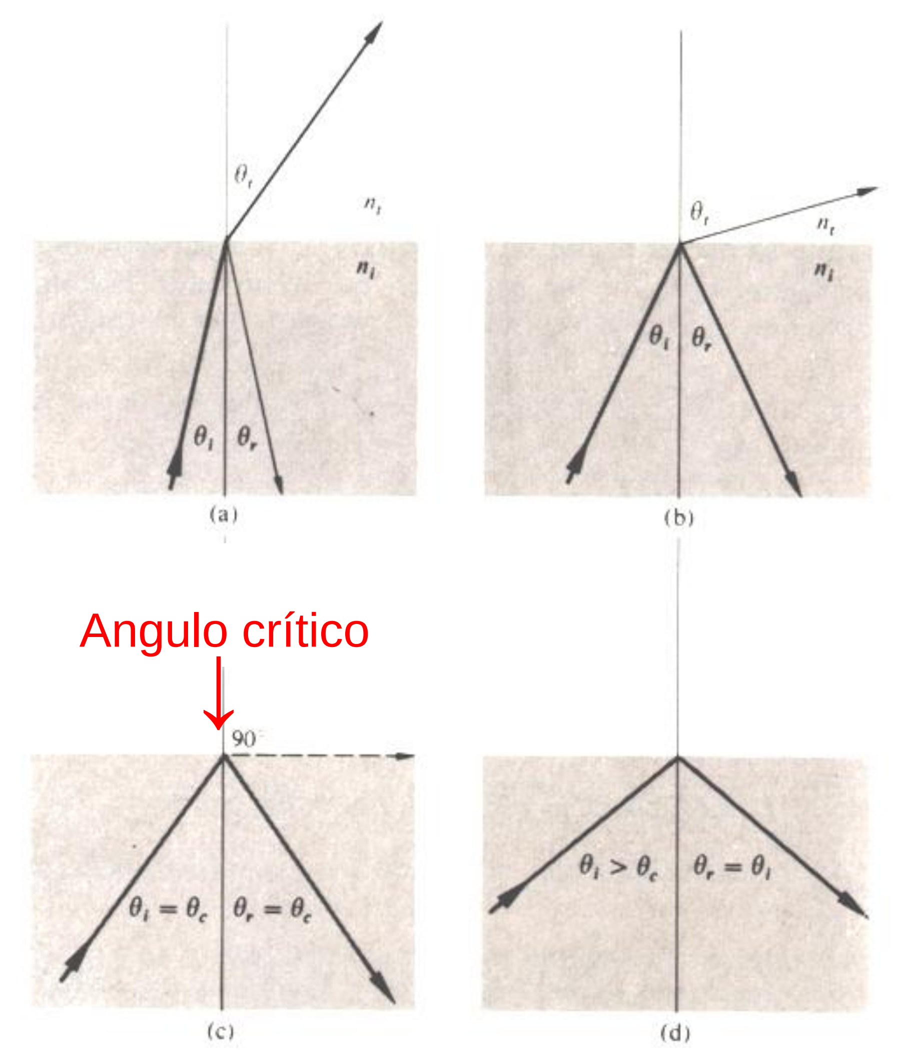
$$c = \nu \times \lambda$$

Cambio de longitud de onda λ al pasar por un medio con índice de refracción mayor.

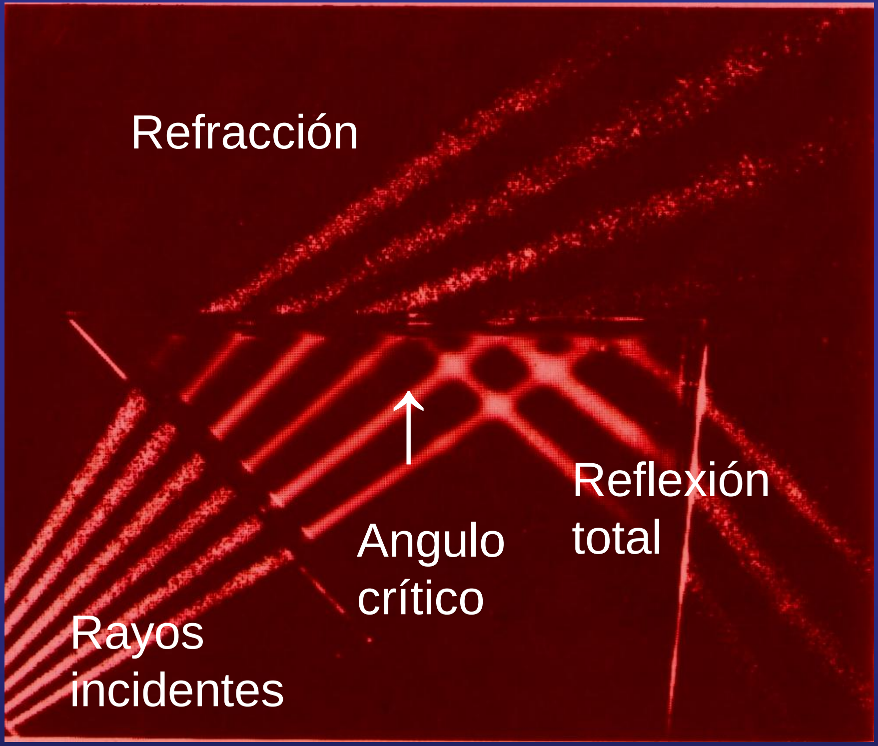
REFRACCION EN UNA PLACA DE CARAS PLANAS Y PARALELAS



REFRACCION Y REFLEXION TOTAL



Angulo crítico



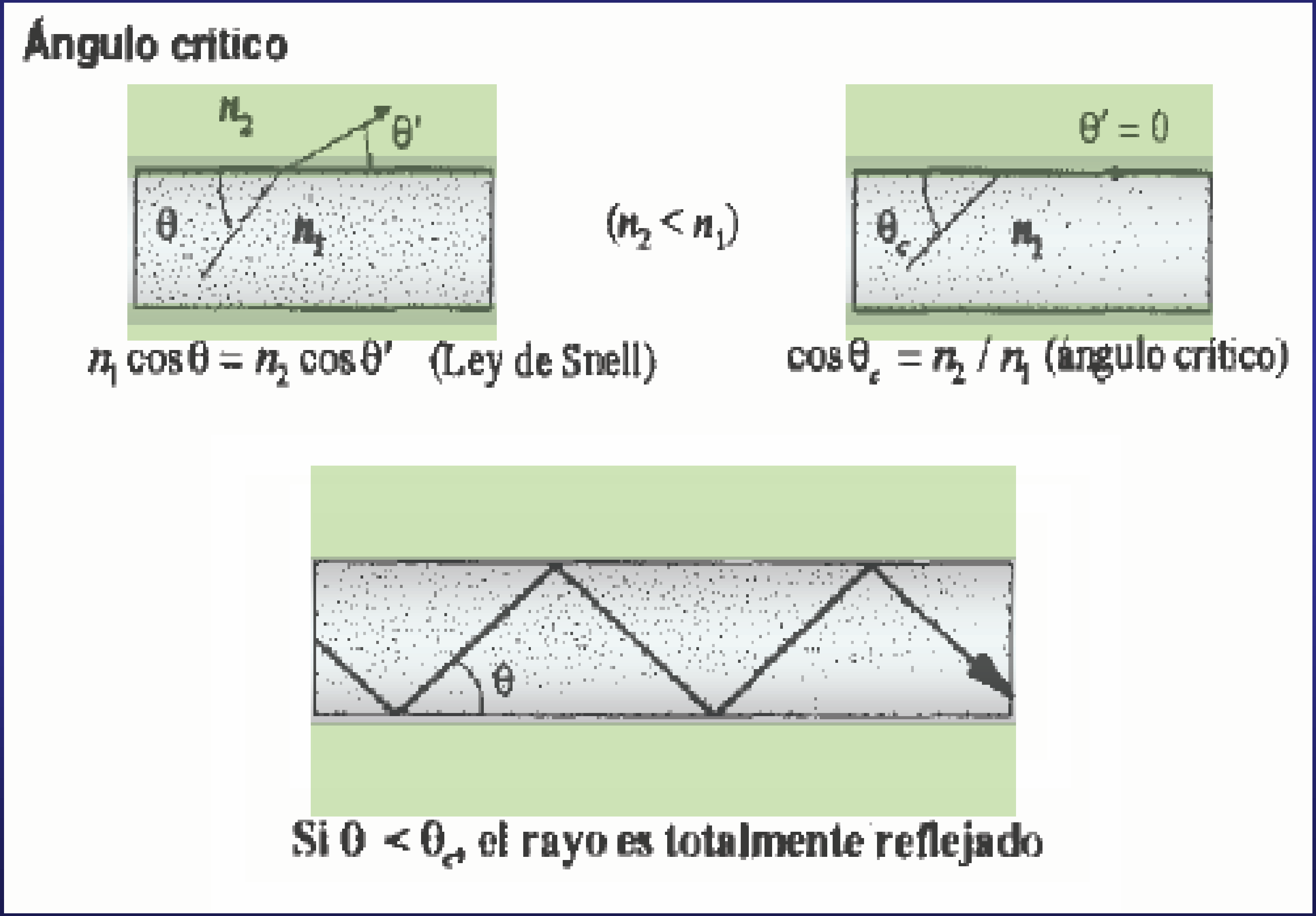
Refracción

Angulo crítico

Reflexión total

Rayos incidentes

REFLEXION TOTAL Y FIBRAS OPTICAS I



Ángulo crítico

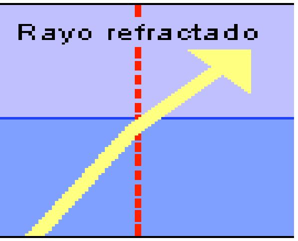
$(n_2 < n_1)$

$n_1 \cos\theta = n_2 \cos\theta'$ (Ley de Snell)

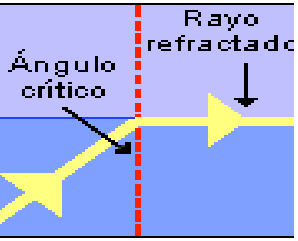
$\cos\theta_c = n_2 / n_1$ (ángulo crítico)

Si $\theta < \theta_c$, el rayo es totalmente reflejado

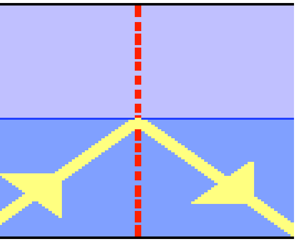
REFLEXION TOTAL Y FIBRAS OPTICAS II



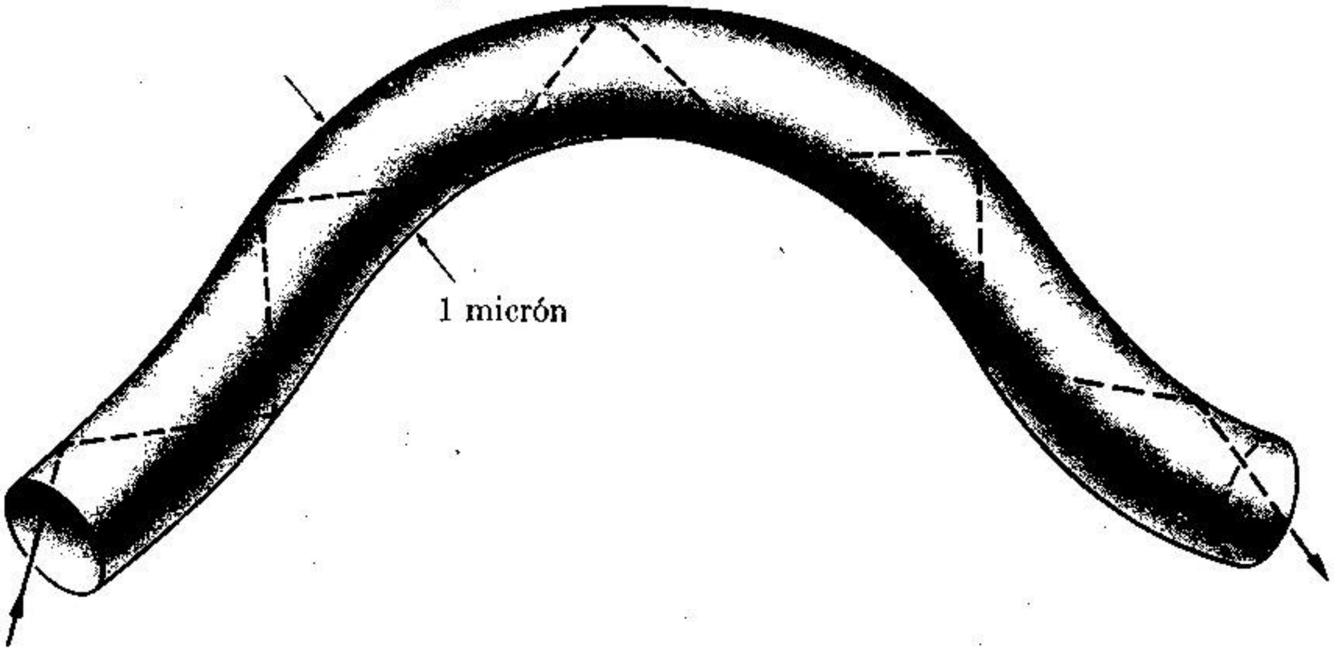
efracción ordinaria



Refracción en el ángulo crítico

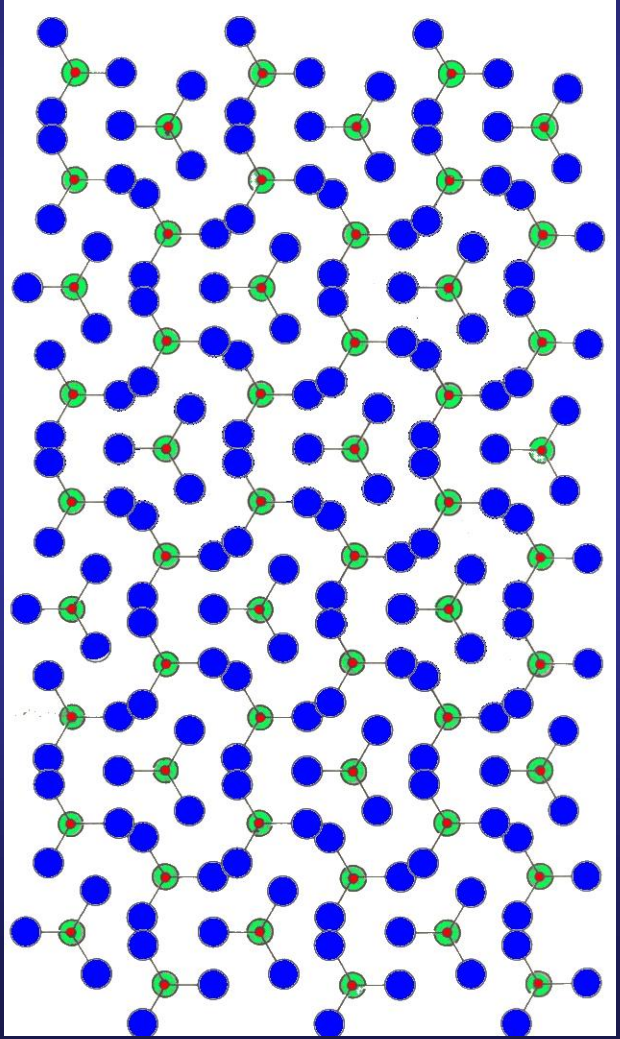


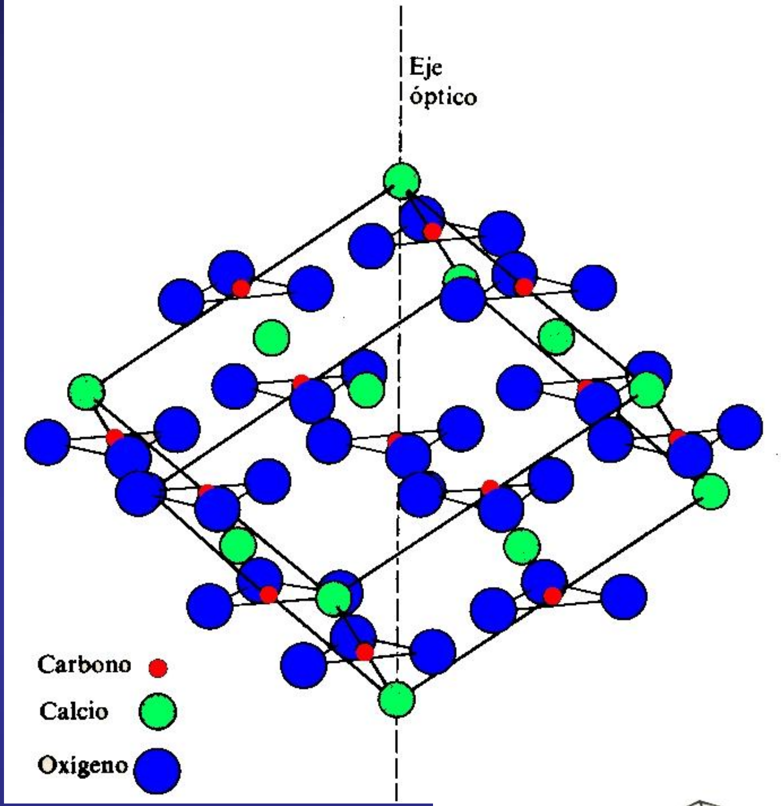
Reflexión total



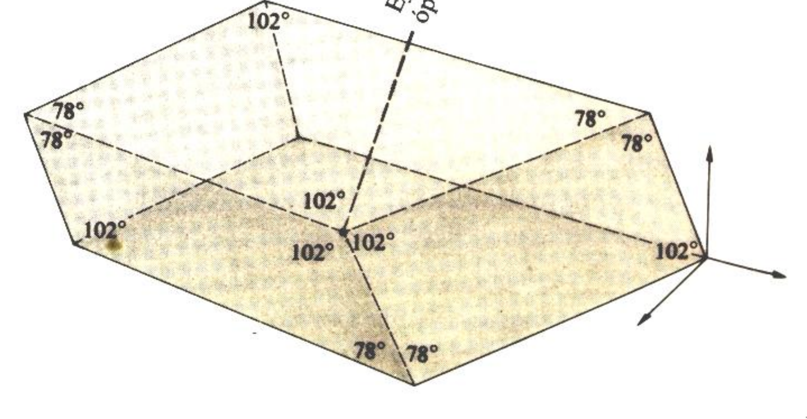
Las fibras ópticas actúan como guías de onda para la luz.

POLARIZACIÓN Y BIRREFRINGENCIA

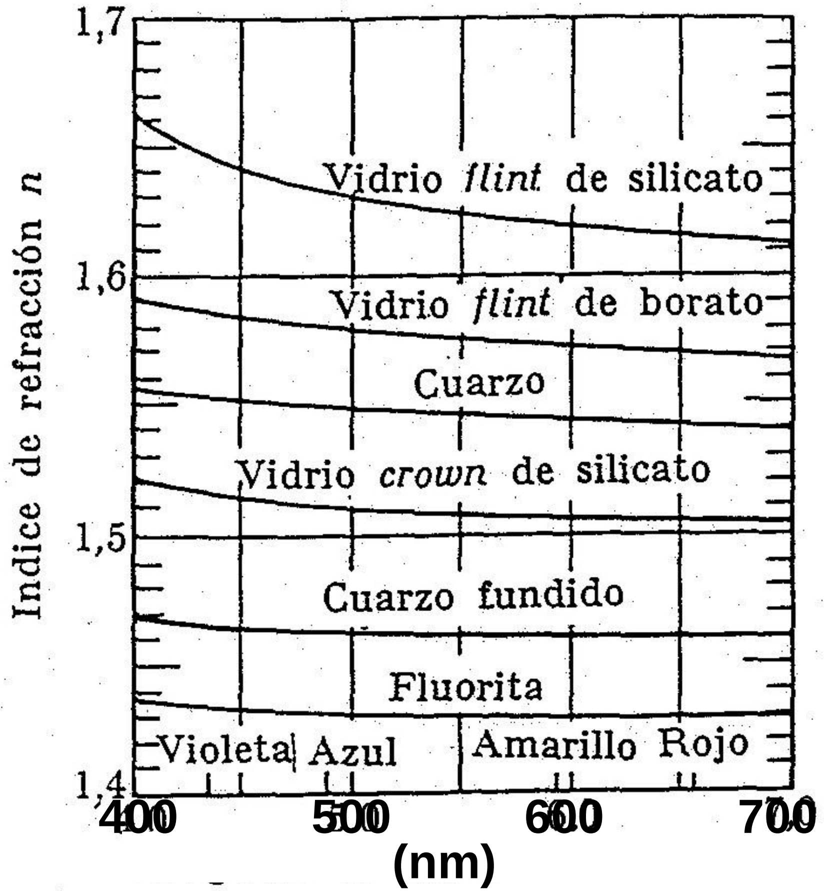




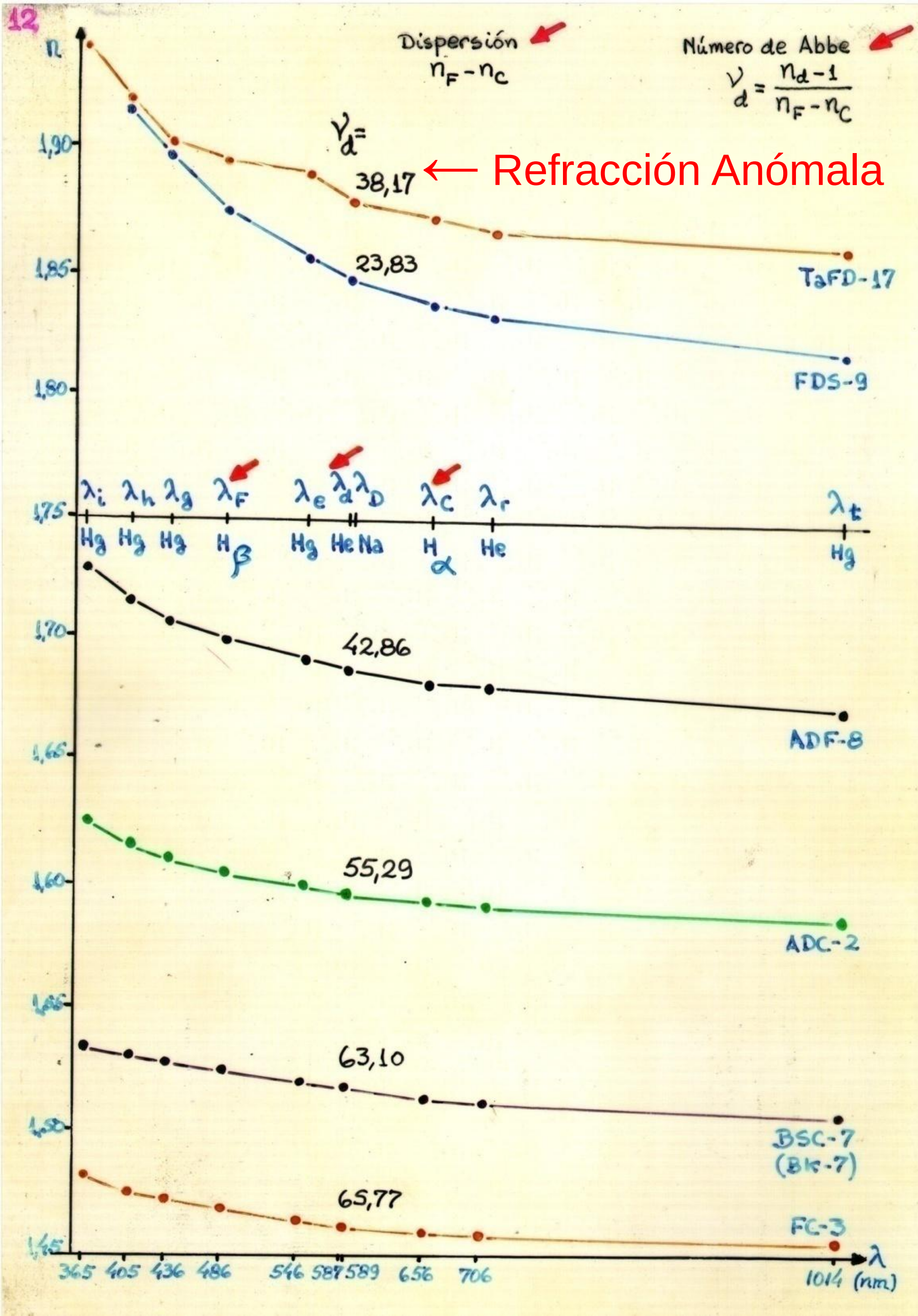
Calcita



INDICE DE REFRACCION I



Variación del índice de refracción con la longitud de onda en la región visible, para algunos materiales.



INDICE DE REFRACCION II

Indice de Refracción:

$n(\lambda)$

Dispersión:

$n_F - n_C$

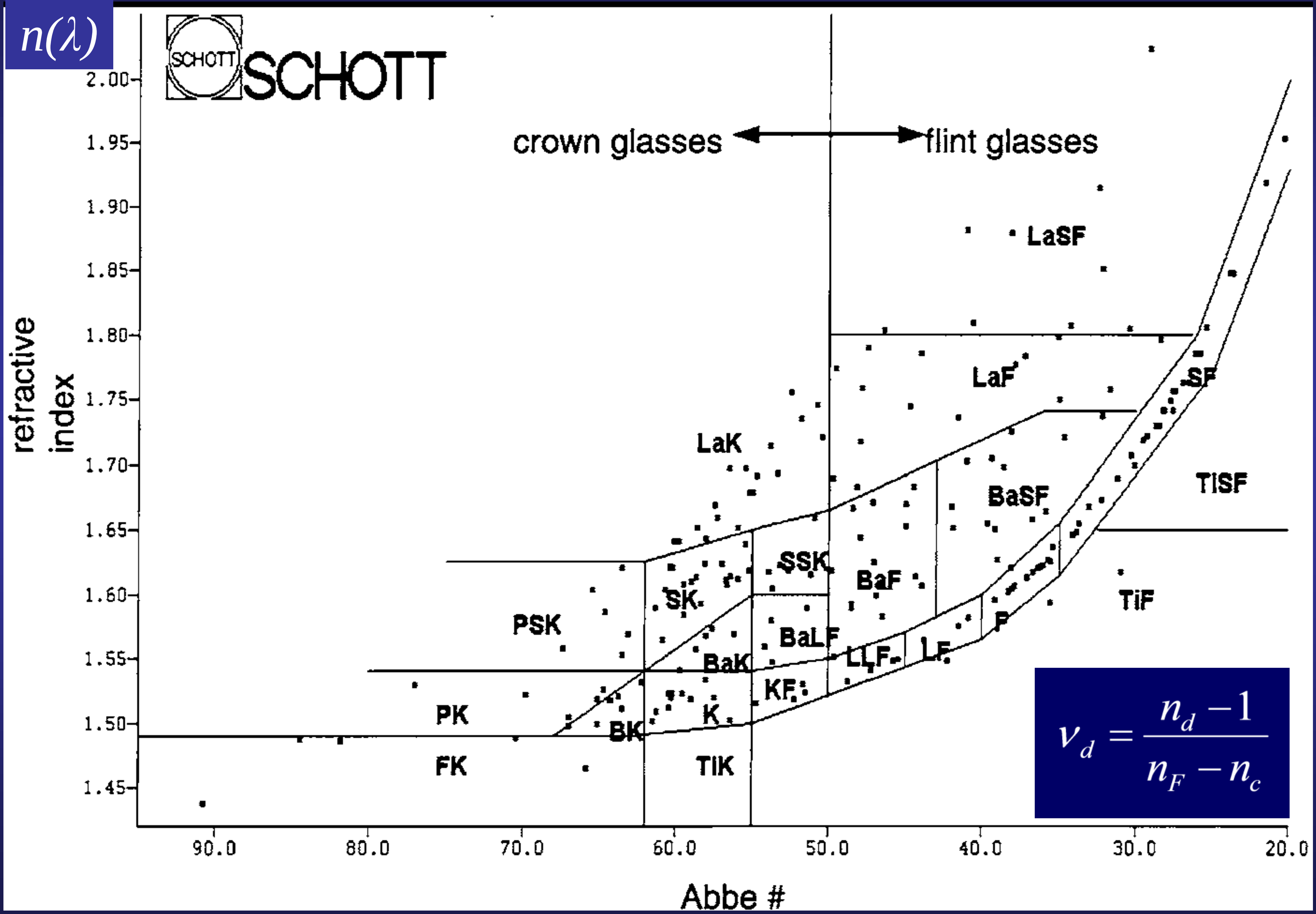
y

Número de Abbe:

$$\nu_d = \frac{n_d - 1}{n_F - n_c}$$

INDICE DE REFRACCION III

$n(\lambda)$



$$\nu_d = \frac{n_d - 1}{n_F - n_c}$$

REFRACCION Y DISPERSION ESPECTRAL

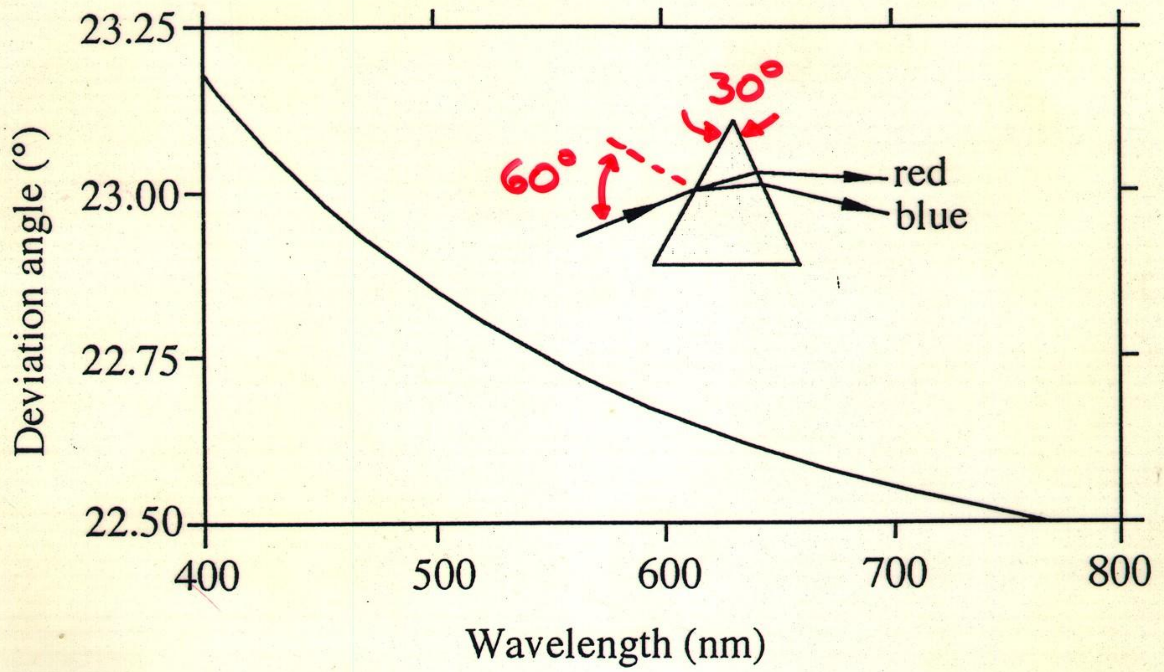


Fig. 8.5: Deviation angle θ as a function of wavelength of a prism (dispersion) made with Schott BK7 glass. The apex angle is 30° and the angle of incidence is 60°.

MEDIOS GRIN Y CRISTALINO I

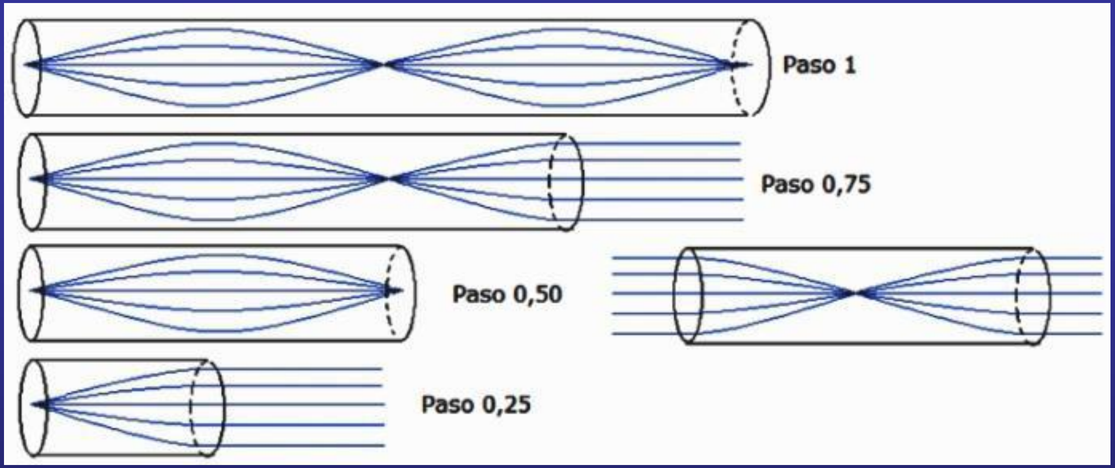
- $n_{\text{Aire}} = 1{,}000$
- $n_{\text{Córnea}} = 1{,}376$
- $n_{\text{H. Acuoso}} = 1{,}336$
- $n_{\text{C. Núcleo}} = 1{,}406$
- $n_{\text{C.Polos}} = 1{,}386$
- $n_{\text{C.Ecuador}} = 1{,}375$
- $n_{\text{C.Cápsula}} = 1{,}360$
- $n_{\text{H.Vítreo}} = 1{,}337$
- $n_{\text{Agua}} = 1{,}333$

Las determinaciones de la forma de la córnea y de los índices de de refracción de los sucesivos medios del ojo propiciaron las propuestas de Lotmar (1971), de Drasdo y Fowler (1974), de Blaker (1980) y de Kooijmar (1980) de considerar al ojo como un sistema óptico **asférico**, mientras que en 1984 Rafael Navarro y sus colaboradores le agregaron su consideración de que sus medios son del tipo **GRIN**. GRIN significa “**GR**adiente en el **IN**dice de refracción” (En castellano).

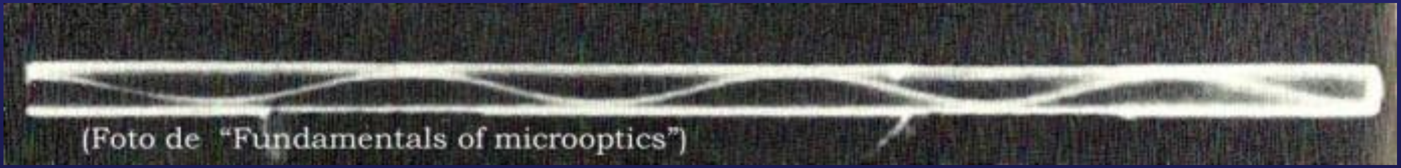
MEDIOS GRIN Y CRISTALINO II

Breve descripción de los Sistemas GRIN

Una lente de un material no homogéneo, que posee un GRadiente de INdice de refracción se conoce como lente GRIN. En un medio inhomogéneo de simetría cilíndrica el confinamiento de luz está relacionado con la variación del índice de refracción que ha de elegirse de tal modo que sea máximo en el centro y disminuya de forma suave y continua hacia su borde para que los rayos de luz describan trayectorias curvas, las que semejan las posiciones sucesivas de cuerdas vibrantes, pudiendo identificarse nodos y vientres.



Esquemas de trayectorias de rayos a través de medios GRIN con perfil parabólico del índice de refracción para diferentes pasos.



Propagación de un rayo meridional a través de un medio GRIN.

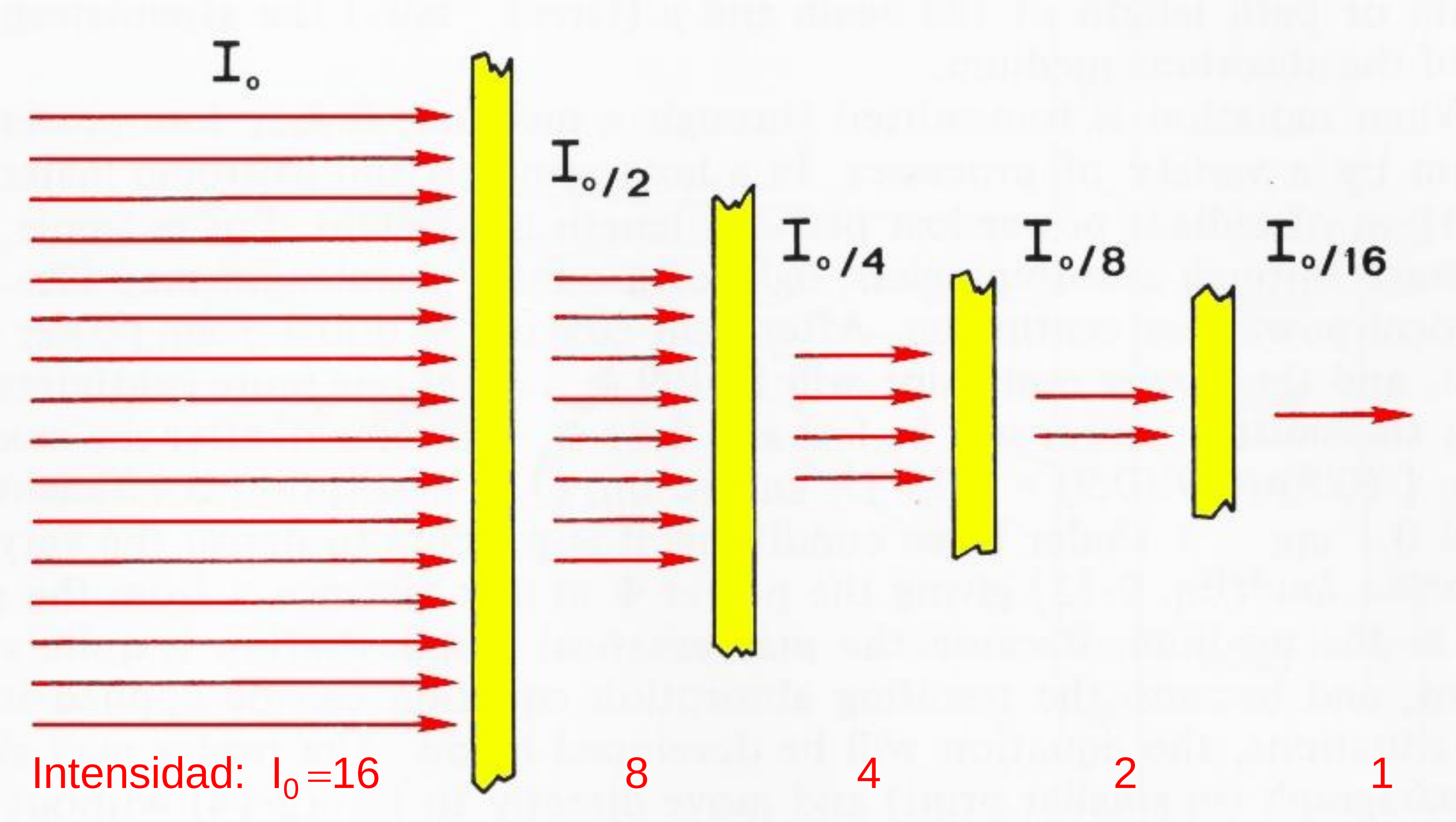
MEDIOS GRIN Y CRISTALINO III

Tesina de la Lic. María Agustina Corti, 2013

Análisis de medios GRIN y su posible empleo en instrumentos médicos de observación

Estudio teórico y experimental de medios GRIN para caracterizarlos como componentes ópticos de "transferencia de imágenes" o "repetidor de imágenes".

ABSORCION DE LA LUZ: FILTROS NEUTROS Y DE COLORES

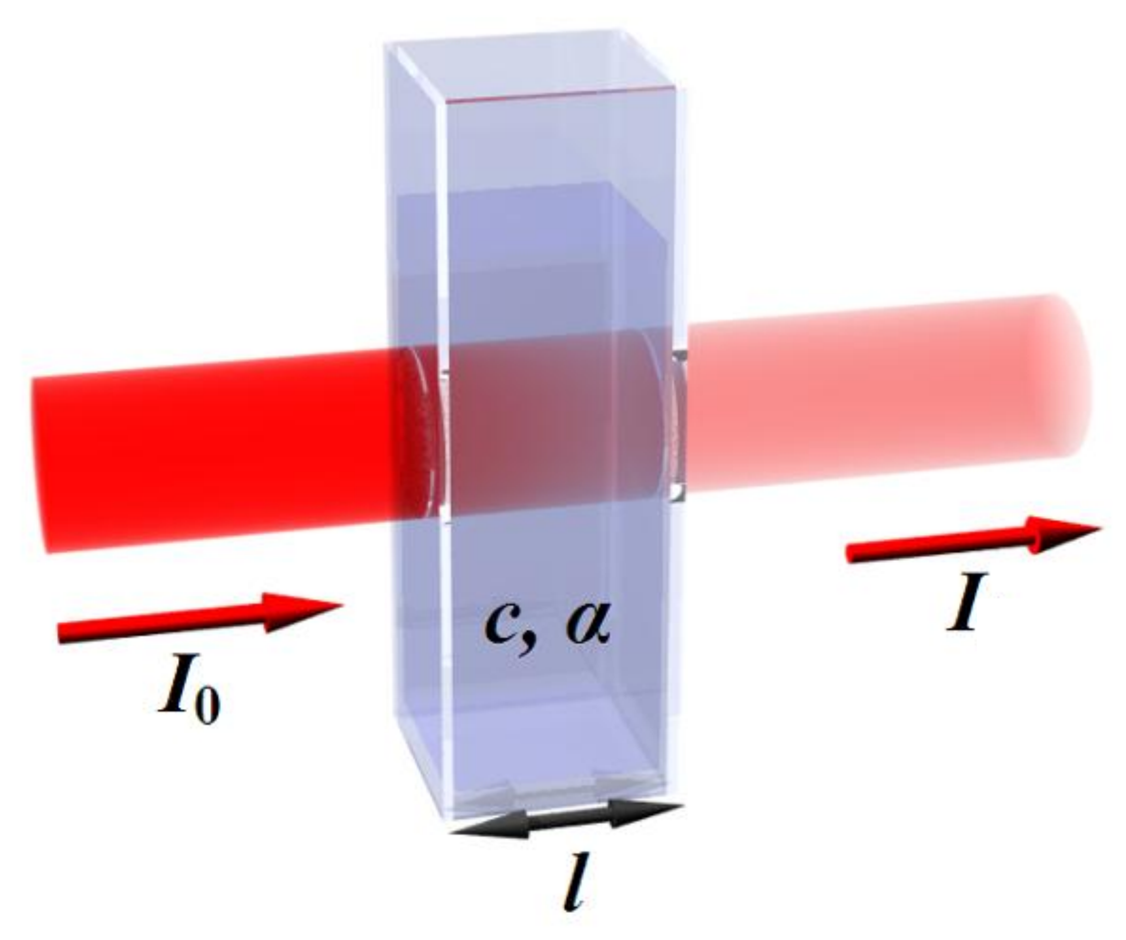


Intensidad: $I_0 = 16$ 8 4 2 1

Ley de Beer: Atenuación exponencial

[Pierre Bouguer (1729), Johann Heinrich Lambert (1760), y August Beer (1852)]

ABSORCIÓN DE LA LUZ POR UNA SOLUCIÓN SEGÚN LA CONCENTRACIÓN *c*



$$T = \frac{I}{I_0} = 10^{-\alpha \ell} = 10^{-\varepsilon \ell c}$$

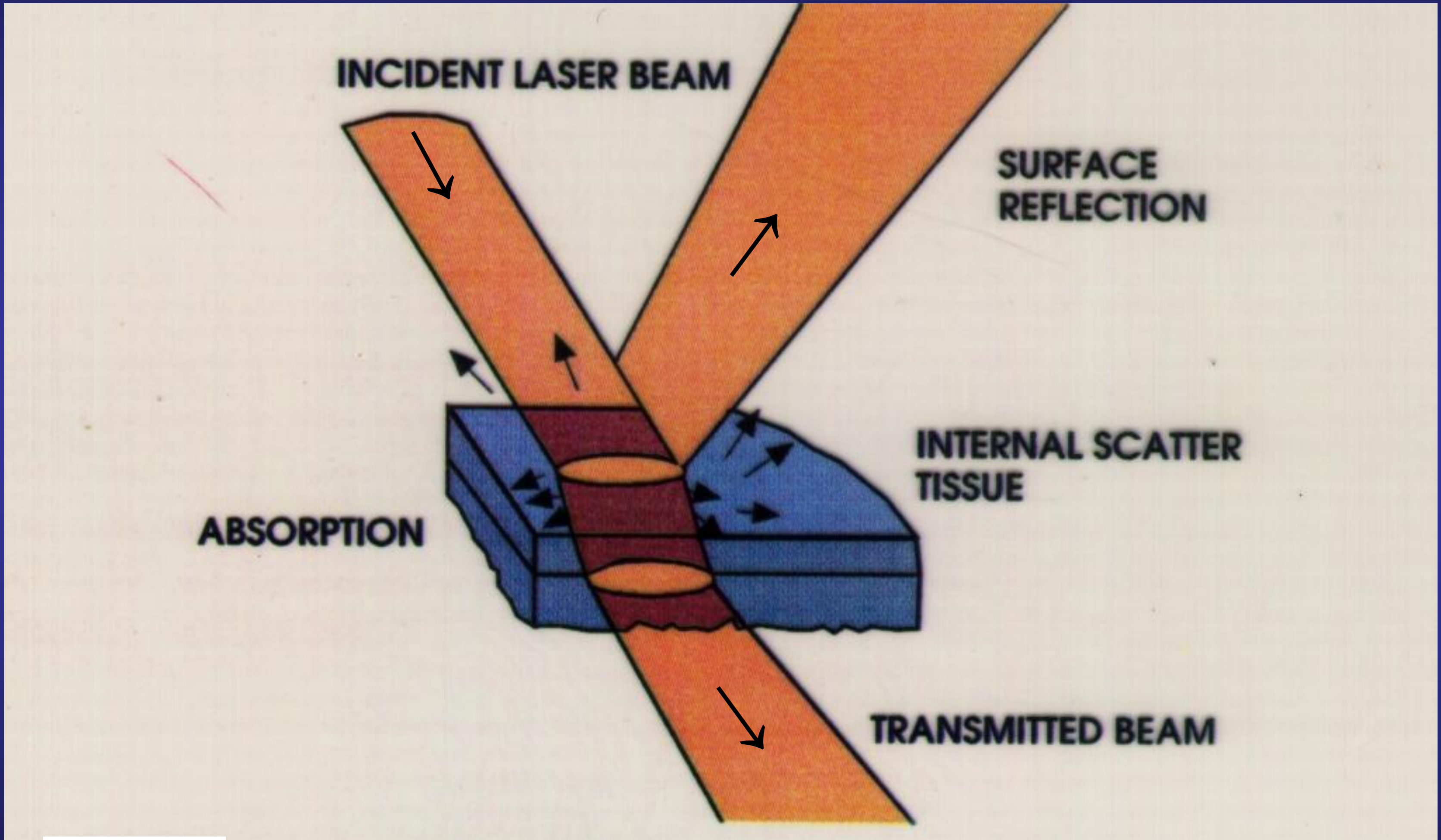
T: Transmisividad

α: Absortividad

ε: Absortividad molar o Coeficiente de extinción

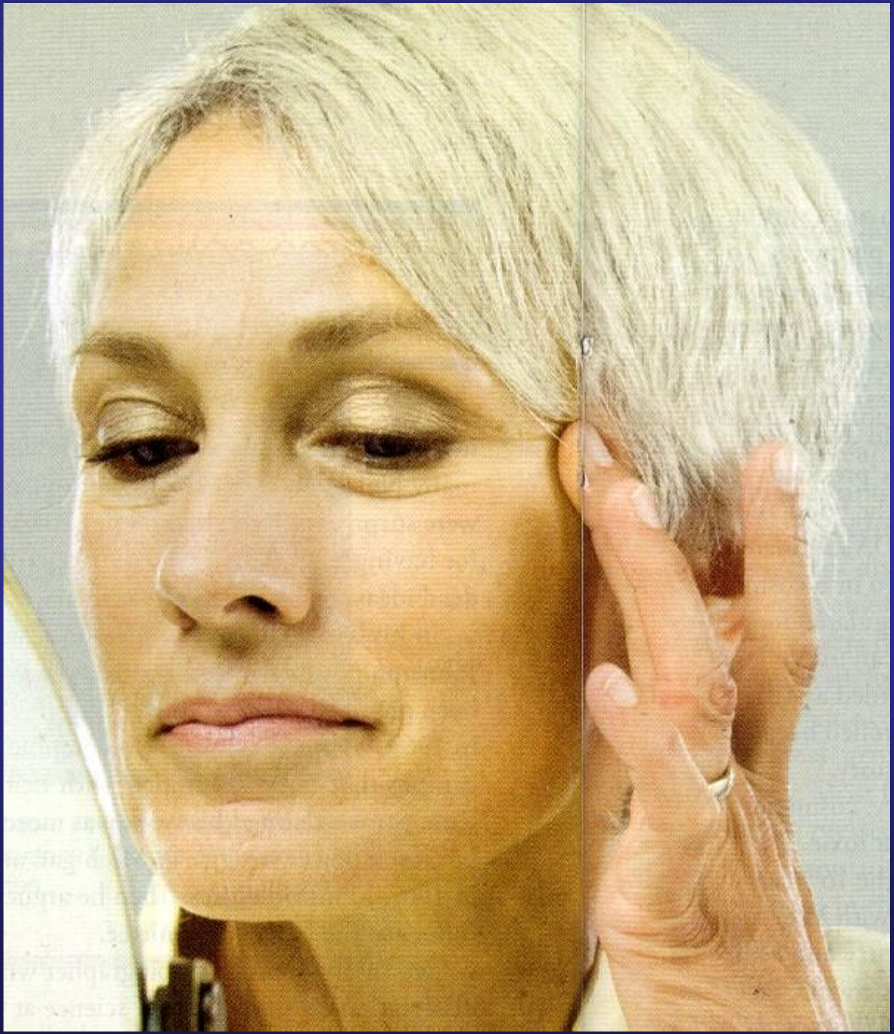
c: Concentración molar

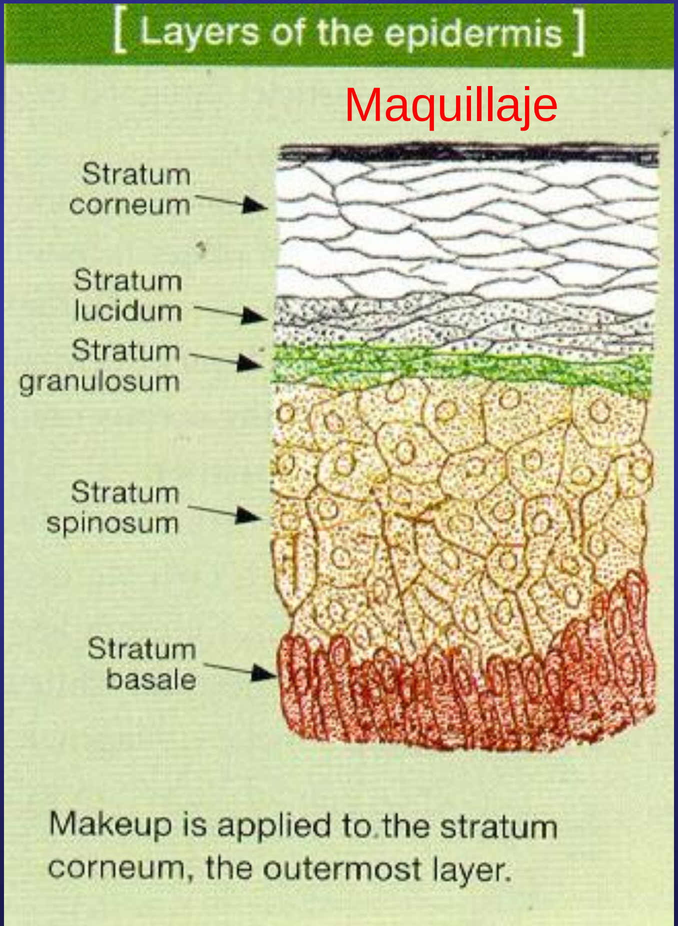
REFLEXION, REFRACCION Y TRANSMISION EN LOS TEJIDOS



The primary interactions of laser light with tissue.

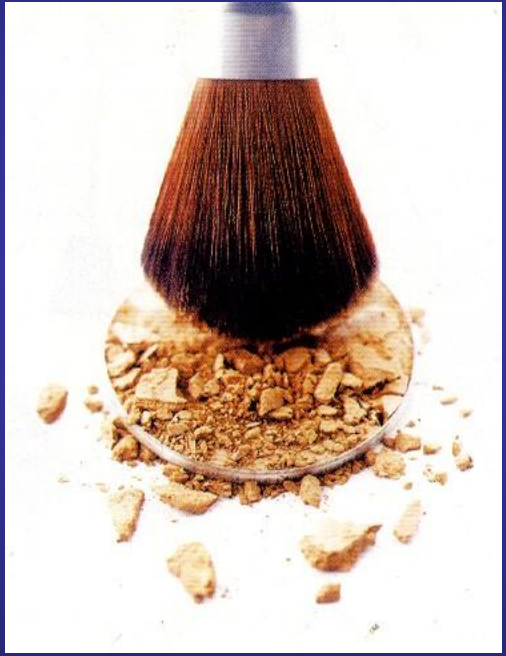
REFLEXION, REFRACCION Y TRANSMISION: COSMÉTICA I





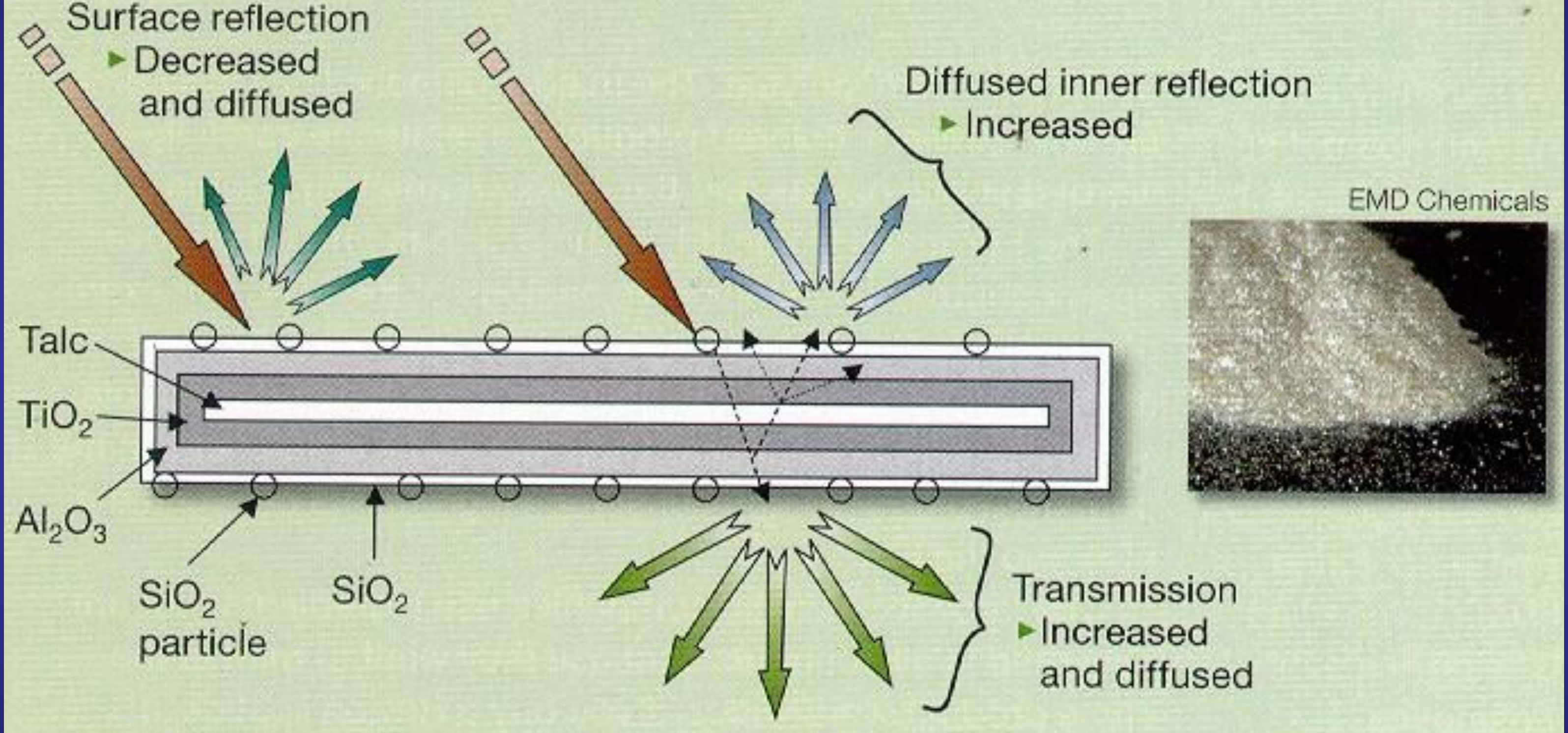
Makeup is applied to the stratum corneum, the outermost layer.

REFLEXION, REFRACCION Y TRANSMISION: COSMÉTICA II



Parecen pigmentos, pero ...

REFLEXION, REFRACCION Y TRANSMISION: COSMÉTICA III

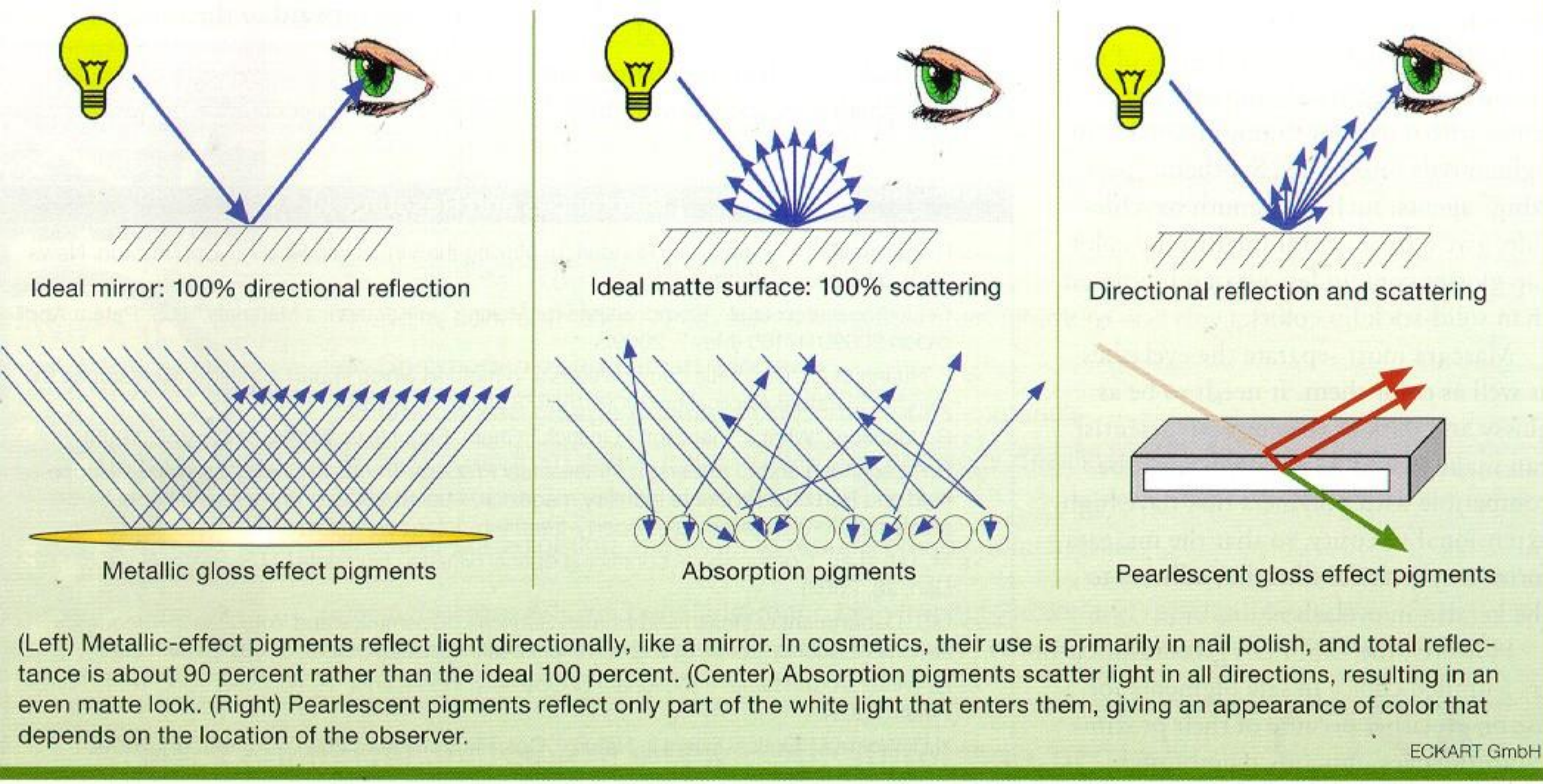


Cosmetics made of multilayered particles reflect and transmit diffuse light to conceal wrinkles or impart different colors to observers at different viewing angles. (Inset) Cosmetic-grade pigment of TiO_2-coated mica particles.

Nick Morante Cosmetic Consultants

... pero son estructuras complejas

REFLEXION, REFRACCION Y TRANSMISION: COSMÉTICA IV



Ideal mirror: 100% directional reflection

Ideal matte surface: 100% scattering

Directional reflection and scattering

Metallic gloss effect pigments

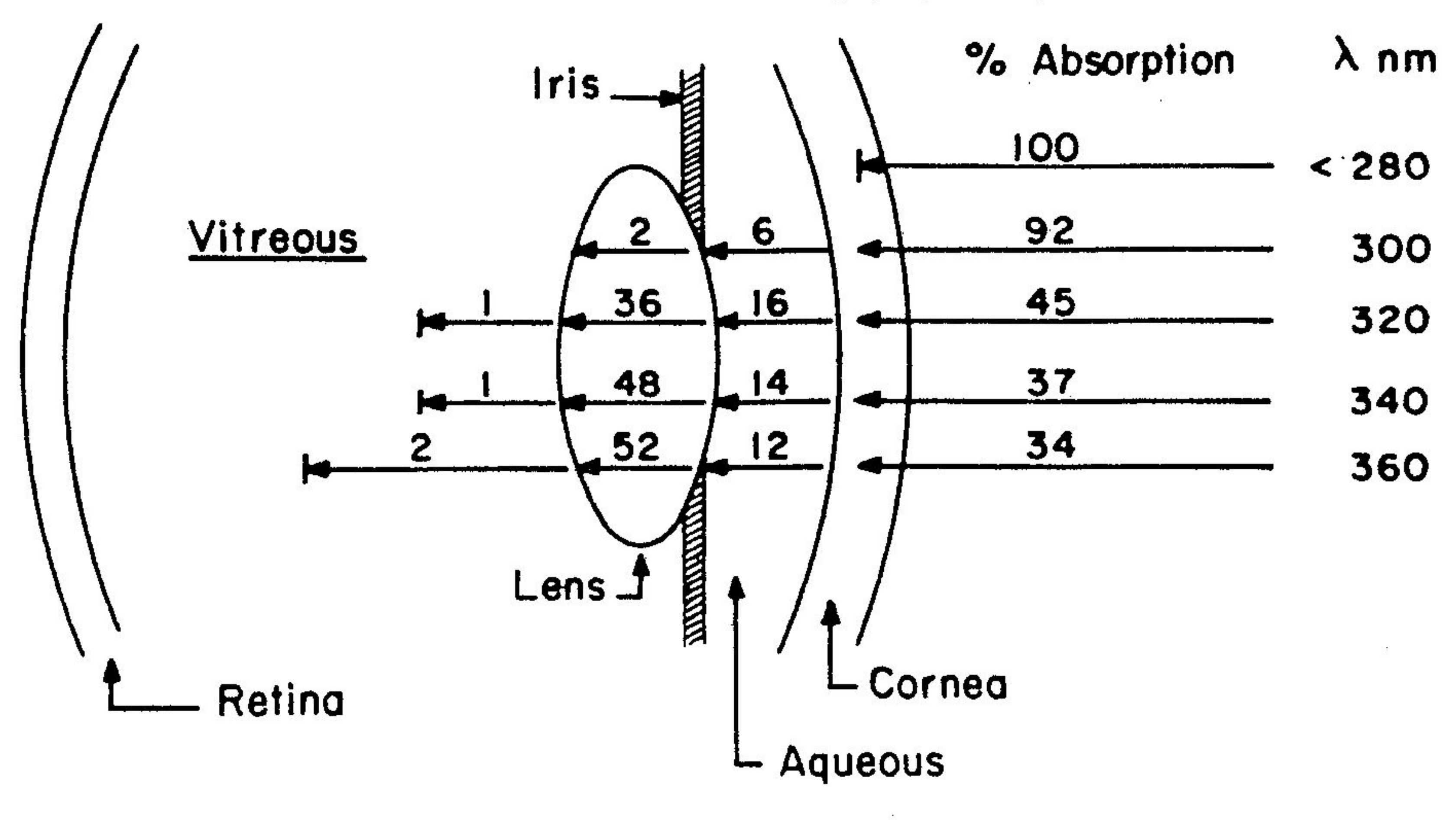
Absorption pigments

Pearlescent gloss effect pigments

(Left) Metallic-effect pigments reflect light directionally, like a mirror. In cosmetics, their use is primarily in nail polish, and total reflectance is about 90 percent rather than the ideal 100 percent. (Center) Absorption pigments scatter light in all directions, resulting in an even matte look. (Right) Pearlescent pigments reflect only part of the white light that enters them, giving an appearance of color that depends on the location of the observer.

ECKART GmbH

PROTECCION DEL OJO AL UV



El espectro ultravioleta (UV) varía entre 100 y 400 nm y se subdivide en cuatro bandas: la región del Vacío (100 a 200 nm), la región UVC (200 a 280 nm), la región UVB (280 a 315 nm) y la región UVA (315 a 400 nm)

IRRADIANCIAS RETINIANAS

La absorción de luz depende del tiempo involucrado en el proceso. En la retina compiten varios:

-Fotoquímico
  $t > 10$ s

-Coagulación térmica
  $10\ \mu s < t < 10$ s

-Termoacústico
  $t \approx 1$ a 5 ps

-Efectos no lineales
  1 fs $< t <$ 1 ps

MPE ≡ Exposición Máxima Permitida

TRANSMISION DE LUZ EN EL OJO

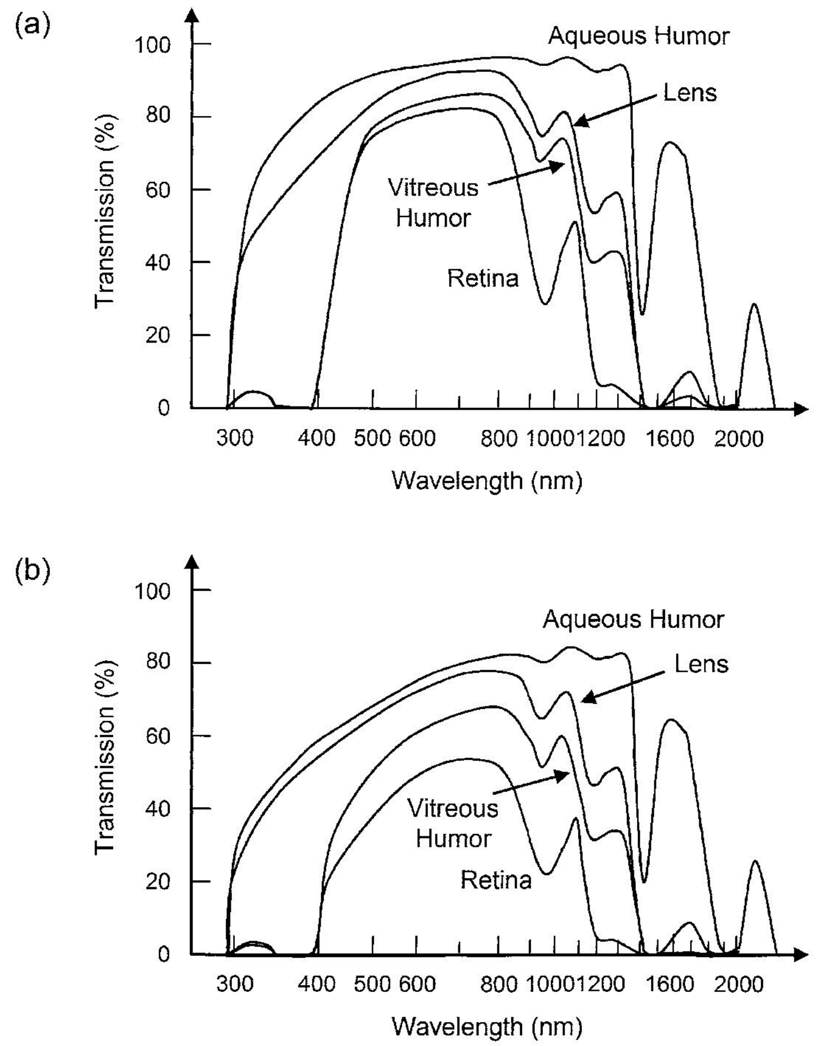


Fig. 11.18. Transmission of near-ultraviolet, visible, and near-infrared light through the eye up to the labeled part of the eye. In (**a**) only transmission losses due to absorption are included, while in (**b**) all transmission losses are accounted for, including those due to absorption and scattering. (Based on [514] and [527])

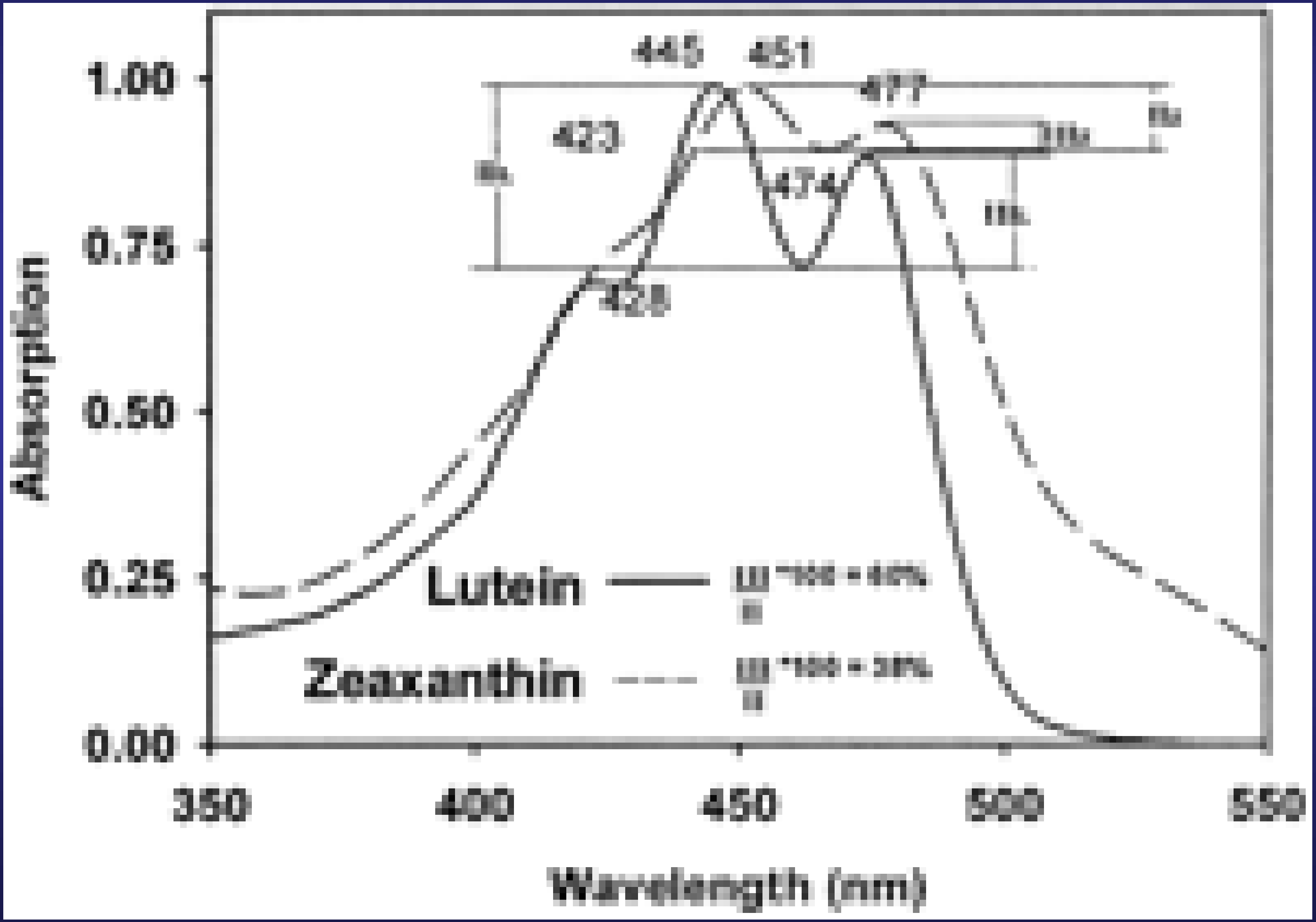
$$R=\left(\frac{n_2-n_1}{n_2+n_1}\right)^2$$

$$I(z)=I(z=0)\exp\left(-\alpha_{Absorción}z\right)$$

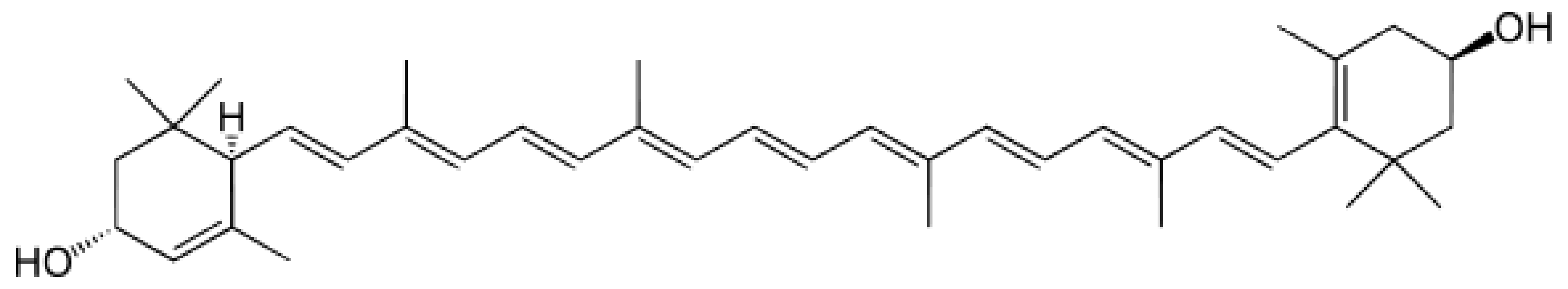
$$I(z)=I(z=0)\exp\left(-\alpha_{Scattering}z\right)$$

$$\alpha_{Scattering}=\frac{8\pi^4}{3}\frac{ND^4}{\lambda^4}\left(\frac{n_p^2-n_a^2}{n_p^2+2n_a^2}\right)^2$$

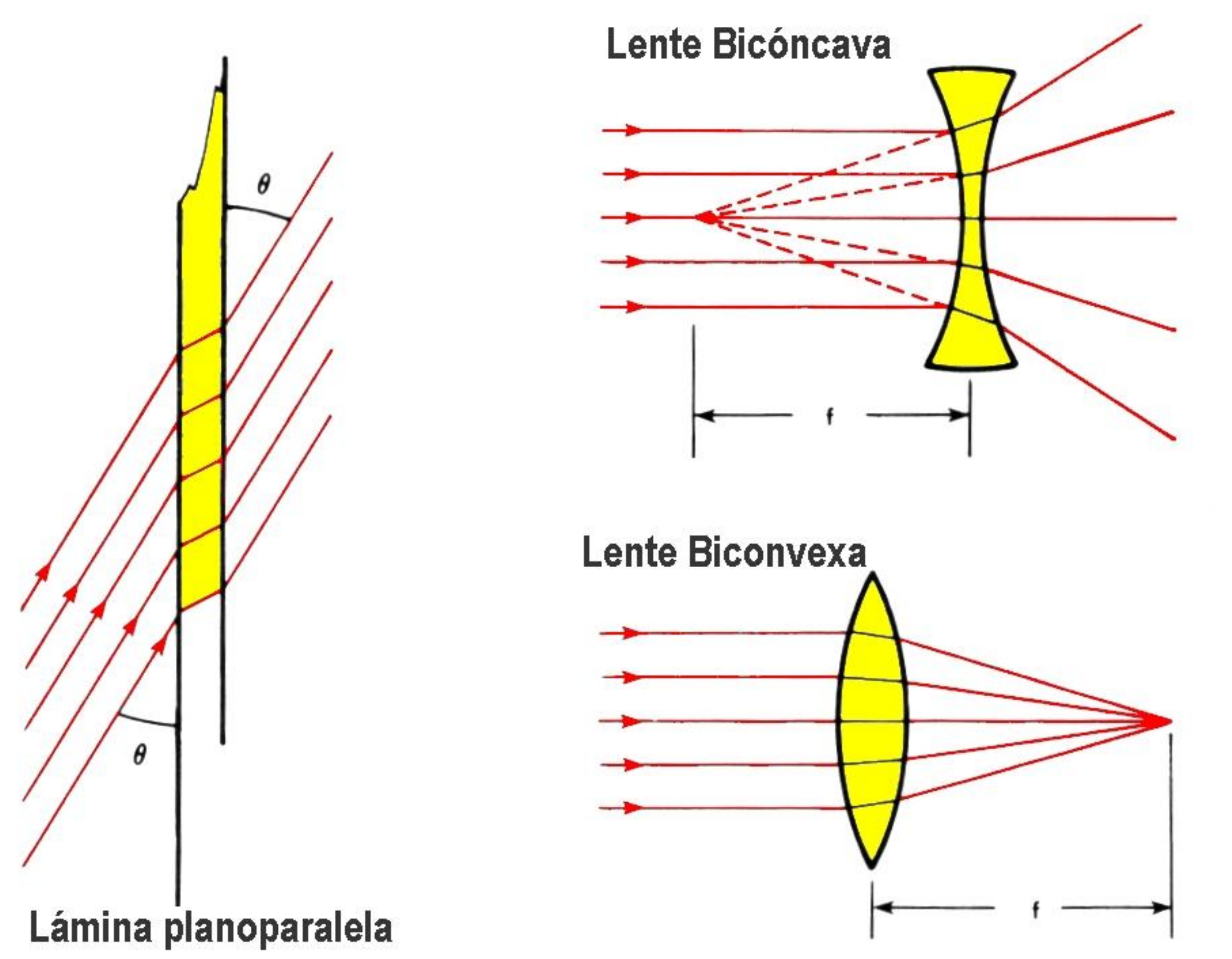
ABSORCION POR LA LUTEINA, EL PIGMENTO MACULAR



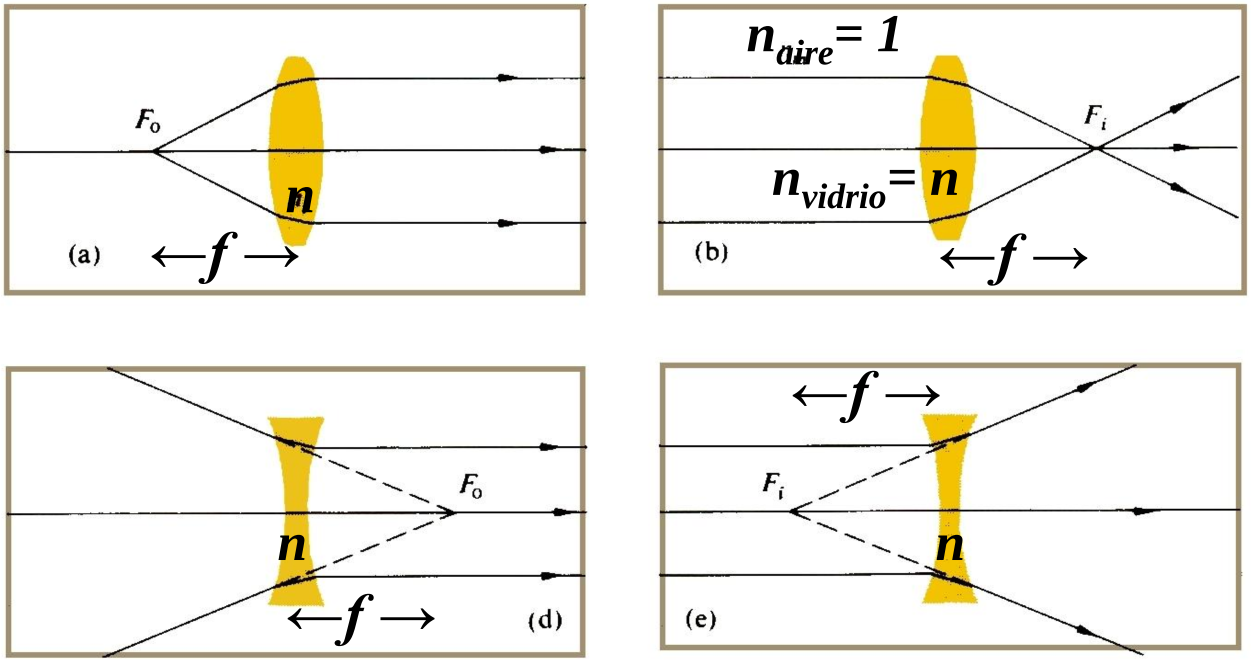
β,ε-carotene-3,3'-diol : LUTEINA



REFRACCION SEGUN LA GEOMETRIA



FORMULA DE LAS LENTES ESFERICAS



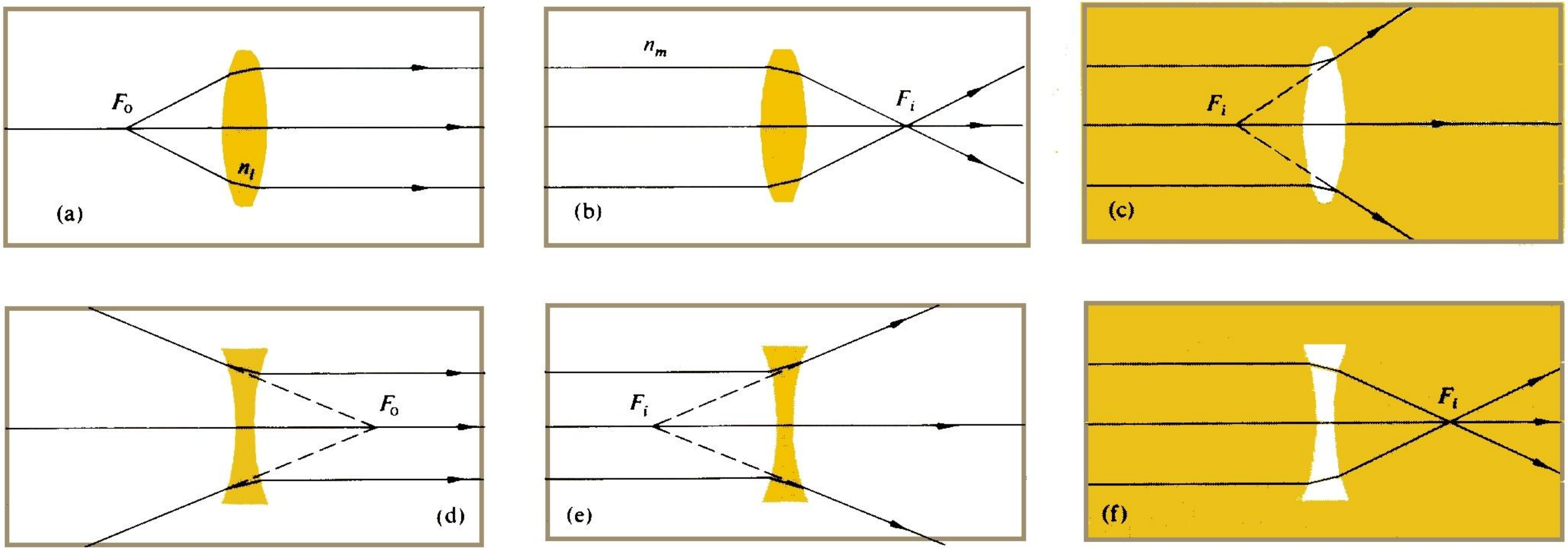
#

$$\frac{1}{f}=(n-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

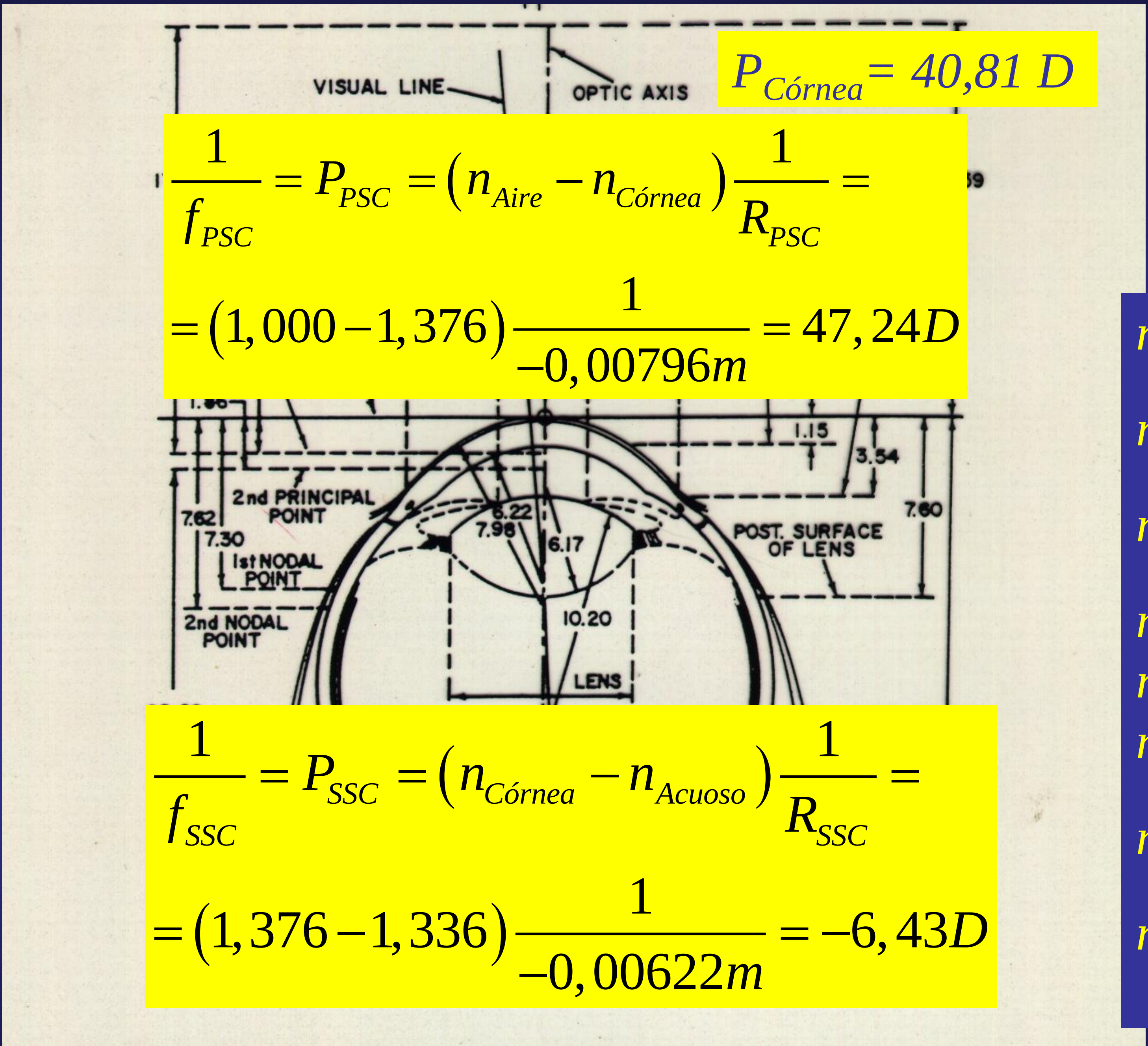
‡

Lentes convergentes para mitigar la hipermetropía
‡ Lentes divergentes para mitigar la miopía

¿Y?



Ojo Derecho Standard



$P_{Córnea} = 40{,}81\ D$

$$\frac{1}{f_{PSC}} = P_{PSC} = \left(n_{Aire} - n_{Córnea}\right)\frac{1}{R_{PSC}} =$$

$$= (1{,}000 - 1{,}376)\frac{1}{-0{,}00796m} = 47{,}24D$$

$$\frac{1}{f_{SSC}} = P_{SSC} = \left(n_{Córnea} - n_{Acuoso}\right)\frac{1}{R_{SSC}} =$$

$$= (1{,}376 - 1{,}336)\frac{1}{-0{,}00622m} = -6{,}43D$$

Figure B-1. Optical Constants For A "Standard Right Eye." Adapted from "Optical Design," MIL-HDBK-141, US Defense Department, 5 October 1962.

$n_{Aire} = 1{,}000$

$n_{Córnea} = 1{,}376$

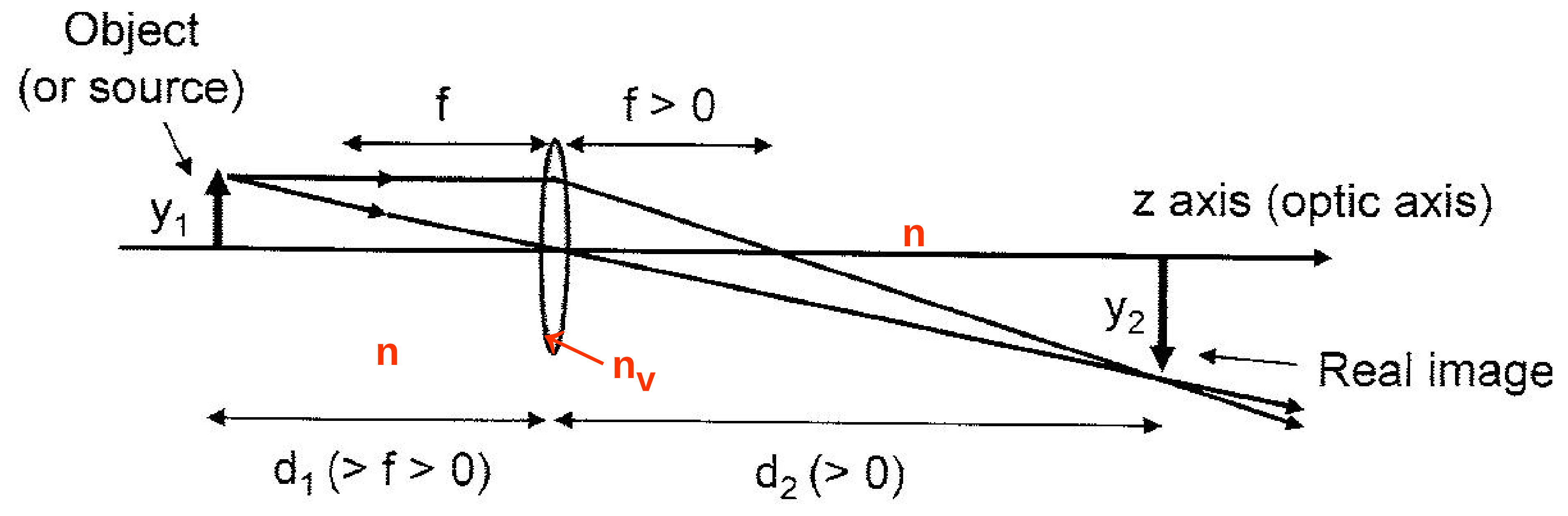
$n_{H.\ A.} = 1{,}336$

$n_{C.\ Núcleo} = 1{,}406$
$n_{C.Polos} = 1{,}386$
$n_{C.Ecuador} = 1{,}375$

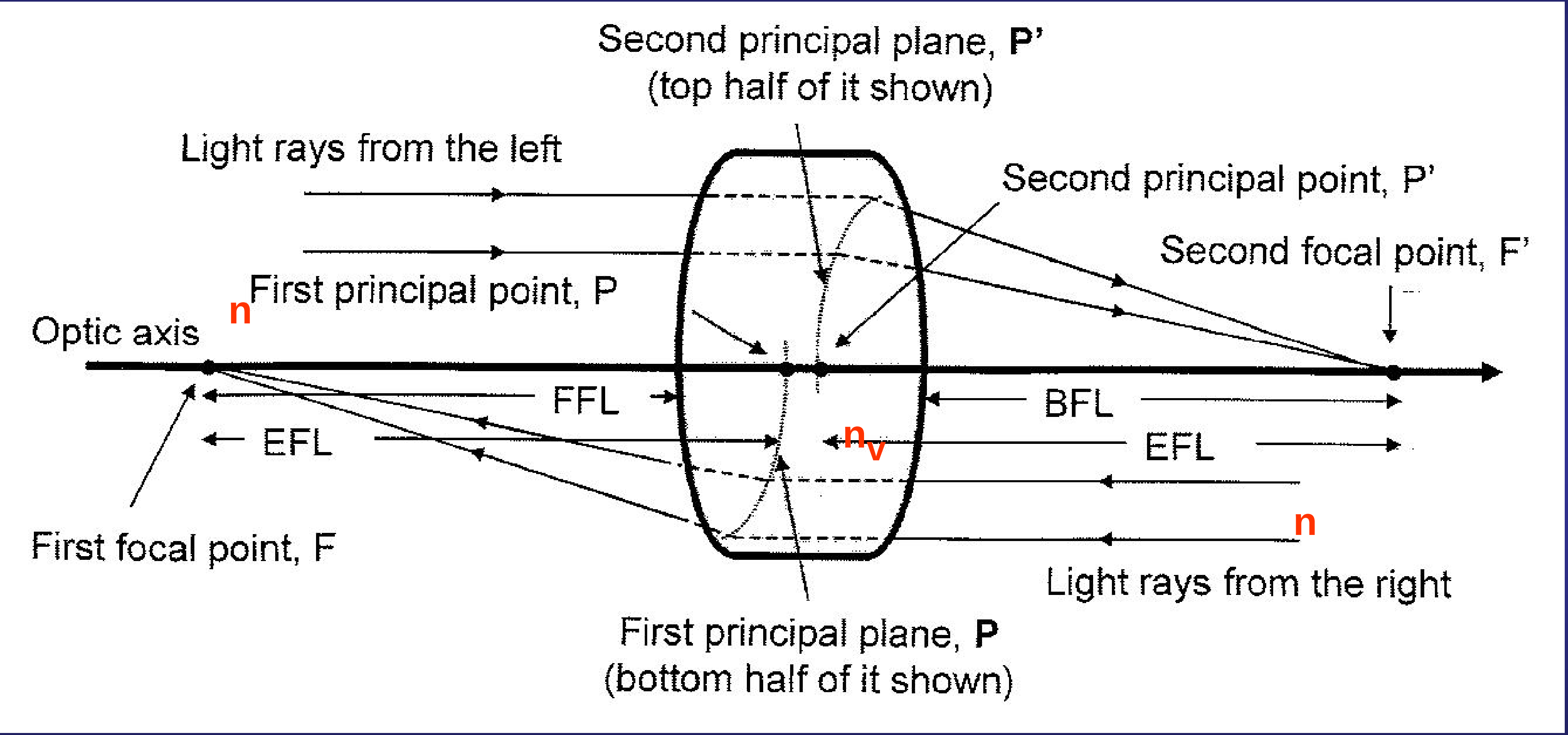
$n_{H.V.} = 1{,}337$

$n_{agua} = 1{,}333$

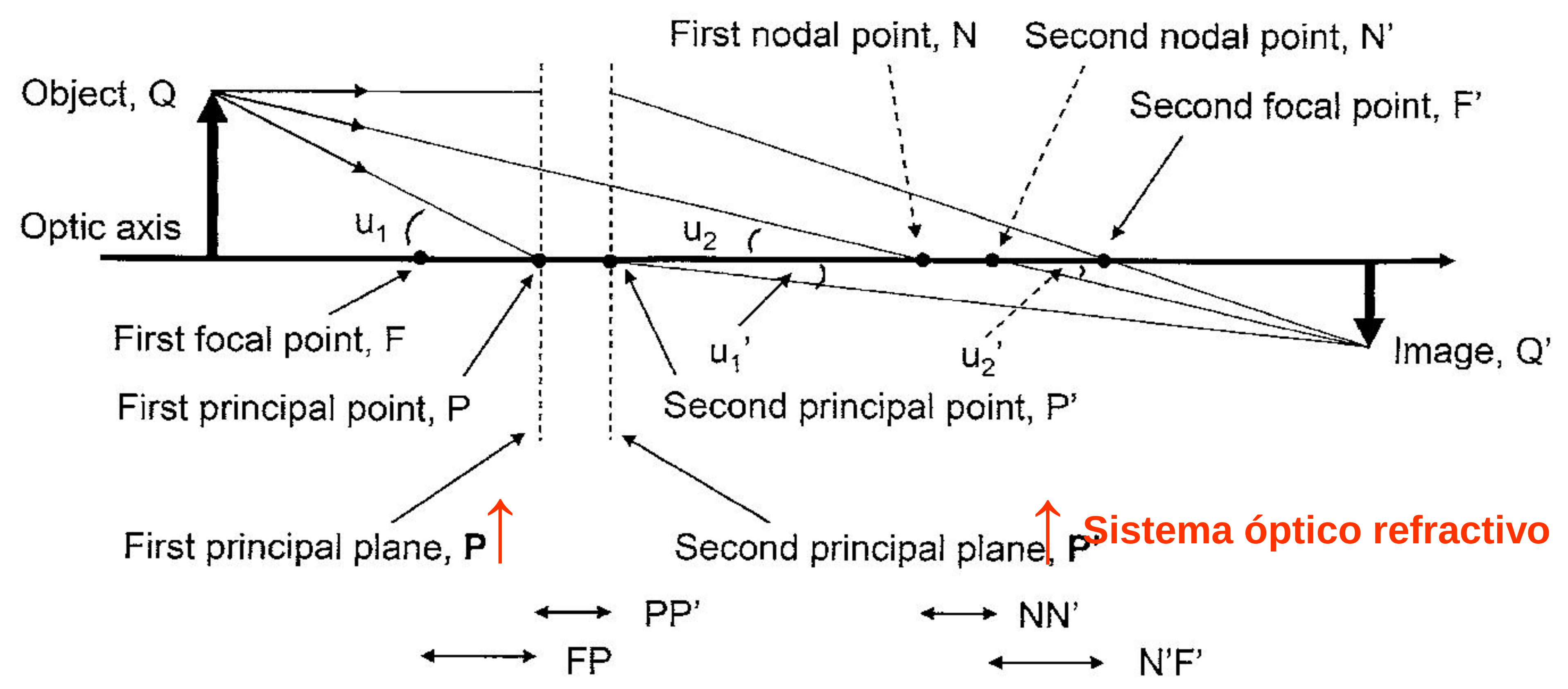
ESQUEMA DE LENTE DELGADA



ESQUEMA DE LENTE GRUESA



ESQUEMA DE SISTEMA OPTICO REFRACTIVO

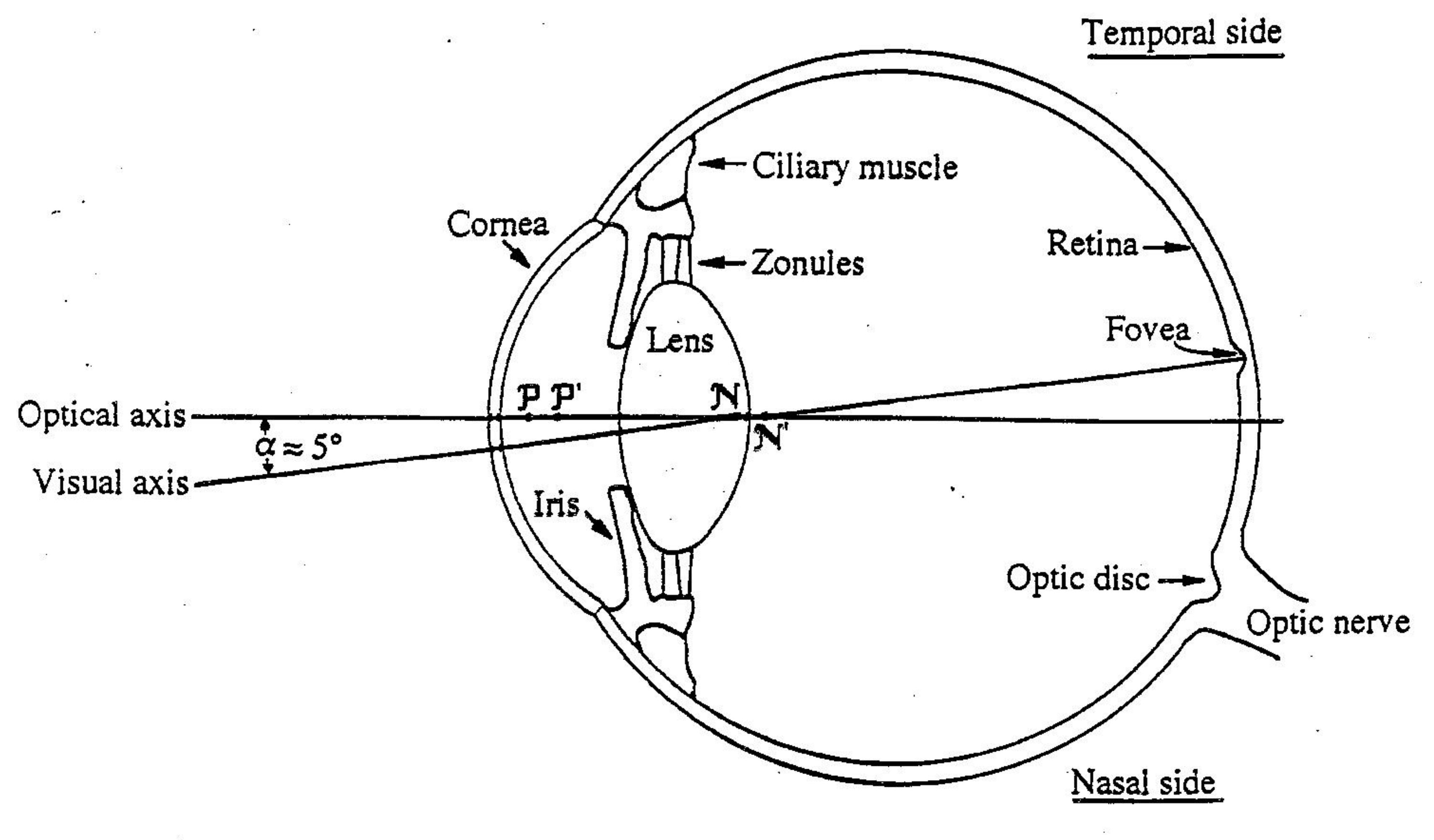


Sistema óptico refractivo

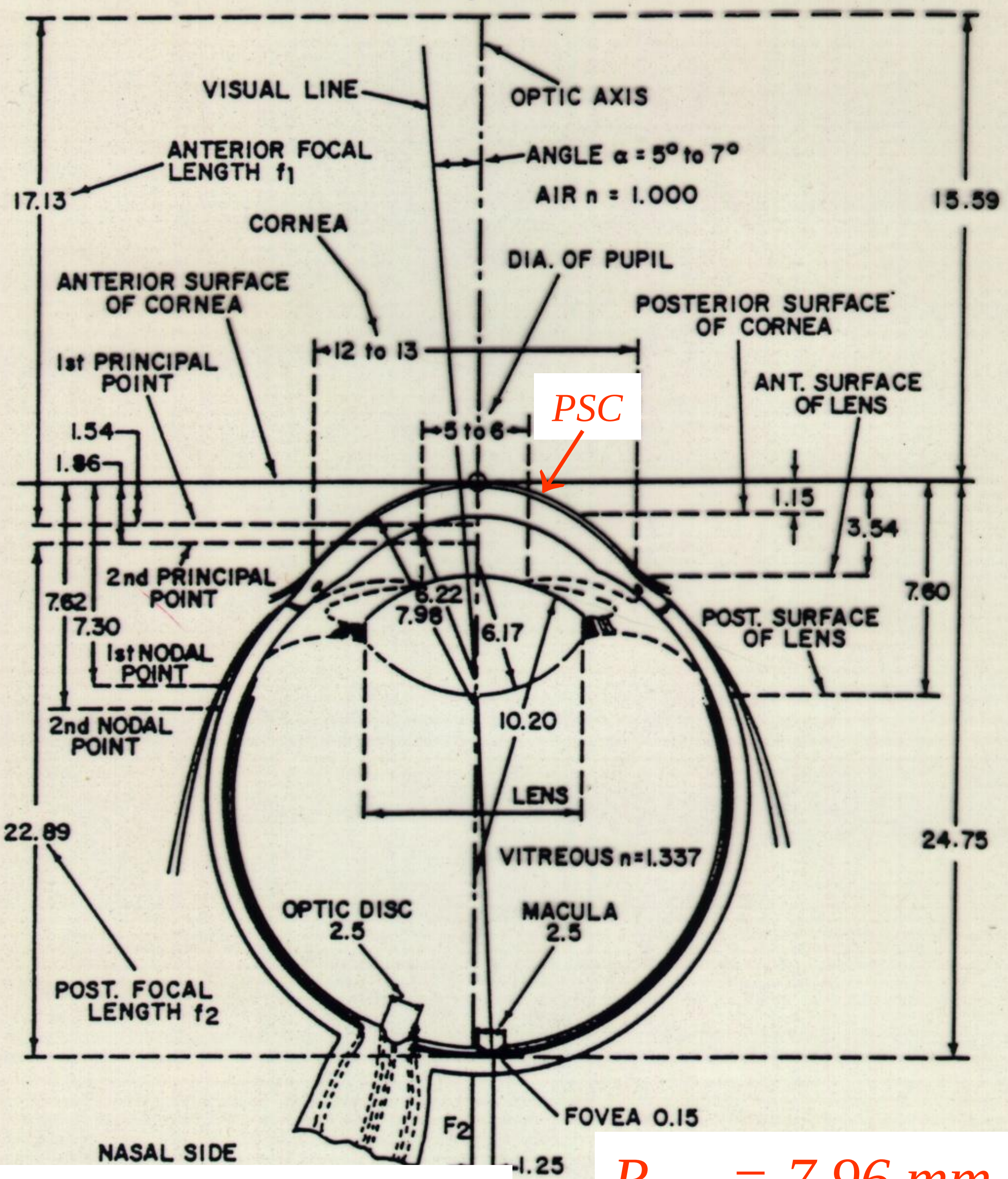
$$P_{eff} = P_a + P_b - \delta P_a P_b$$

$$\delta = \frac{t}{n_v}$$

ESQUEMA DE SISTEMA OPTICO OCULAR



Ojo Derecho Standard



PSC : Primera Superficie de la Córnea

$R_{PSC} = 7,96\ mm$

Figure B-1. Optical Constants For A "Standard Right Eye." Adapted from "Optical Design," MIL-HDBK-141, US Defense Department, 5 October 1962.

$n_{Aire} = 1,000$

$n_{Córnea} = 1,376$

$n_{H.\ A.} = 1,336$

$n_{C.\ Núcleo} = 1,406$
$n_{C.Polos} = 1,386$
$n_{C.Ecuador} = 1,375$
$n_{C.Cápsula} = 1,360$

$n_{H.V.} = 1,337$

$n_{agua} = 1,333$

MODELO ESQUEMATICO DE OJO 1 DE ALVAR GULLSTRAND

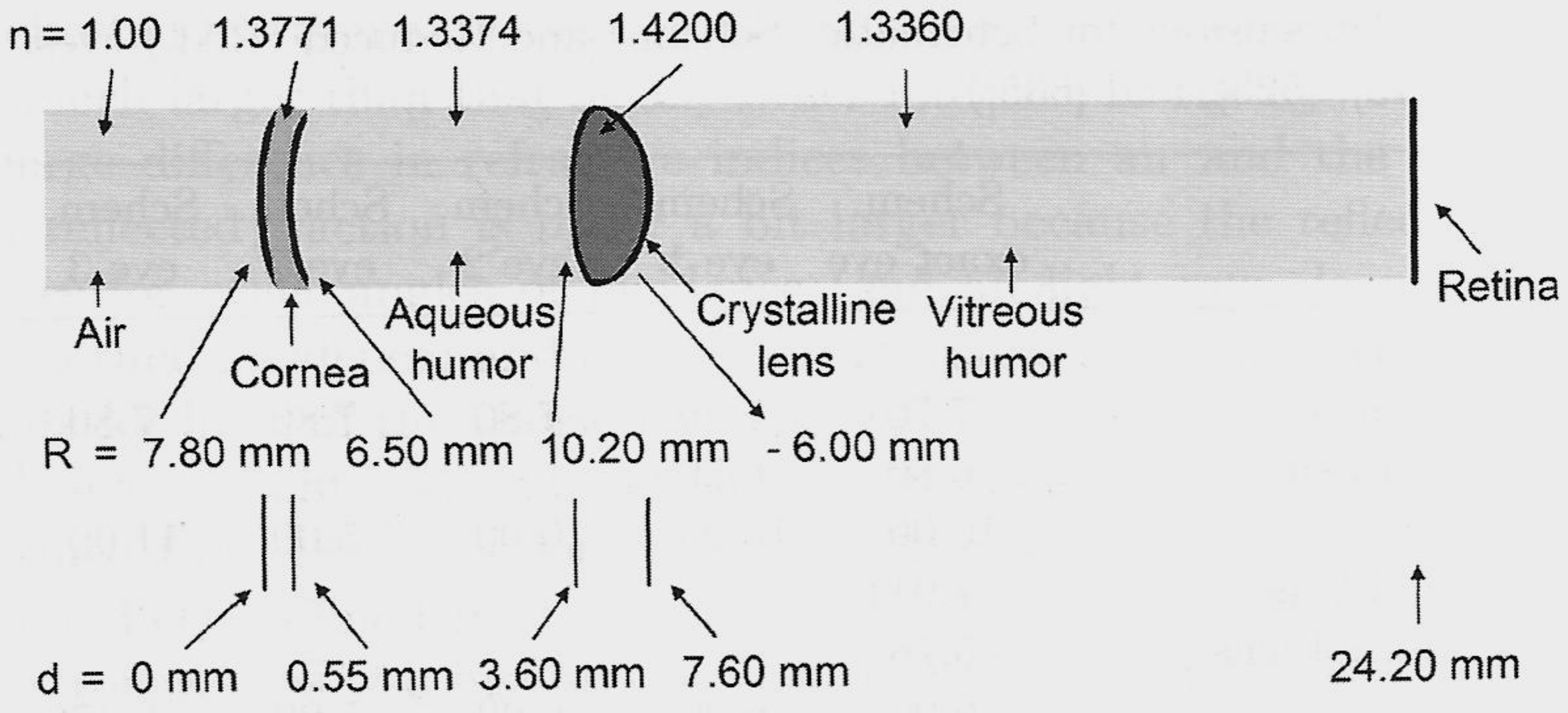


Fig. 11.19. Schematic eye 1

Alvar Gullstrand fue galardonado con el Premio Nobel de Medicina o Fisiología en 1911.

MODELO ESQUEMATICO DE OJO 2 (*Arriba*) Y OJO REDUCIDO (*Abajo*)

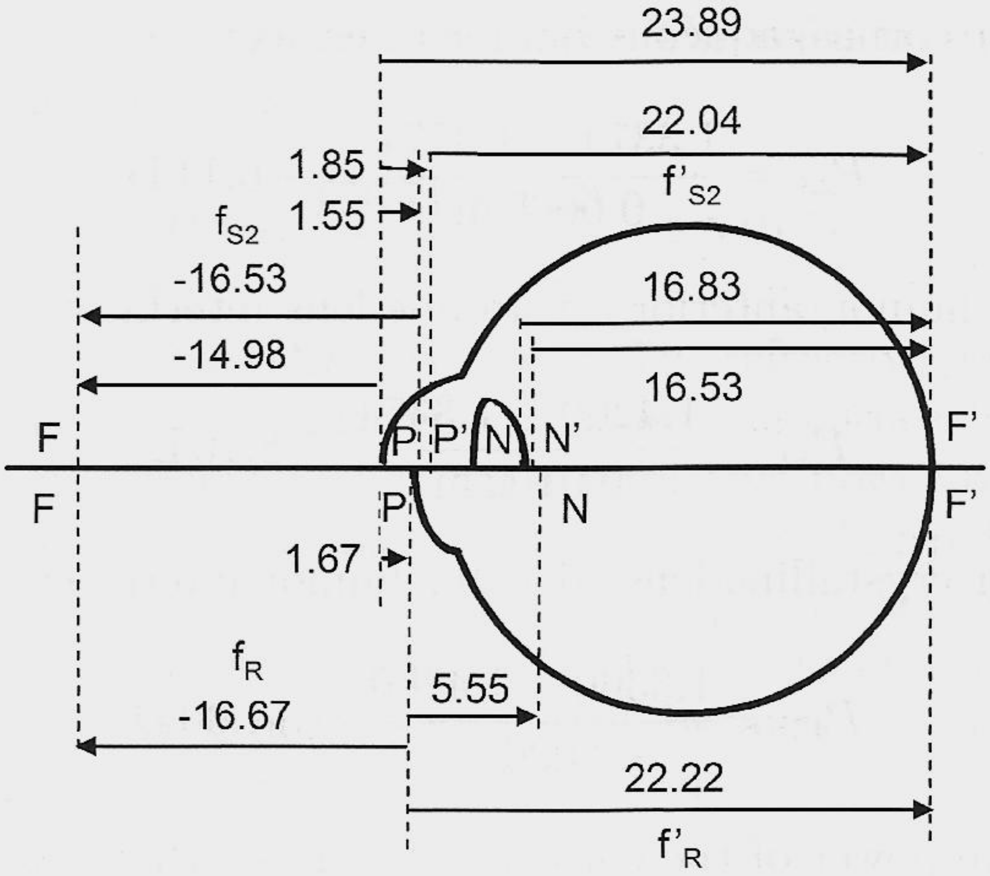


Fig. 11.20. Comparison of the cardinal points of the three-surface, relaxed Gullstrand–Emsley Schematic eye 2 in the *top* half and the Reduced eye in the *bottom* half. Distances are in mm. (Based on [513])

DIMENSIONES DE LOS MODELOS ESQUEMATICOS Y REDUCIDO

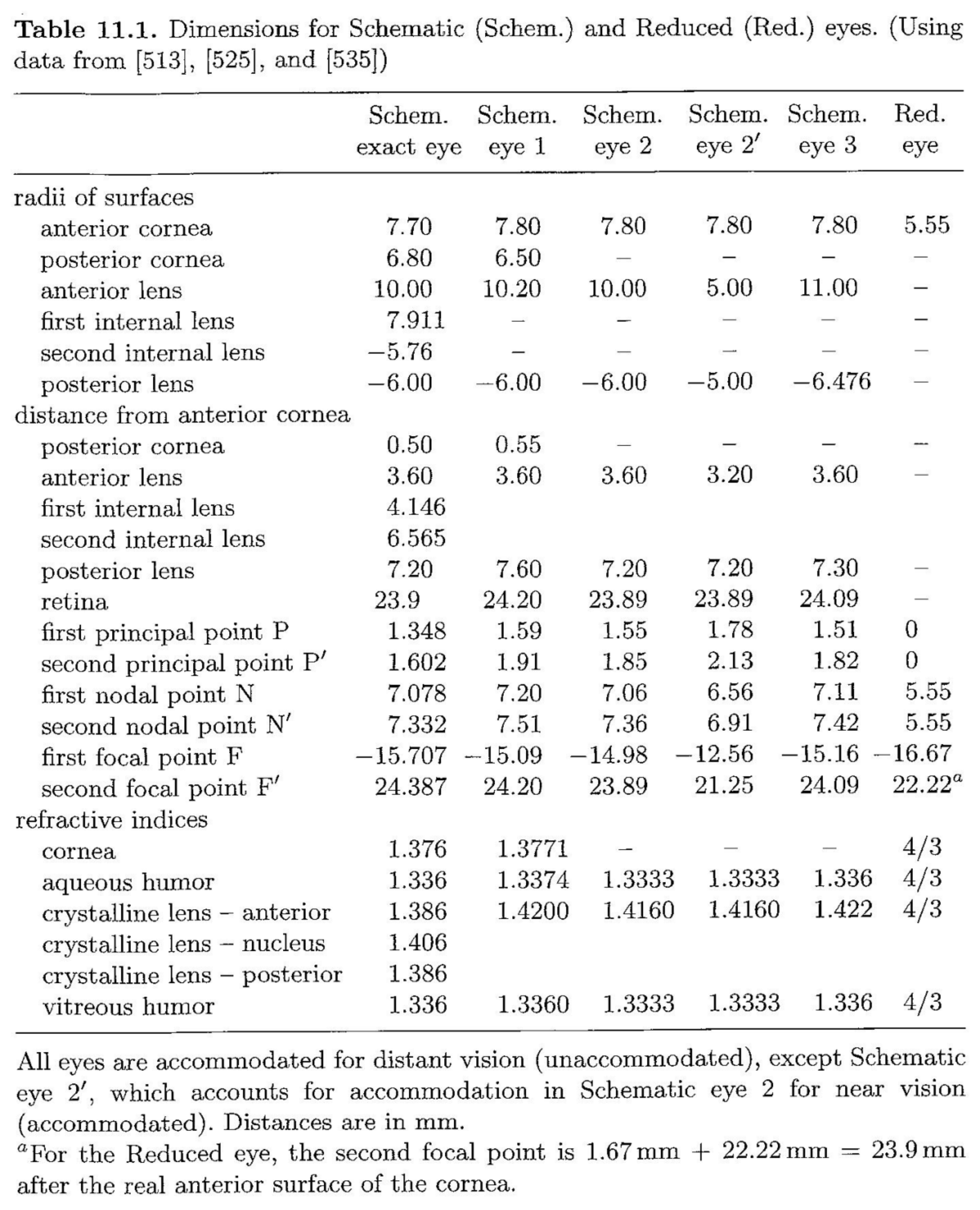


Table 11.1. Dimensions for Schematic (Schem.) and Reduced (Red.) eyes. (Using data from [513], [525], and [535])

	Schem. exact eye	Schem. eye 1	Schem. eye 2	Schem. eye $2'$	Schem. eye 3	Red. eye
radii of surfaces						
anterior cornea	7.70	7.80	7.80	7.80	7.80	5.55
posterior cornea	6.80	6.50	–	–	–	–
anterior lens	10.00	10.20	10.00	5.00	11.00	–
first internal lens	7.911	–	–	–	–	–
second internal lens	−5.76	–	–	–	–	–
posterior lens	−6.00	−6.00	−6.00	−5.00	−6.476	–
distance from anterior cornea						
posterior cornea	0.50	0.55	–	–	–	–
anterior lens	3.60	3.60	3.60	3.20	3.60	–
first internal lens	4.146					
second internal lens	6.565					
posterior lens	7.20	7.60	7.20	7.20	7.30	–
retina	23.9	24.20	23.89	23.89	24.09	–
first principal point P	1.348	1.59	1.55	1.78	1.51	0
second principal point P'	1.602	1.91	1.85	2.13	1.82	0
first nodal point N	7.078	7.20	7.06	6.56	7.11	5.55
second nodal point N'	7.332	7.51	7.36	6.91	7.42	5.55
first focal point F	−15.707	−15.09	−14.98	−12.56	−15.16	−16.67
second focal point F'	24.387	24.20	23.89	21.25	24.09	22.22^a
refractive indices						
cornea	1.376	1.3771	–	–	–	4/3
aqueous humor	1.336	1.3374	1.3333	1.3333	1.336	4/3
crystalline lens – anterior	1.386	1.4200	1.4160	1.4160	1.422	4/3
crystalline lens – nucleus	1.406					
crystalline lens – posterior	1.386					
vitreous humor	1.336	1.3360	1.3333	1.3333	1.336	4/3

All eyes are accommodated for distant vision (unaccommodated), except Schematic eye $2'$, which accounts for accommodation in Schematic eye 2 for near vision (accommodated). Distances are in mm.

[a] For the Reduced eye, the second focal point is 1.67 mm + 22.22 mm = 23.9 mm after the real anterior surface of the cornea.

CORRECCIONES DE DEFECTOS VISUALES

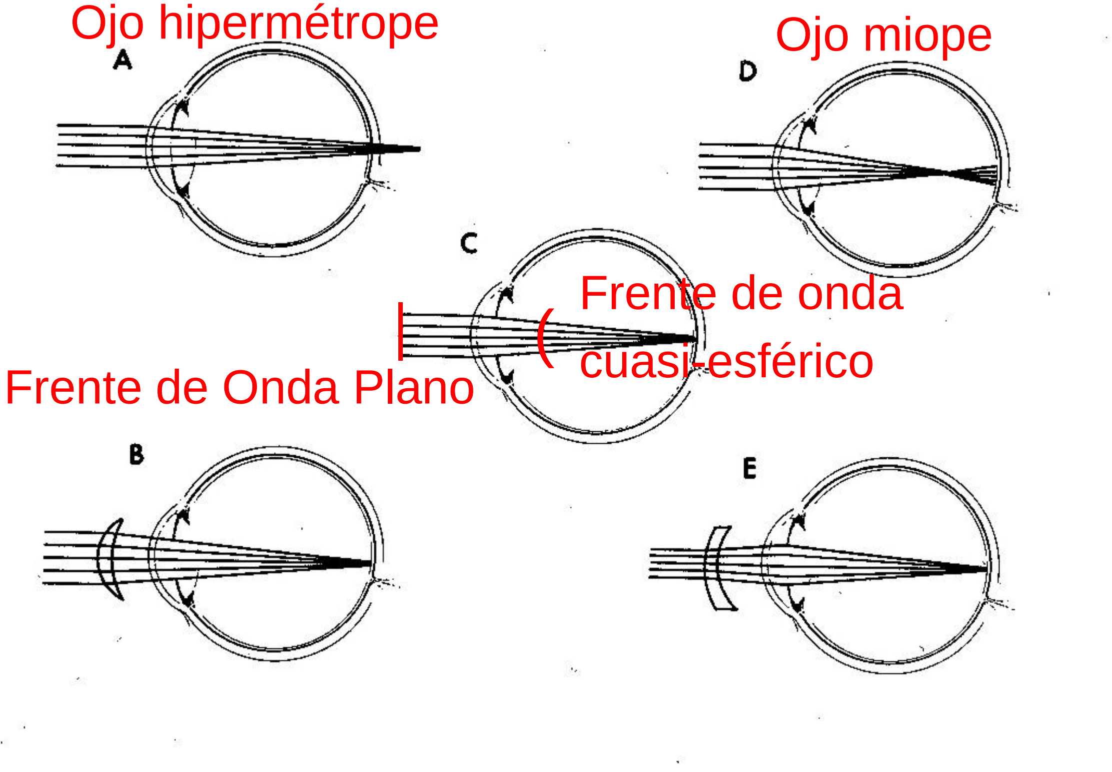


Figure 3-8. Illustration of optical defects of the human eye and the corresponding spectacle lens corrections. The simple ray diagrams illustrate how the rays from a collimated point source at infinity would be imaged at the retina. In hyperopia shown in panel A (farsightedness), the rays are imaged behind the retina. Panel B shows how a positive lens is used to correct this problem. The middle panel, C, illustrates emmetropia, the normal eye. Panel D shows myopia, or nearsightedness, where the rays are imaged in front of the retina. Panel E illustrates how a negative lens corrects this problem.

Así no se corrigen *todos* los defectos visuales, ni se mejora la Audeza Visual, porque el Frente de Onda Cuasi-esférico puede haber sido aberrado por el propio ojo.

CIRUGIA FOTORREFRACTIVA **LASIK** (**L**ASER **A**SSISTED IN **SI**TU **K**ERATOMILEUSIS)

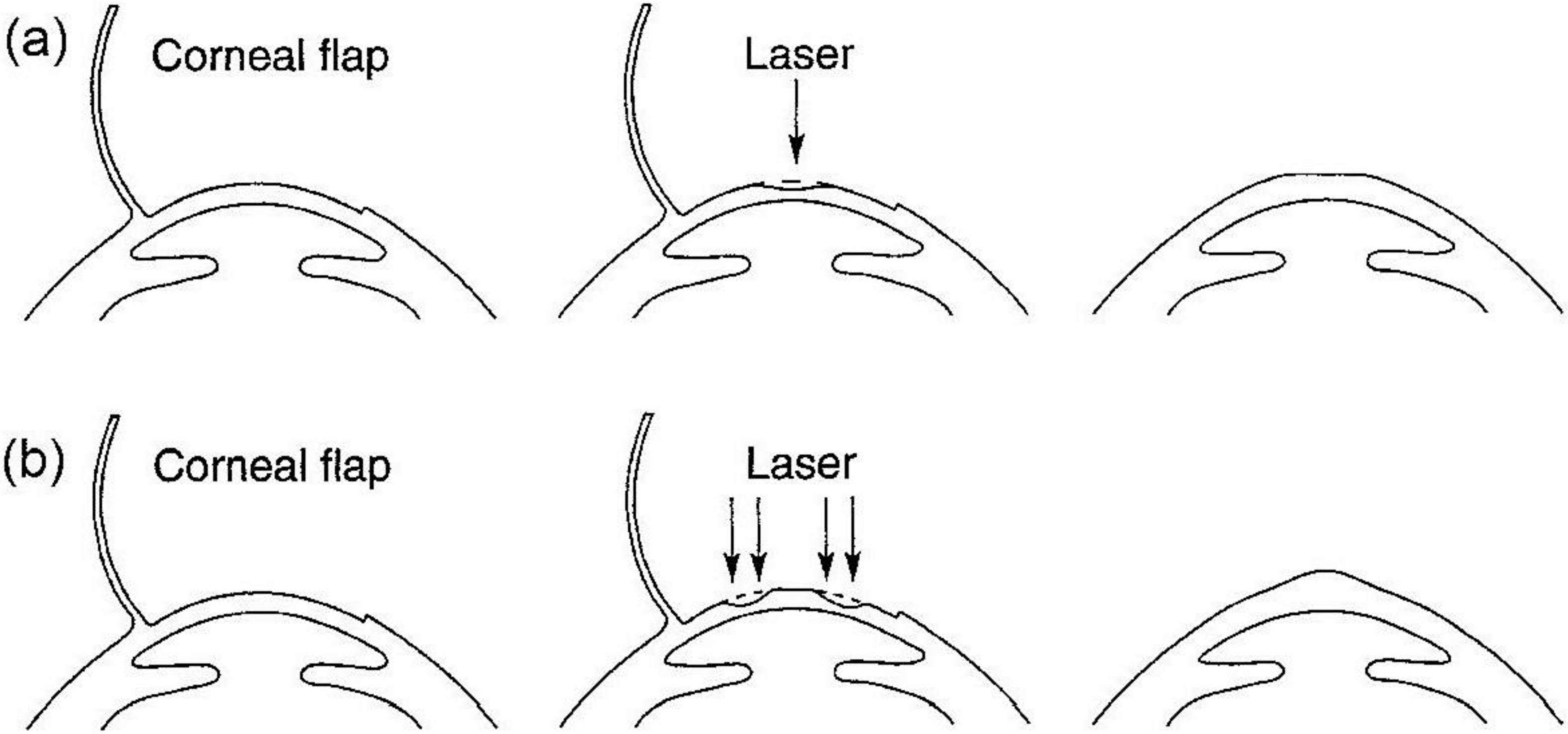


Fig. 11.43. In LASIK surgery the central cornea is made (**a**) more flat to correct for myopia and (**b**) more curved to correct for hyperopia. (From [553]. Reprinted with permission of McGraw-Hill)

EL ESPECTRO ELECTROMAGNETICO III

Velocidad de la luz en el vacío

$$c = \nu \times \lambda$$

$c = 299\,792\,458$ m/s

Energía de un fotón

$$E = h \times \nu$$

Constante de Planck

$h = 6{,}6256 \times 10^{-34}$ Js

EJEMPLO:

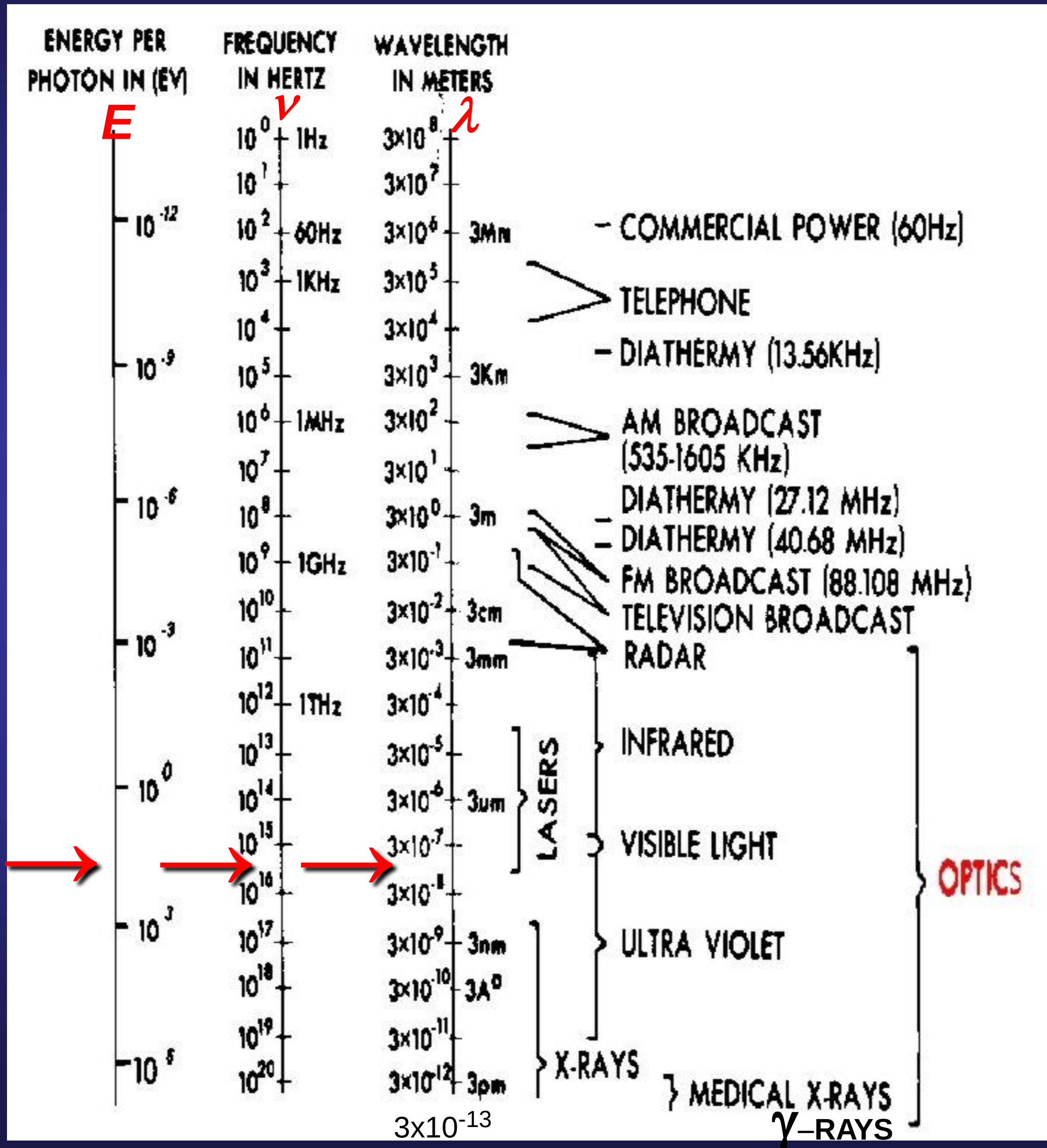
Láser de EXCIMERO (Ar-F).

λ = **193 nm**

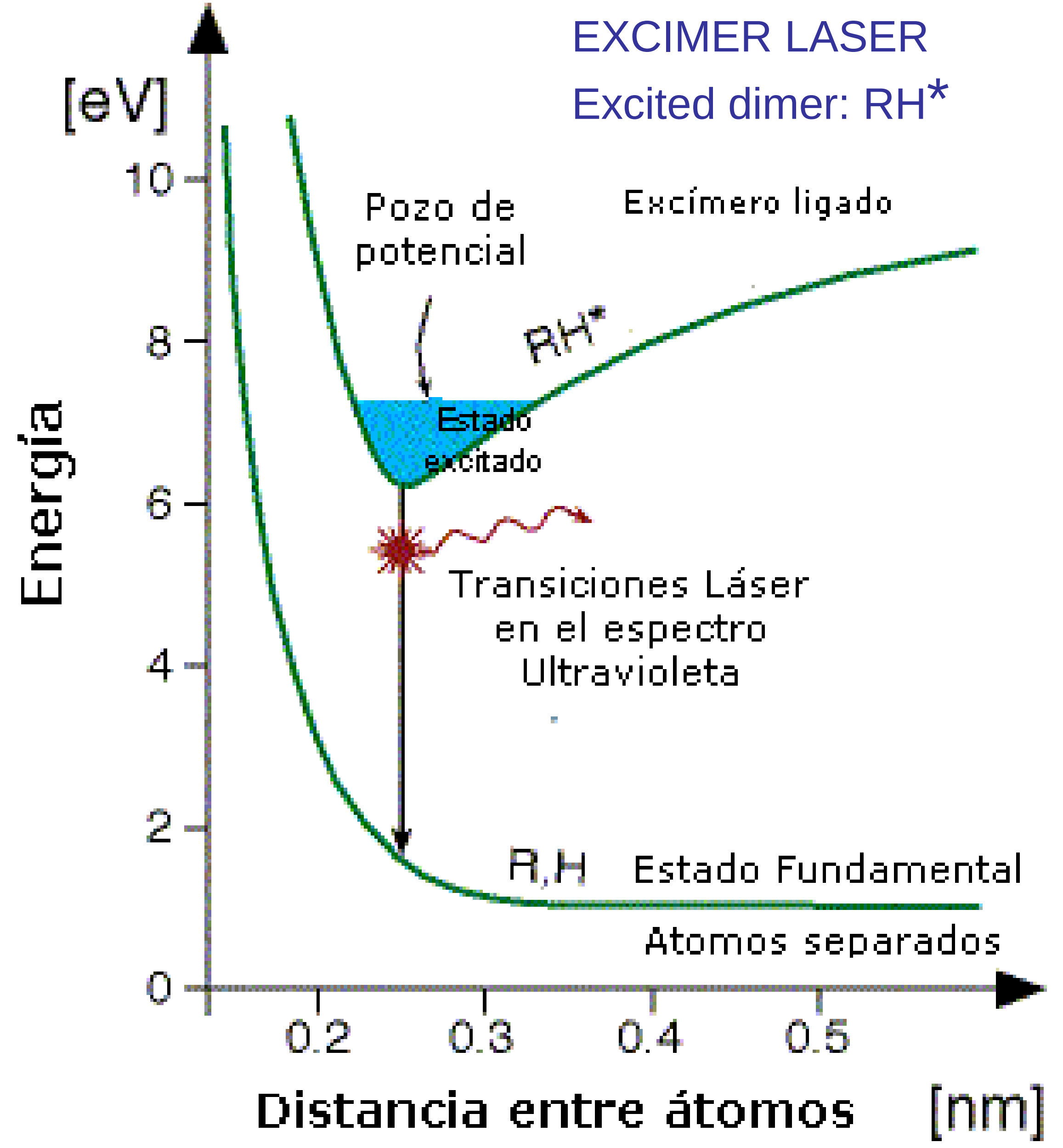
ν = **1, 5 x 10^{15} Hz = 1, 5 PHz**

E_ν = **1,03 x 10^{-15} mJ = 1,03 aJ**

P se lee Peta (5), y el **a**, atto (18).



FISICA DE LOS LASERES DE EXCIMEROS



R ≡ Gases Raros o Nobles
H ≡ Halógenos

* ≡ Excitados

LASERES

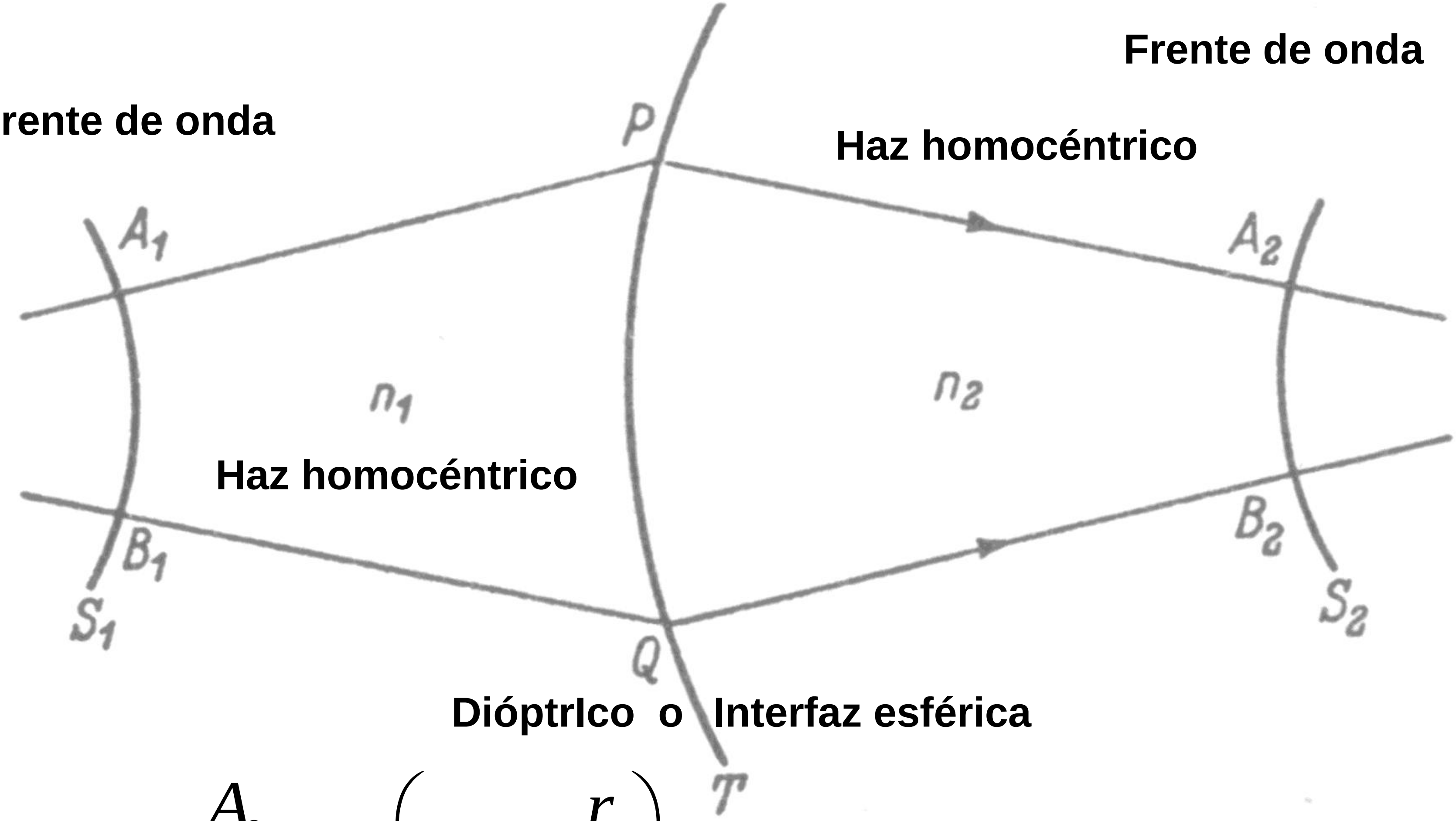
XeF $\lambda = 353$ nm

XeCl $\lambda = 308$ nm

KrF $\lambda = 248$ nm

ArF $\lambda = 193$ nm

TEOREMA DE MALUS (1808) Y DUPIN (1816)



Frente de onda

Frente de onda

Haz homocéntrico

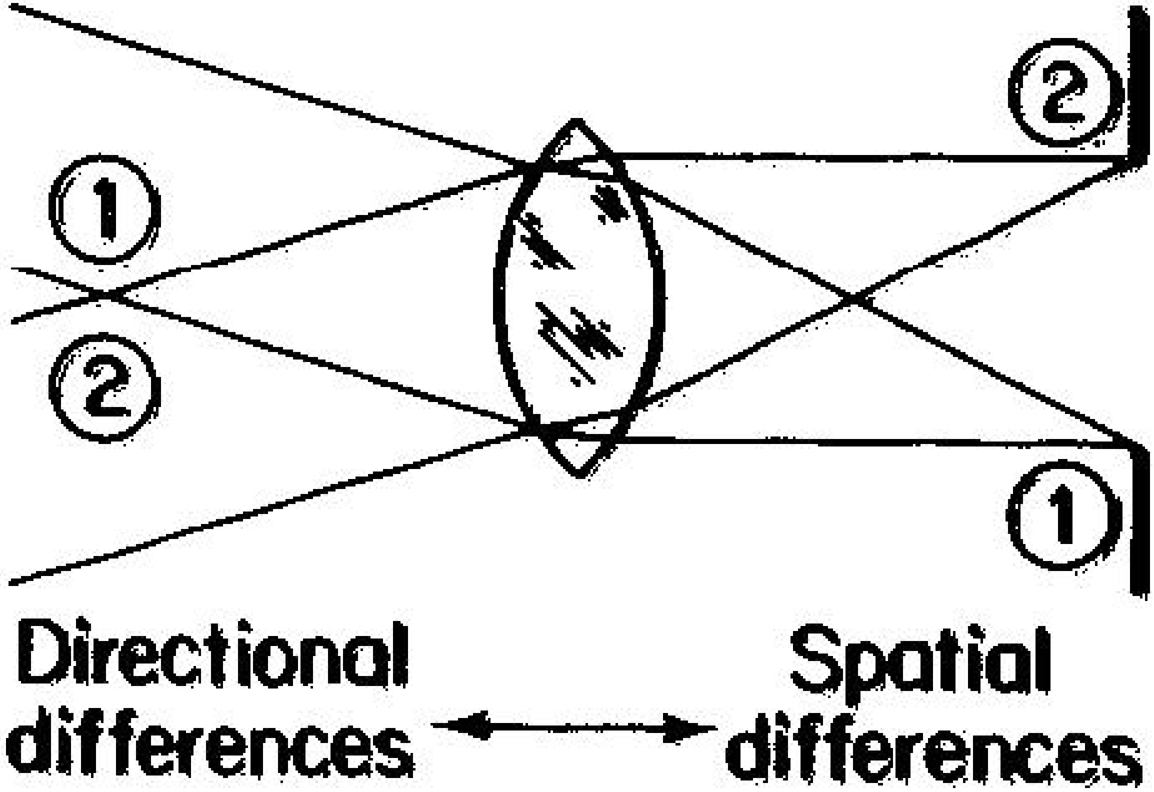
Haz homocéntrico

DióptrIco o Interfaz esférica

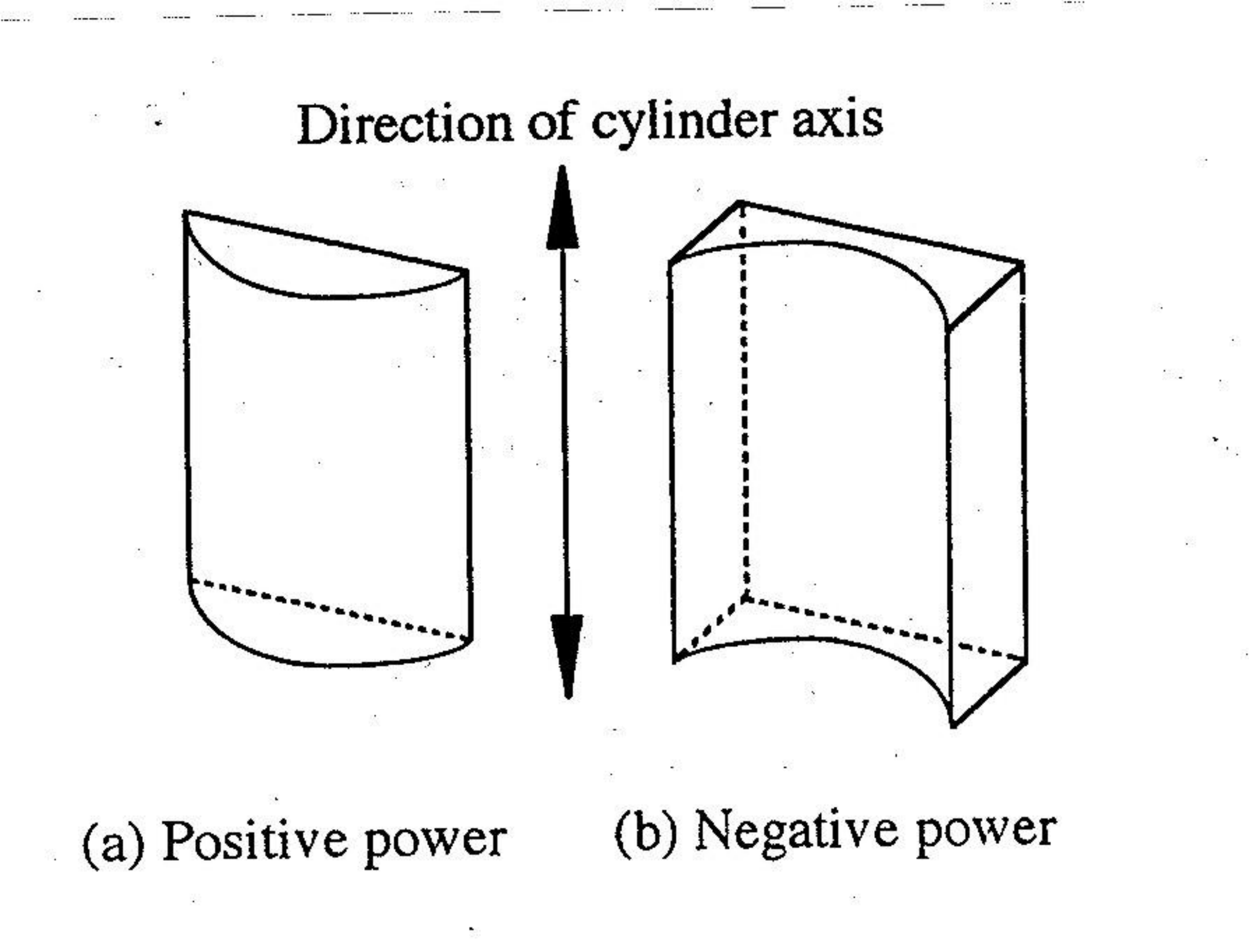
$$A_{Esférica} = \frac{A_0}{r} \exp\left(\pm 2\pi i \frac{r}{\lambda} \right)$$

LAS LENTES SON TRANSFORMADORES DE LAS FASES DE LAS ONDAS

$$A_{Plana} = A_0 \exp\left(\pm 2\pi i \frac{r}{\lambda} \right) \qquad A_{Esférica} = \frac{A_0}{r} \exp\left(\pm 2\pi i \frac{r}{\lambda} \right)$$

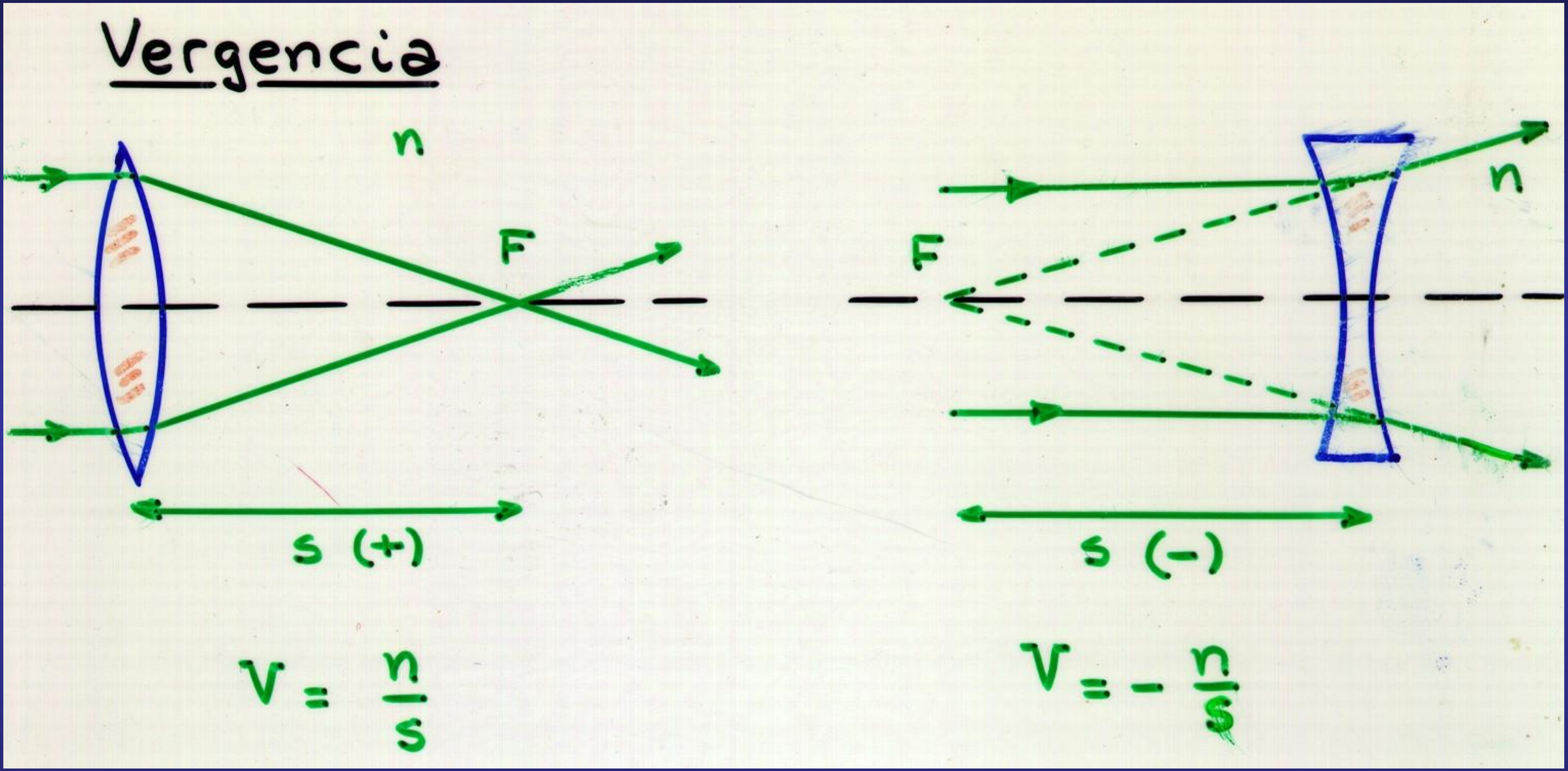


LENTES CILINDRICAS



Lentes cilíndricas para mitigar el astigmatismo en un eje

POTENCIA Y VERGENCIA



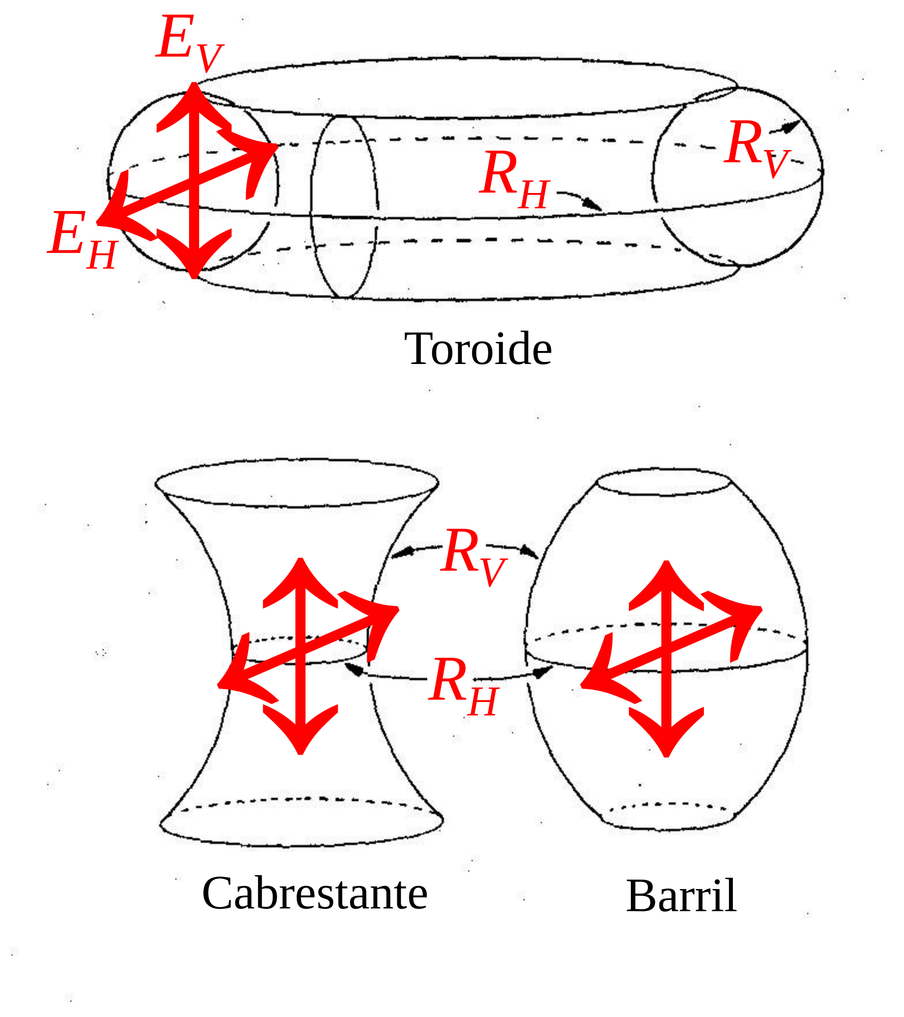
$$\frac{1}{f_{PSC}} = P_{PSC} = \left(n_{Aire} - n_{\text{Córnea}}\right)\frac{1}{R_{PSC}} =$$

$$= \left(1{,}000 - 1{,}376\right)\frac{1}{-0{,}00796m} = 47{,}24D$$

$$\frac{1}{f_{SSC}} = P_{SSC} = \left(n_{\text{Córnea}} - n_{Acuoso}\right)\frac{1}{R_{SSC}} =$$

$$= \left(1{,}376 - 1{,}336\right)\frac{1}{-0{,}00622m} = -6{,}43D$$

LENTES TORICAS



Lentes tóricas para mitigar el astigmatismo en dos ejes

LENTES DE FOCO VARIABLE I

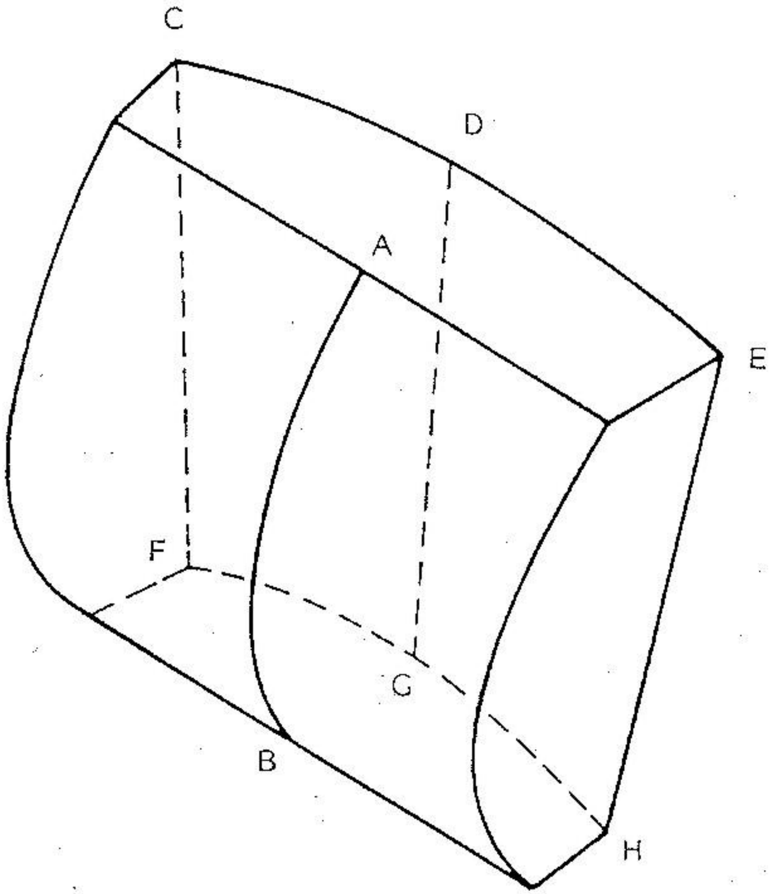


Figure 1 A schematic illustration (after Bennett, 1970) showing the Aves (1907) lens. One surface is a horizontally orientated cylinder in which the power increases continuously from A to B. The second surface of the lens consists of a portion of a conical section with a vertical axis and an inferior apex. The curvature of arc FGH is greater than CDE.

LENTES DE FOCO VARIABLE II

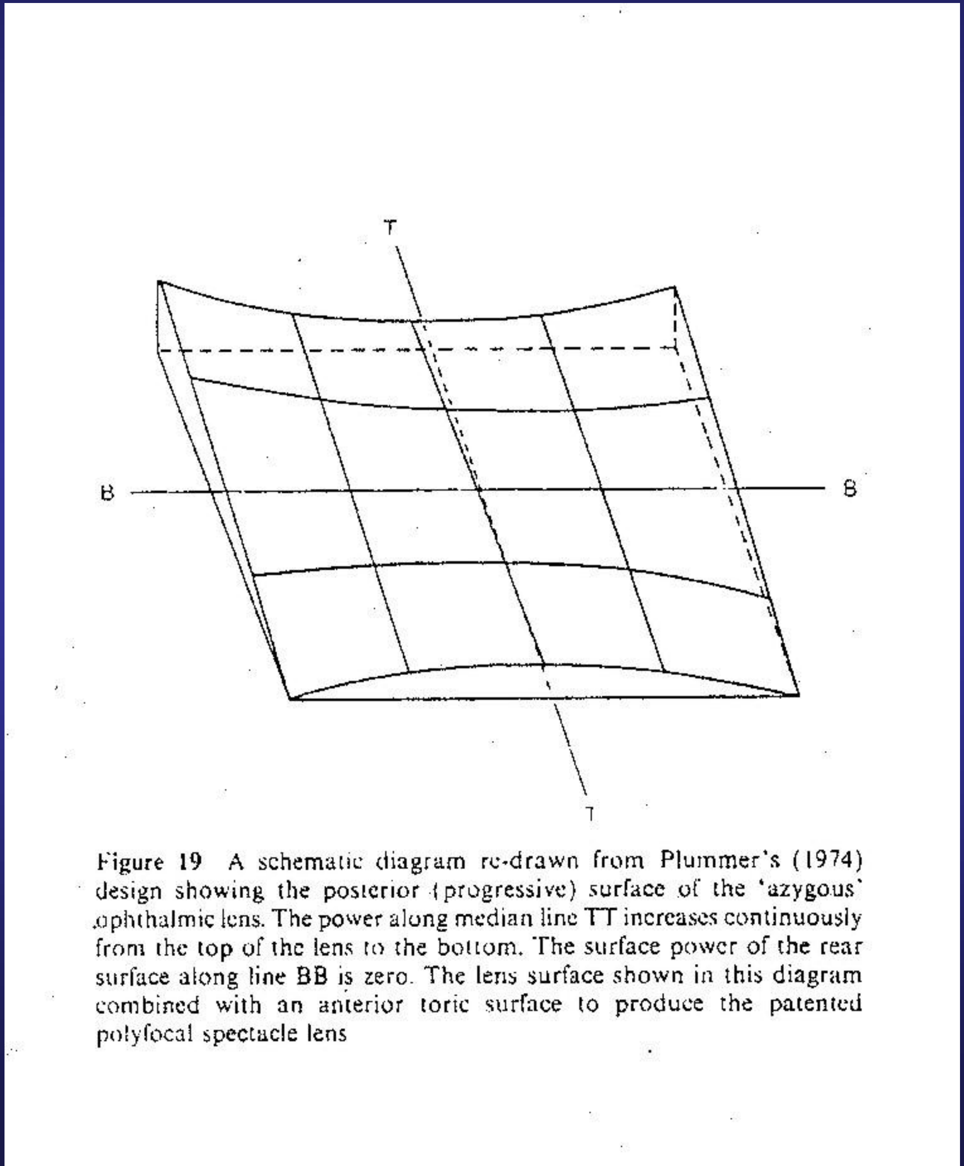
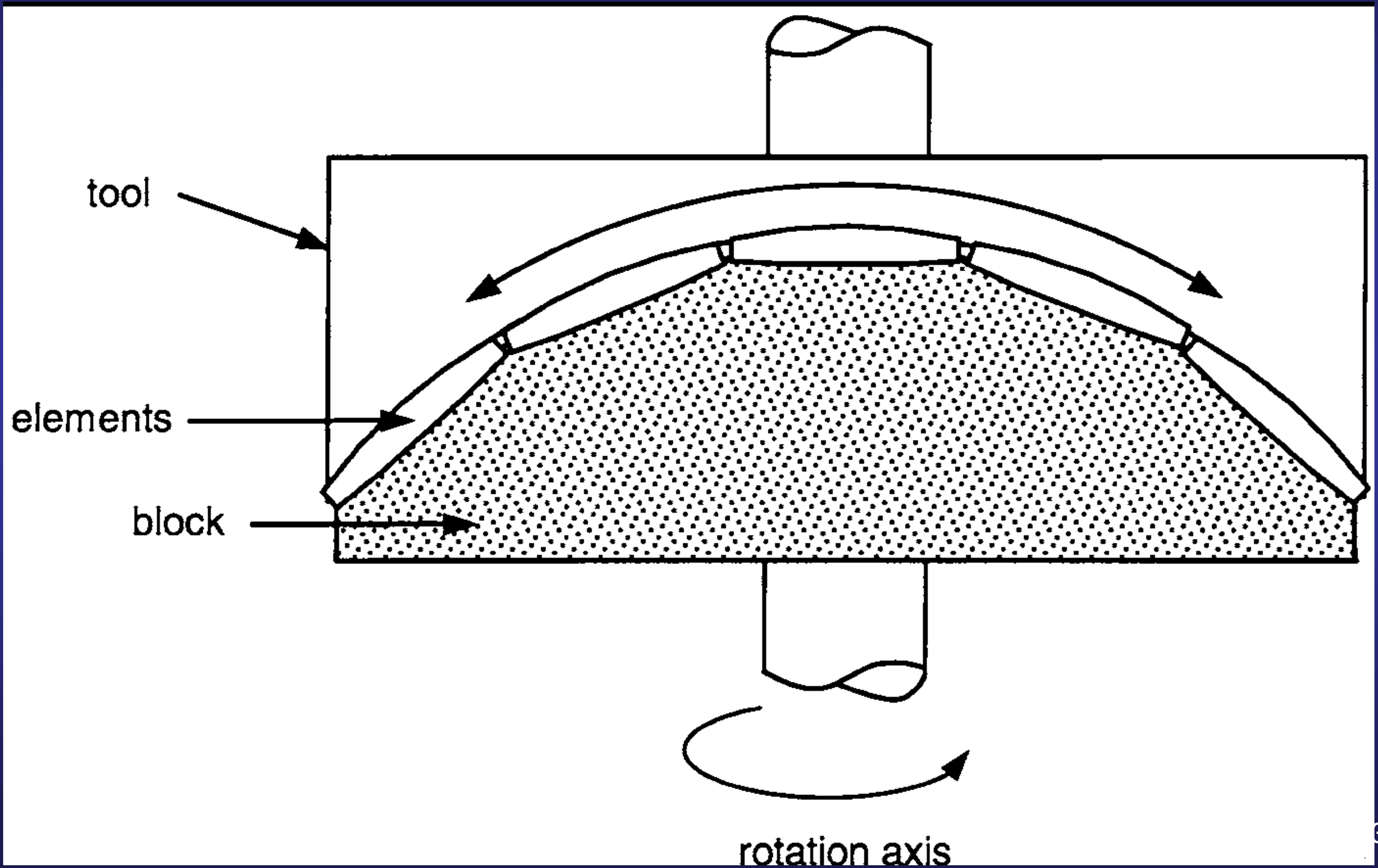
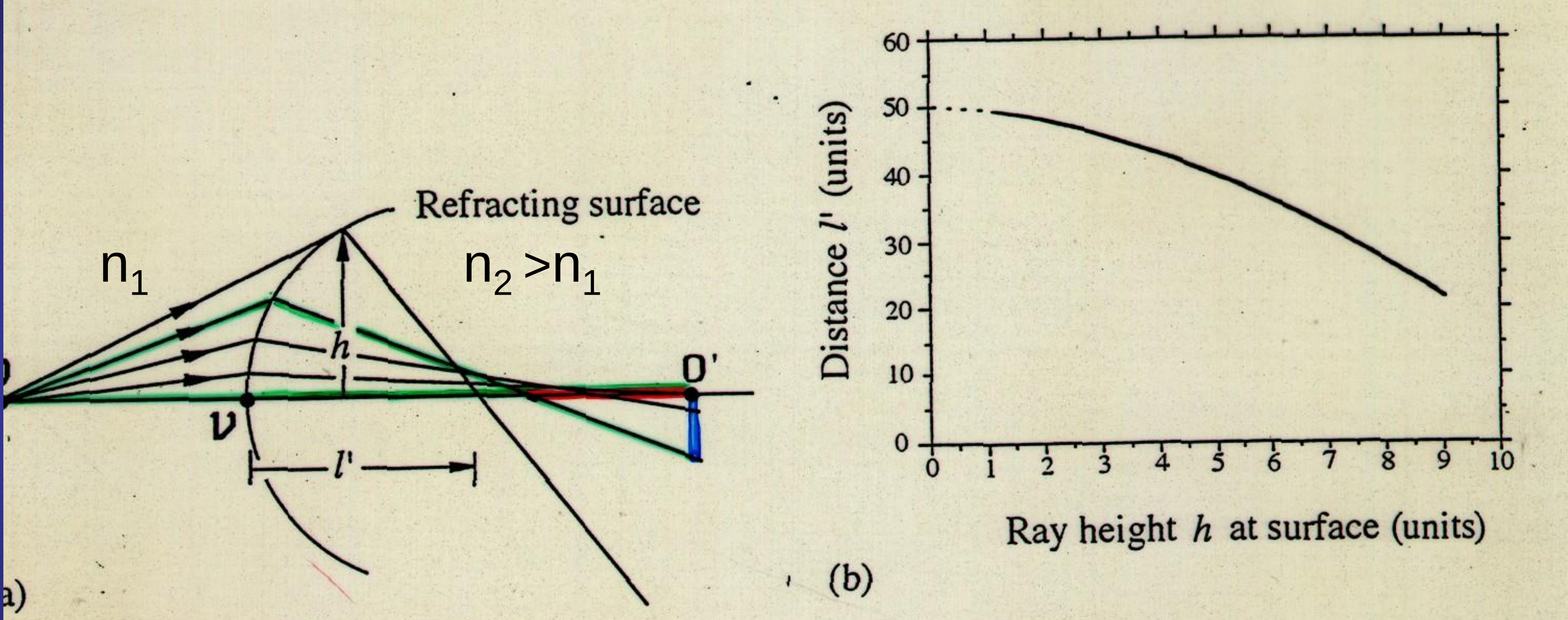


Figure 19 A schematic diagram re-drawn from Plummer's (1974) design showing the posterior (progressive) surface of the 'azygous' ophthalmic lens. The power along median line TT increases continuously from the top of the lens to the bottom. The surface power of the rear surface along line BB is zero. The lens surface shown in this diagram combined with an anterior toric surface to produce the patented polyfocal spectacle lens

PRODUCCIÓN DE SUPERFICIES ÓPTICAS ESFÉRICAS



ABERRACION DE UN CASQUETE ESFERICO O DIOPTRO



🟥 Aberración longitudinal

🟦 Aberración transversal

ABERRACIONES DE LAS LENTES I

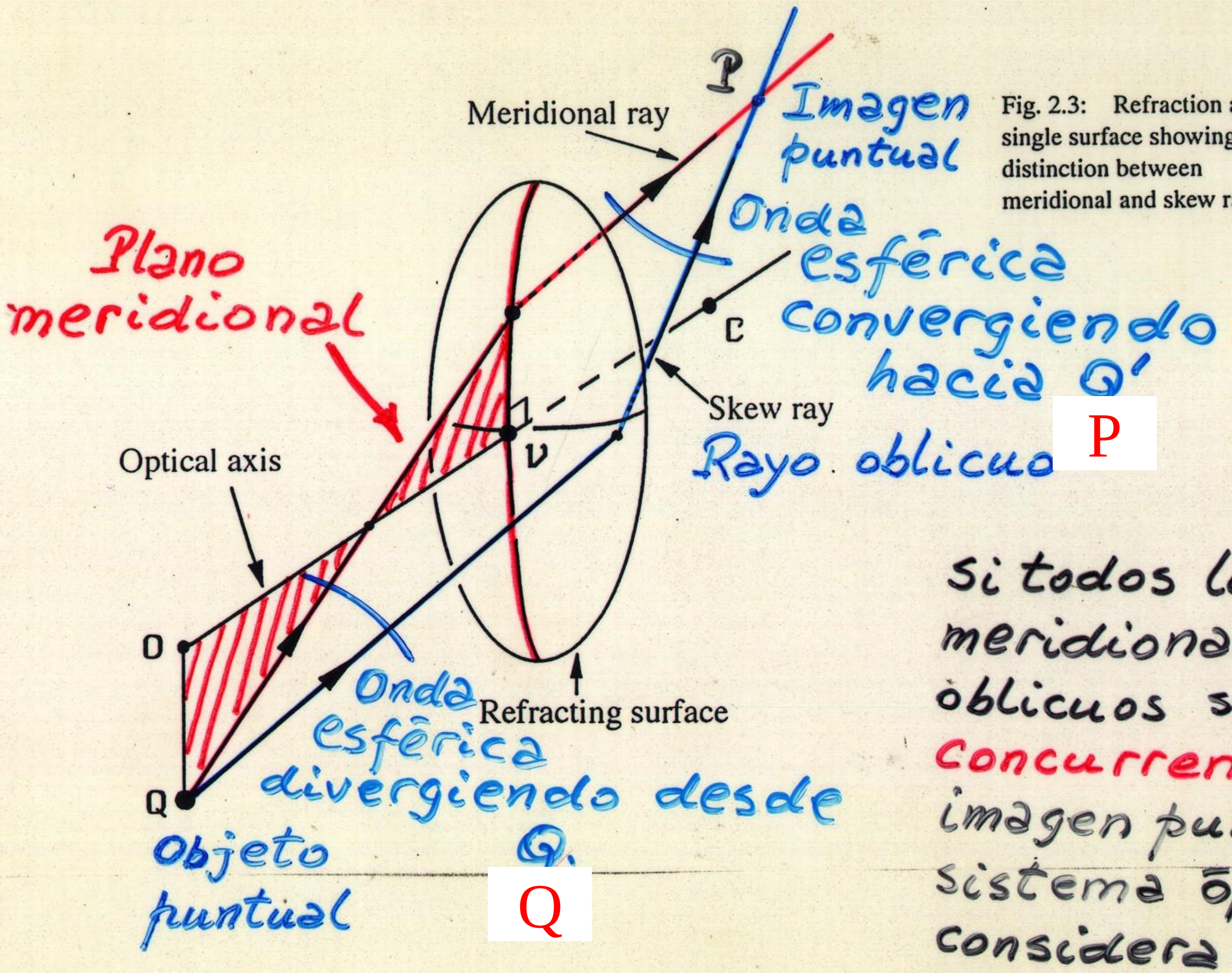
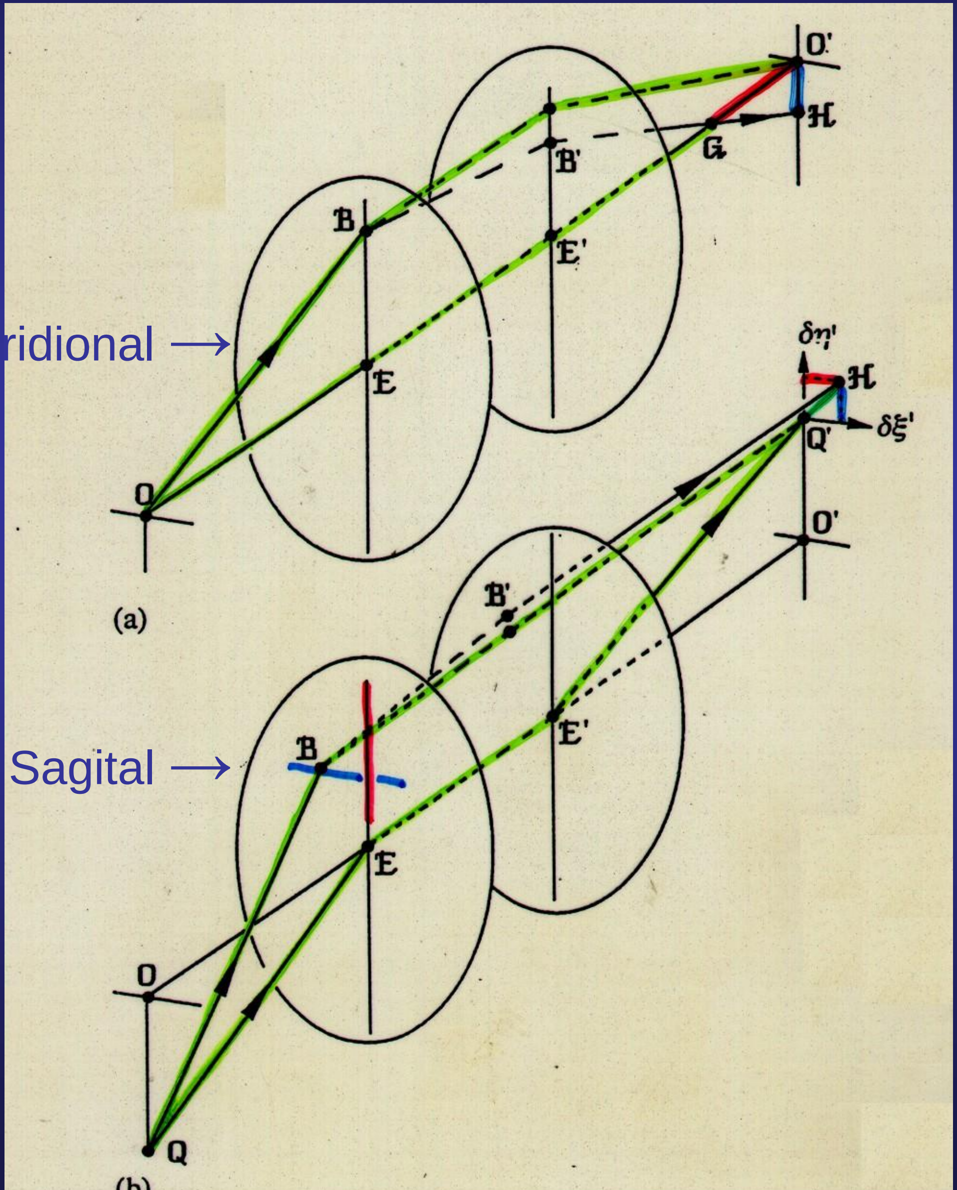


Fig. 2.3: Refraction at a single surface showing the distinction between meridional and skew rays.

Si todos los rayos meridionales y oblicuos son concurrentes en la imagen puntual, el sistema óptico se considera libre de aberraciones

Q y P son puntos conjugados

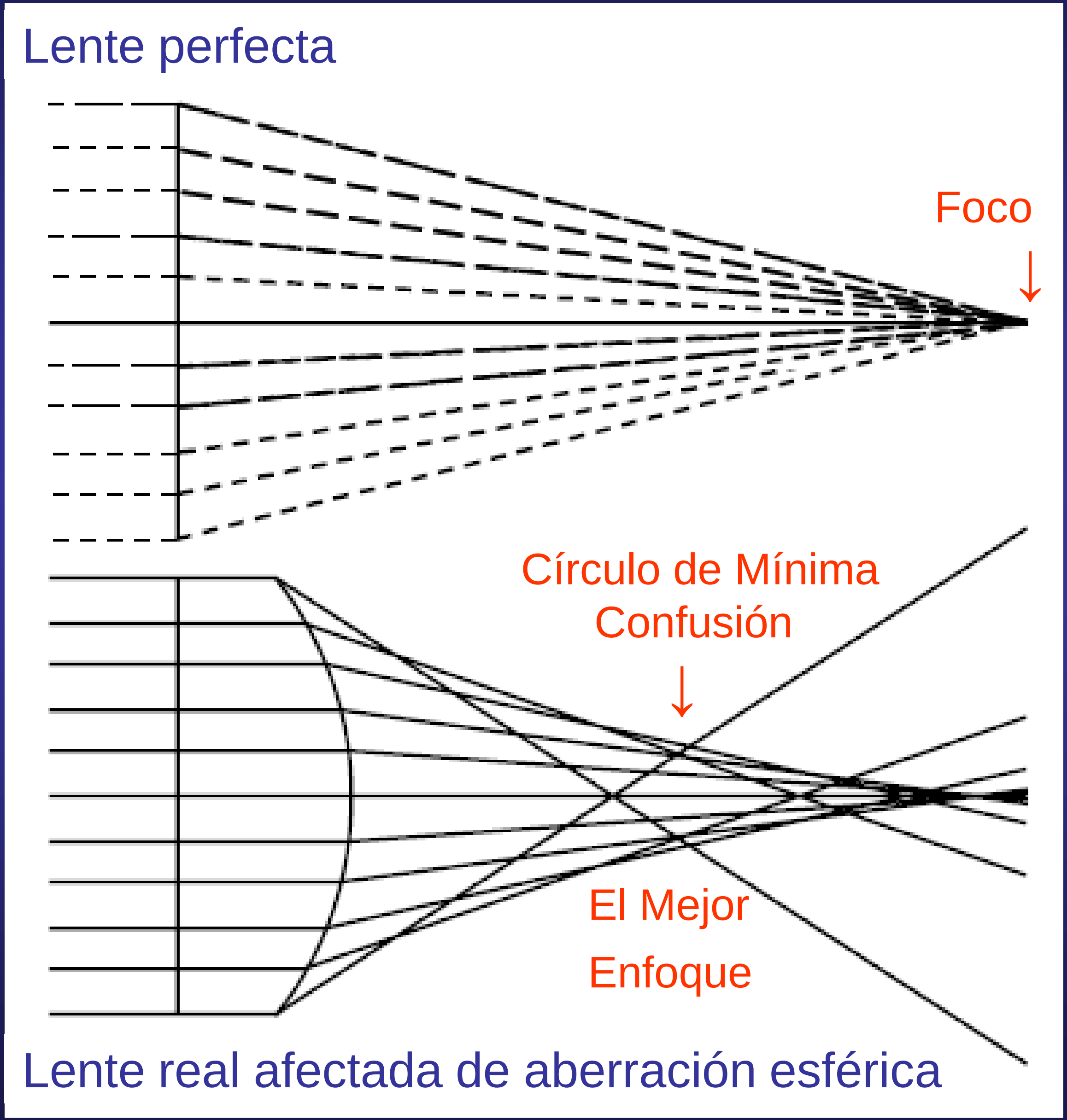
ABERRACIONES DE LAS LENTES II



Plano Meridional ⟶

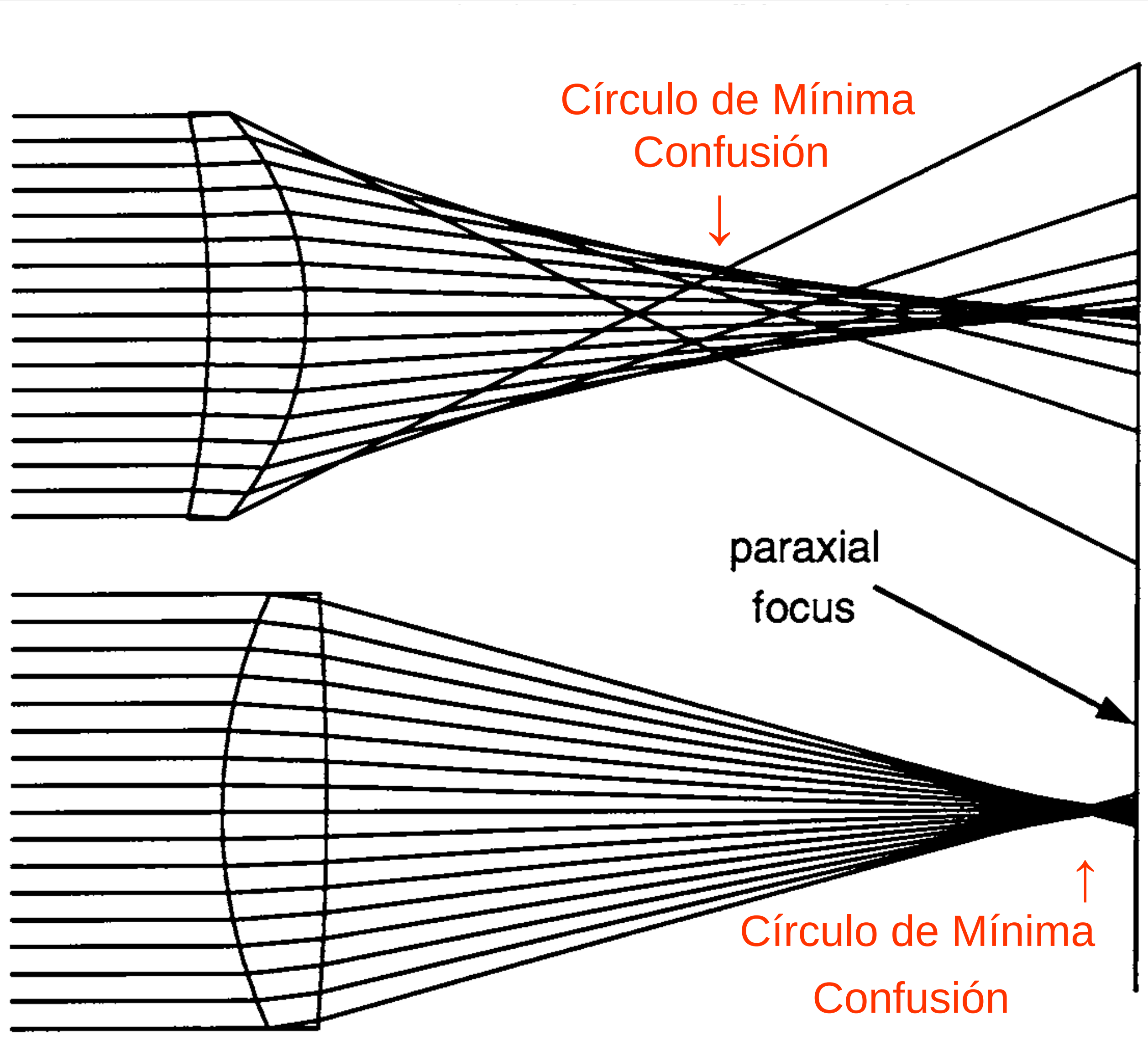
Plano Sagital ⟶

ABERRACION ESFERICA I

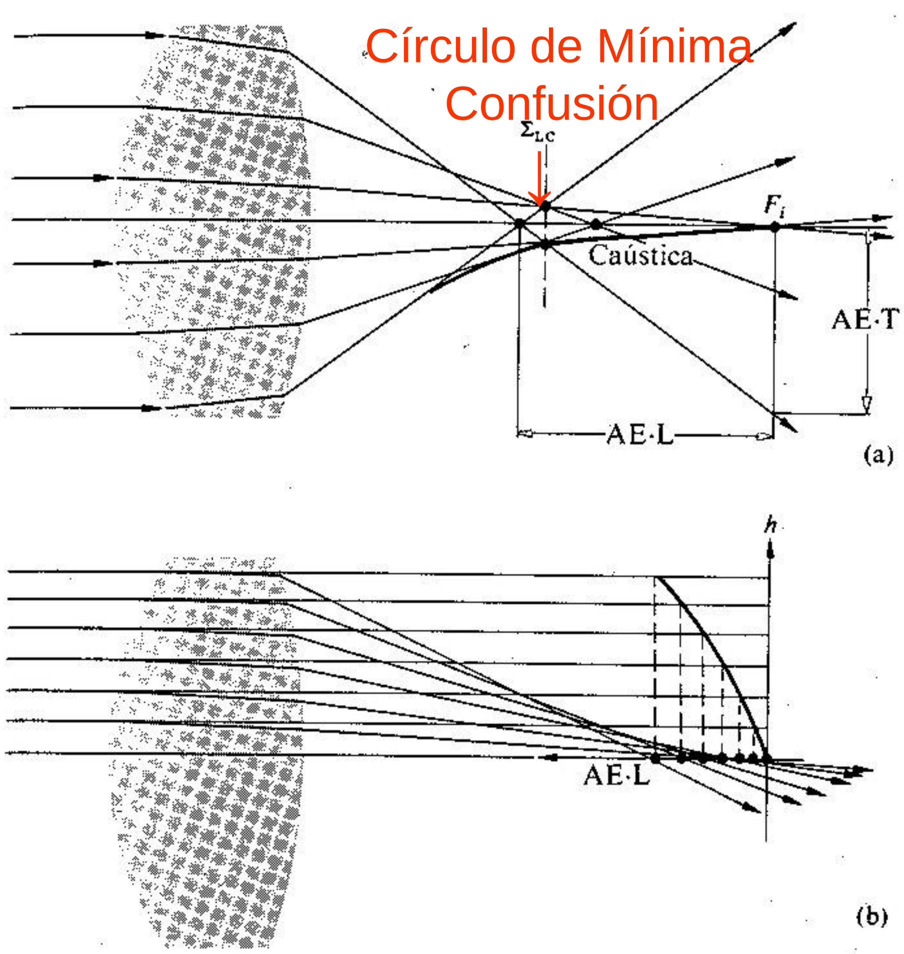

Lente perfecta

Lente real afectada de aberración esférica

ABERRACION ESFERICA II



ABERRACION ESFERICA III



Círculo de Mínima Confusión

Fig. 6.13 Aberración esférica para una sola lente. La envolvente de los rayos refractados es llamada la cáustica. La intersección de los rayos marginales y la cáustica localiza el plano Σ_{LC}.

ABERRACION POR COMA

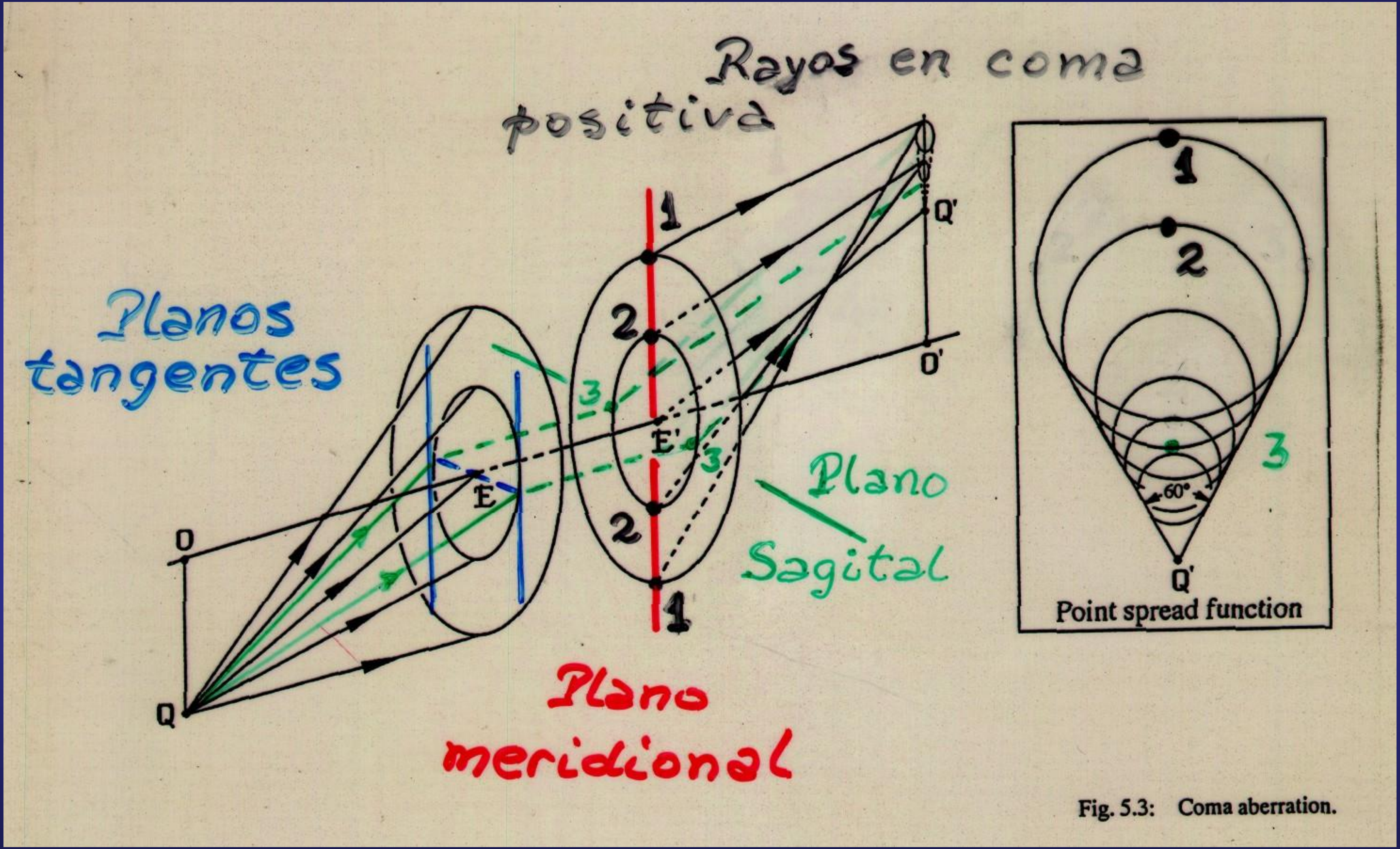
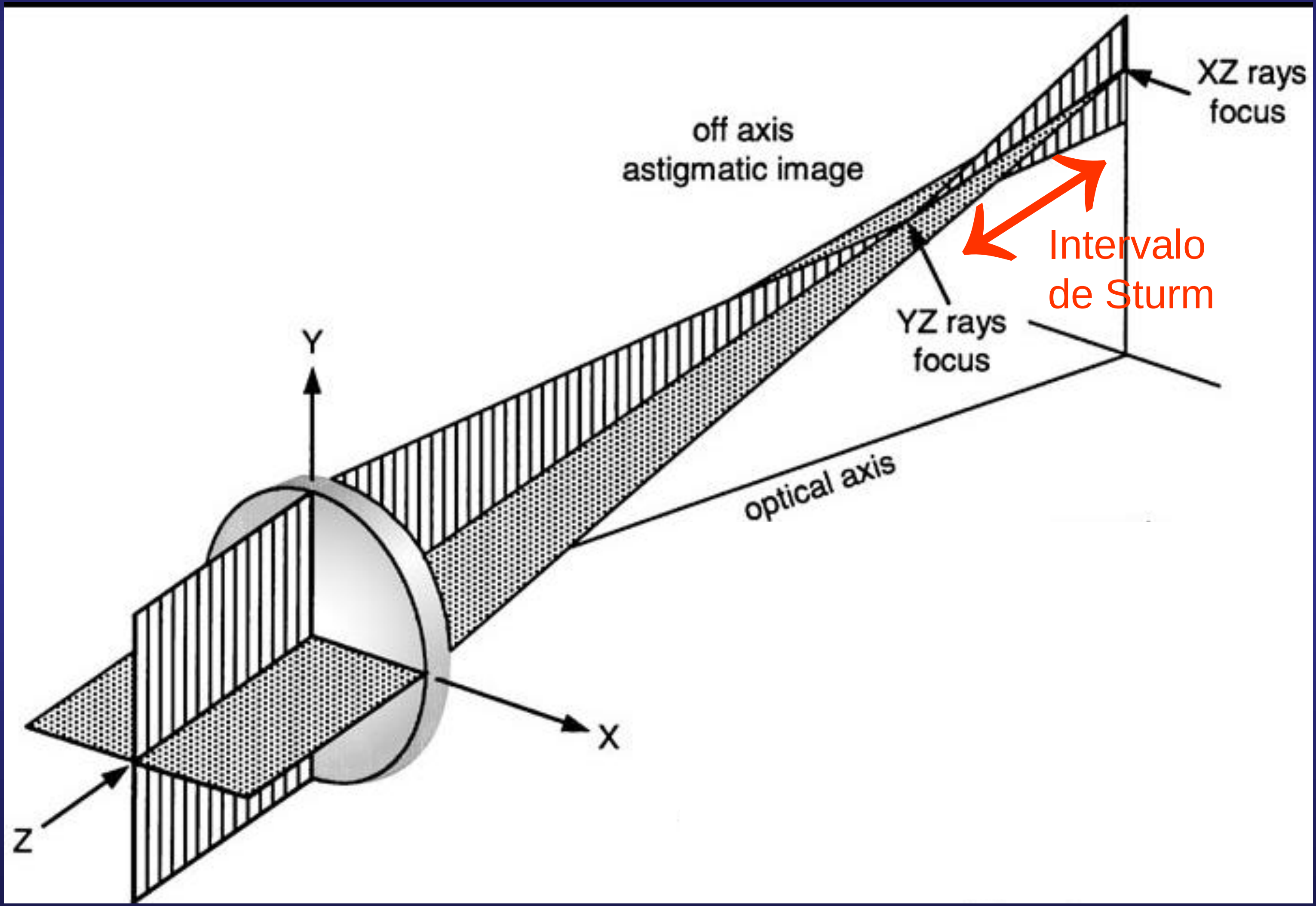
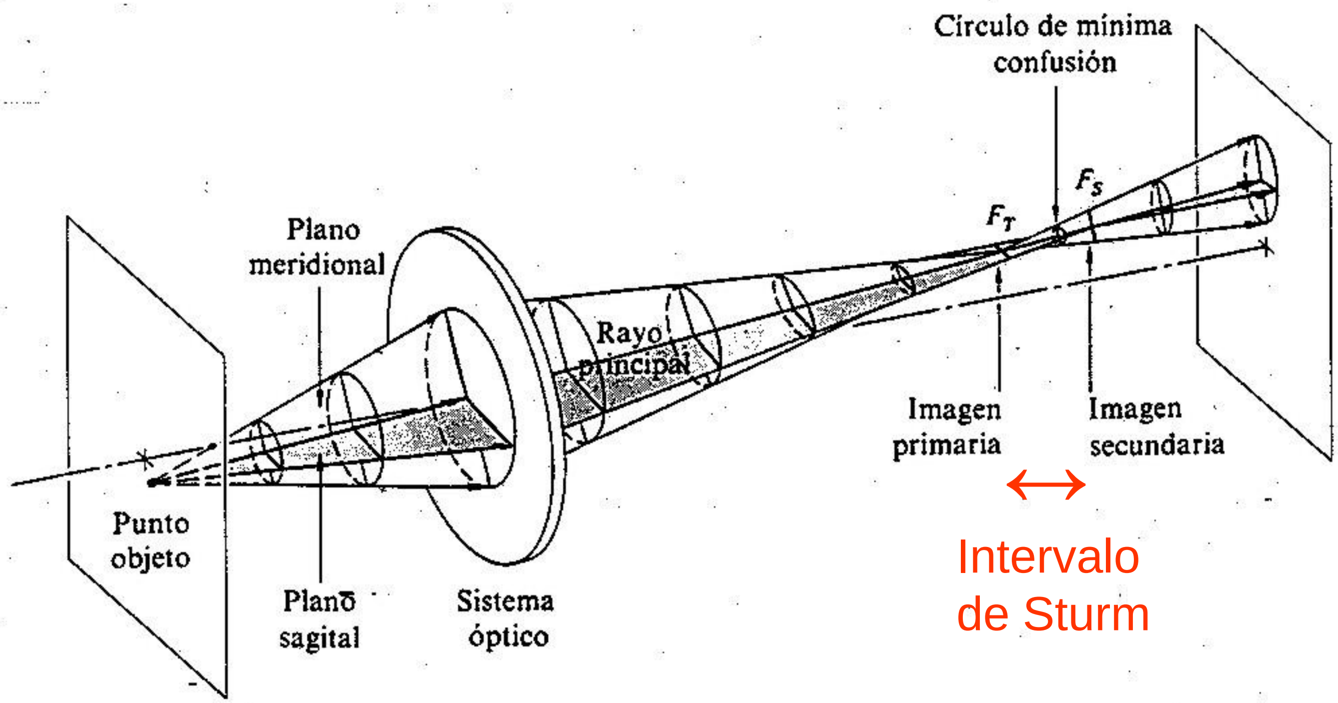


Fig. 5.3: Coma aberration.

ABERRACION POR ASTIGMATISMO I



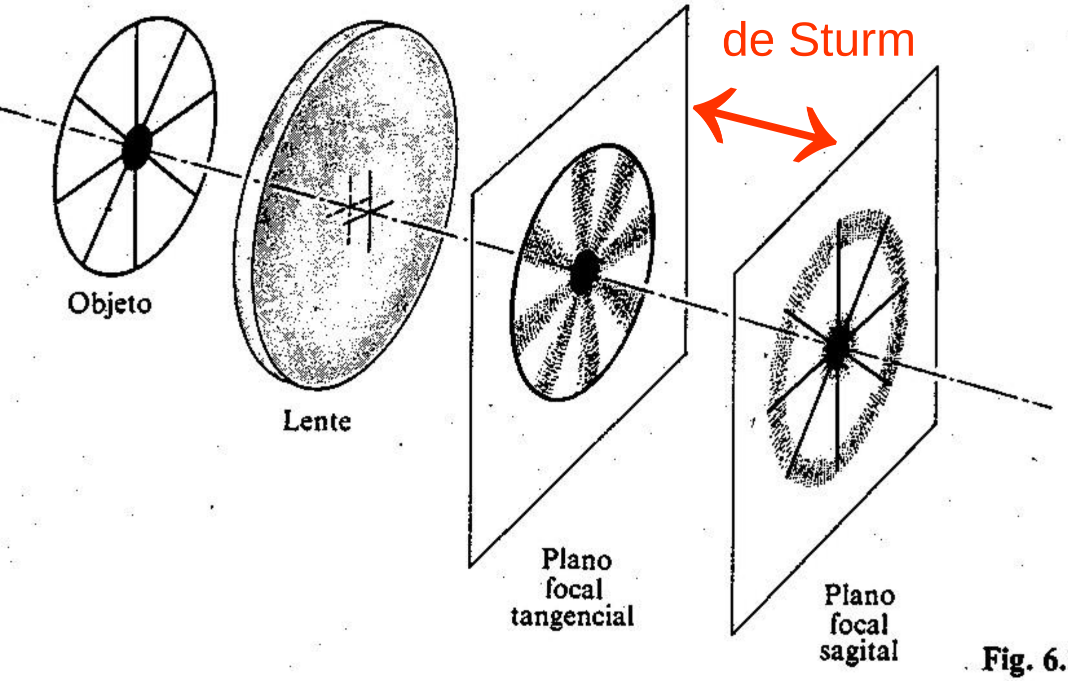
ABERRACION POR ASTIGMATISMO II



Intervalo
de Sturm

Fig. 6.23 Astigmatismo.

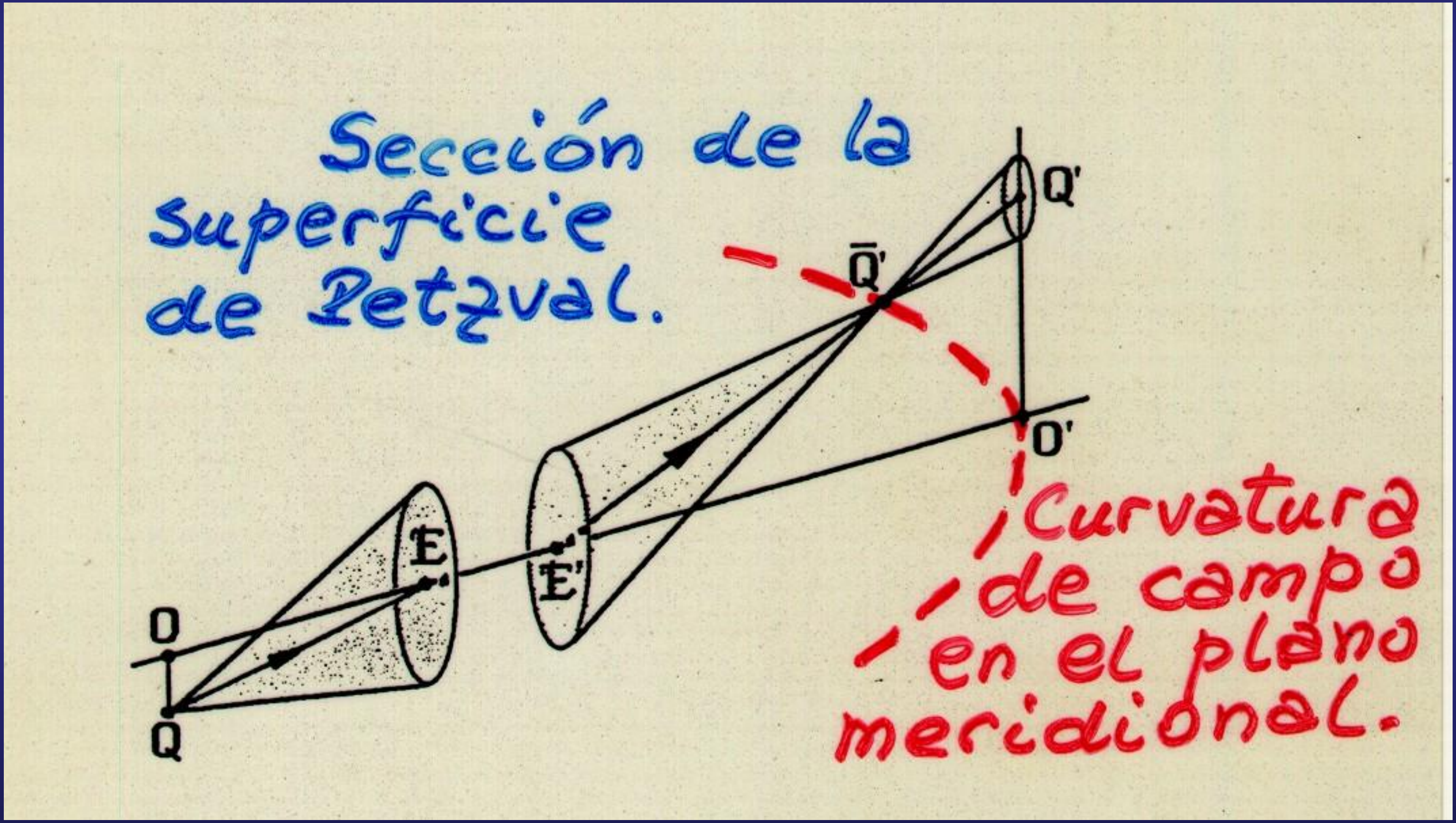
ABERRACIONES POR ASTIGMATISMO III



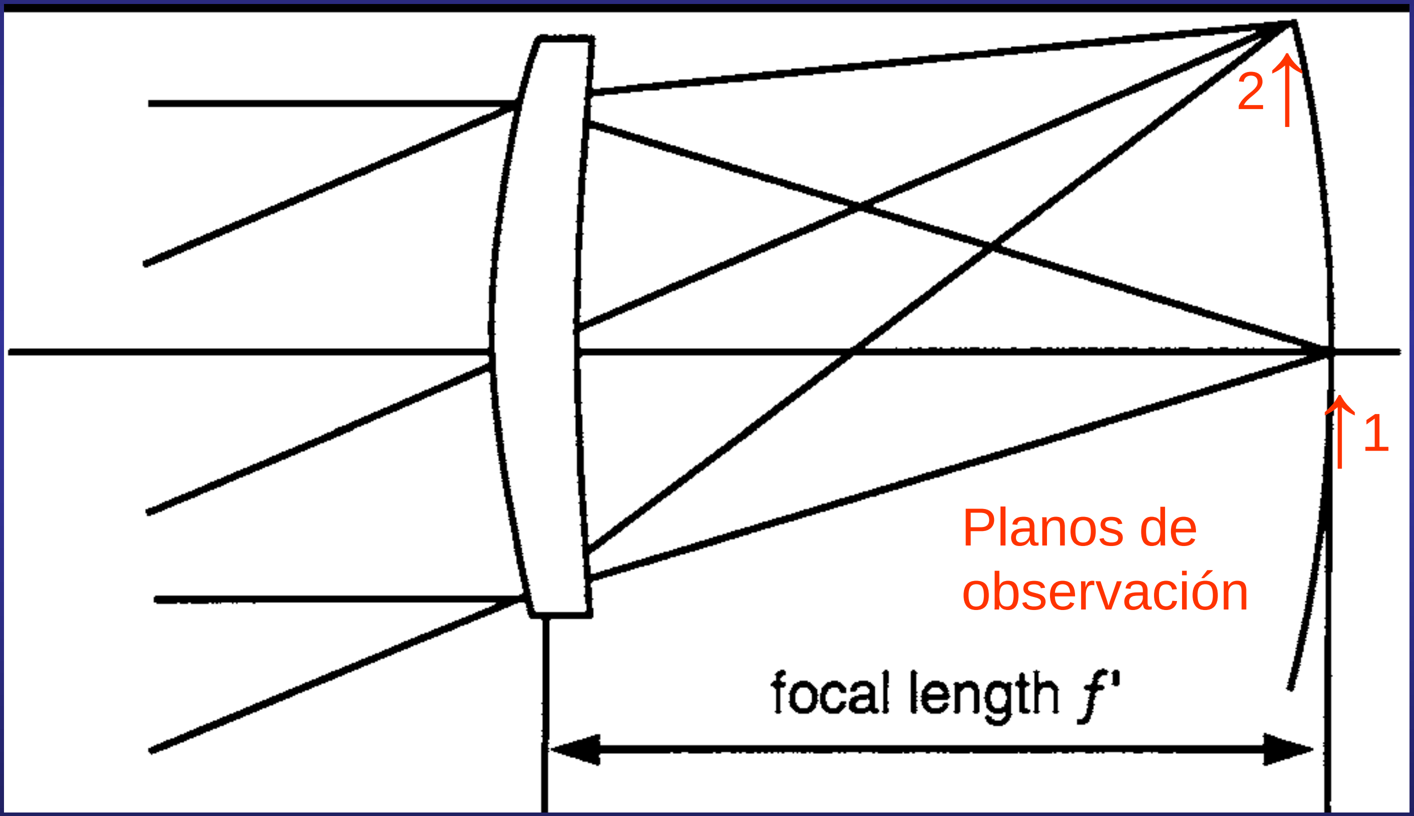
Intervalo de Sturm

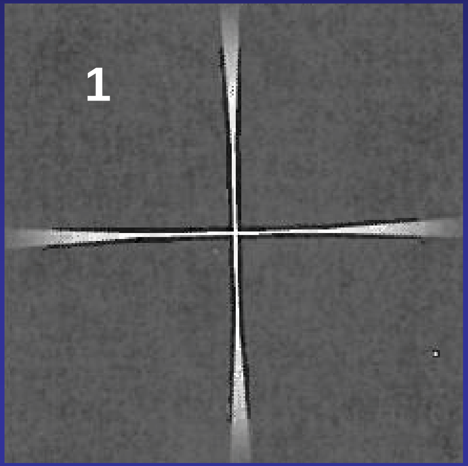
Fig. 6.24 Imágenes en los planos focal, tangencial y sagital.

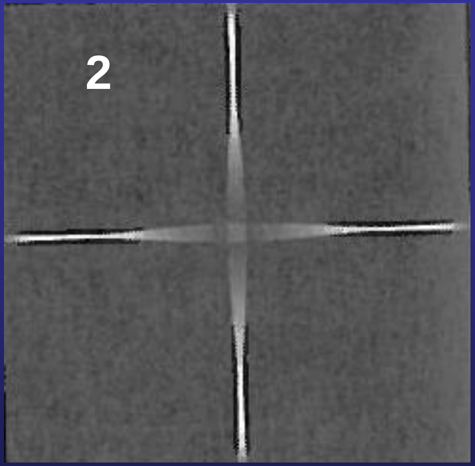
ABERRACION POR CURVATURA DE CAMPO O DE PETZVAL I



ABERRACION POR CURVATURA DE CAMPO O DE PETZVAL II







ABERRACION POR DISTORSION

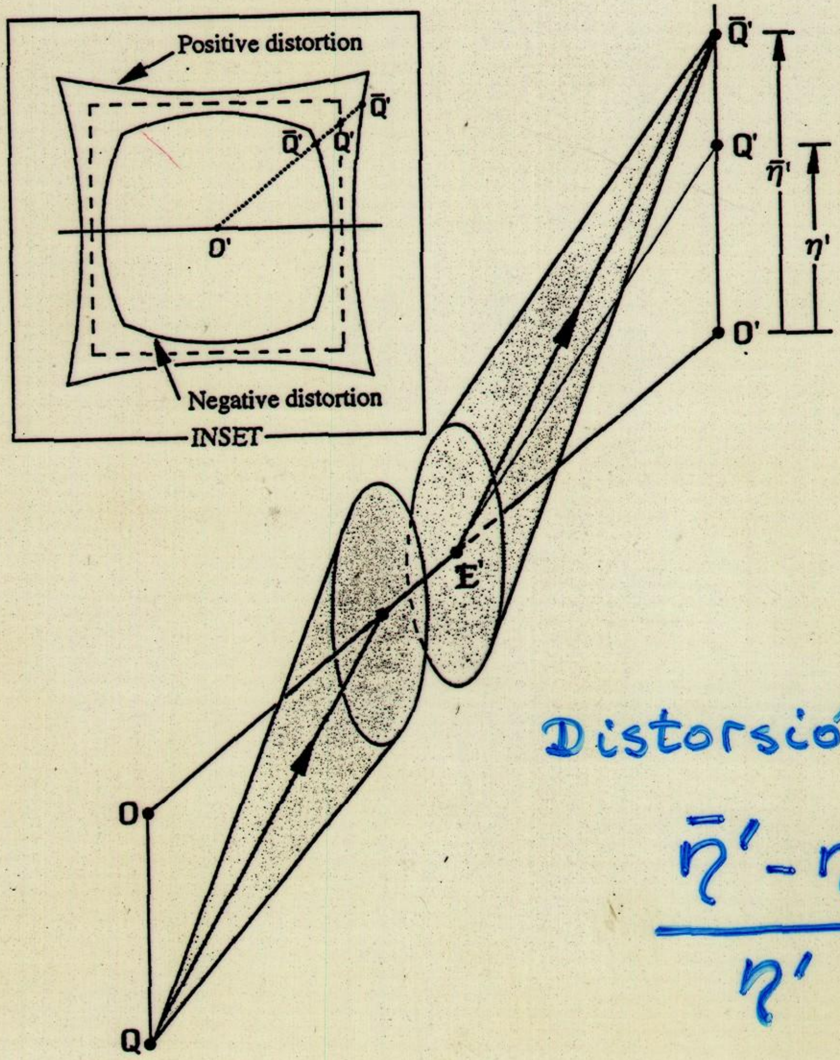


Fig. 5.8: Distortion aberration and, in the inset, the effect of distortion on the image of a square. The dashed line is the Gaussian image of the square.

Distorsión relativa:

$$\frac{\bar{\eta}' - \eta'}{\eta'} \gtrless 0$$

LAS ABERRACIONES ESFERICAS Y POR COMA Y EL DISEÑO DE LAS LENTES

Factor de Forma o de Coddington

$$\Gamma = \frac{R_2 + R_1}{R_2 - R_1}$$

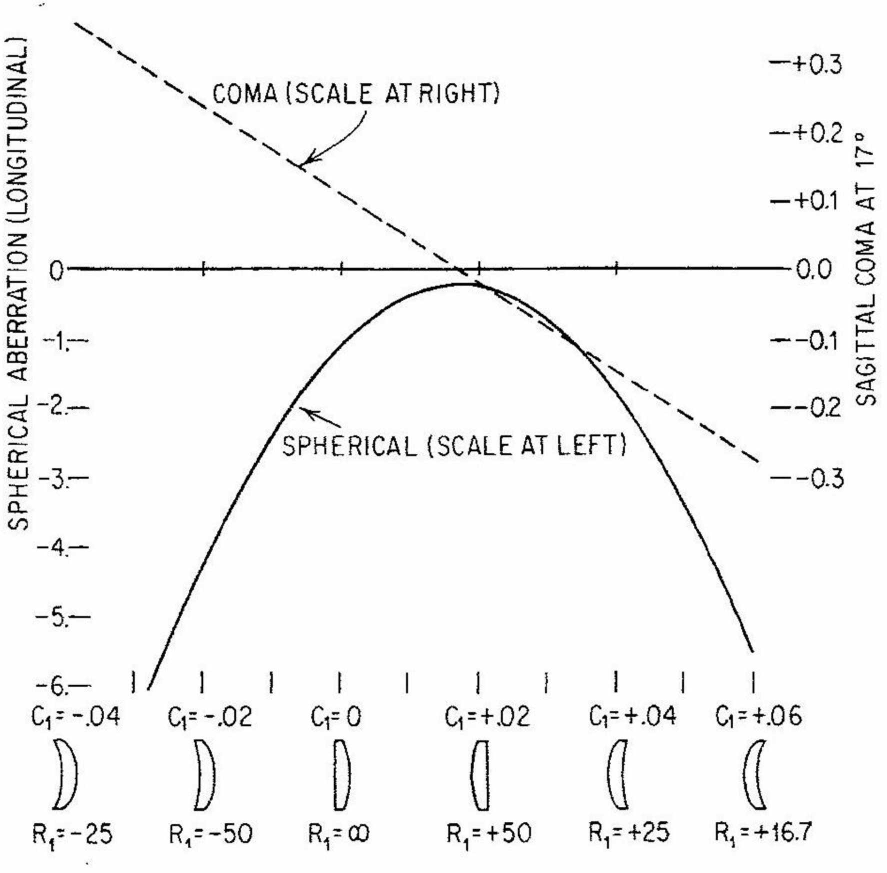


Fig. 11.27. Spherical aberration and coma as a function of lens shape for a 100-mm focal length lens (with a stop at the $f/10$ lens, covering a ±17° field). The radius of curvature of the left interface in mm is labeled as R_1 – which is given in the text as R_{12}, and its reciprocal is shown as $C_1 = 1/R_1$. (From [555]. Reprinted with permission of McGraw-Hill)

ABERRACION CROMATICA I

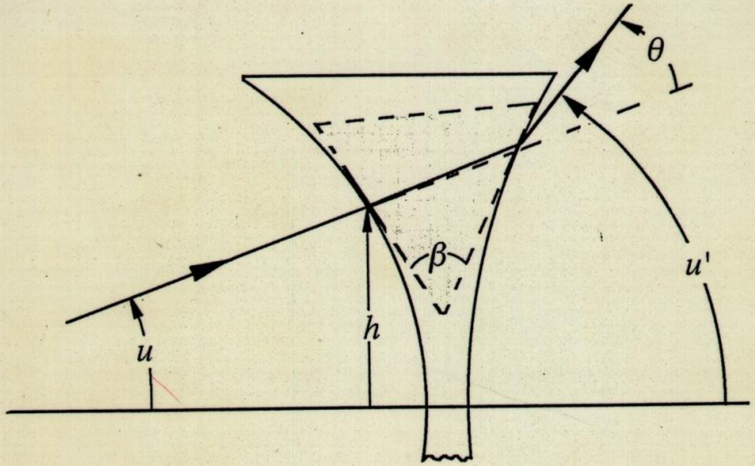
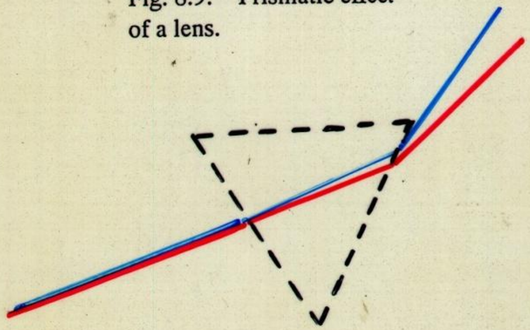
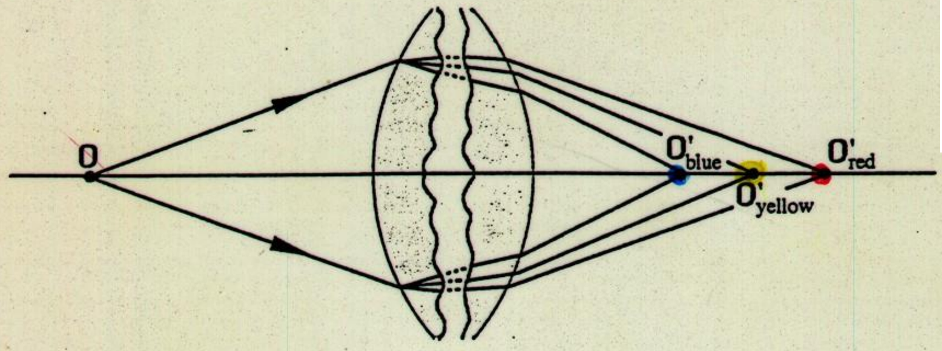


Fig. 8.9: Prismatic effect of a lens.

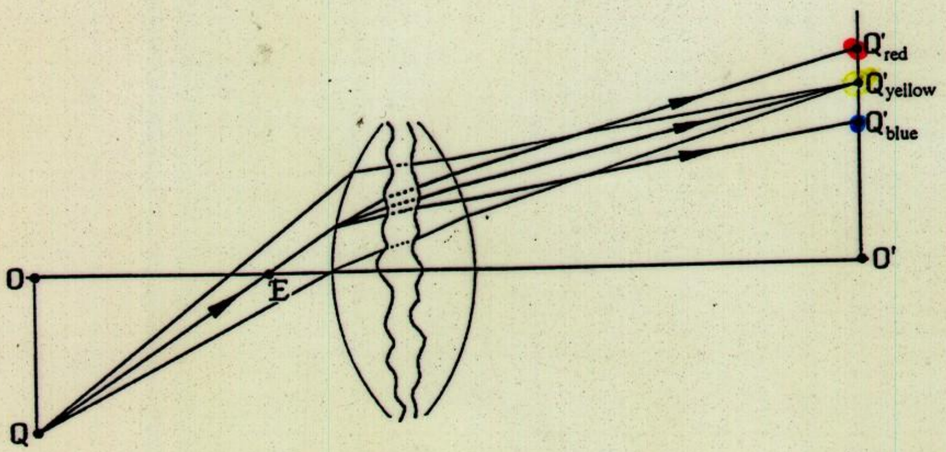


Efecto prismático y aberración cromática

ABERRACION CROMATICA II



Aberración cromática longitudinal



Aberración cromática transversal

DISPERSION CROMATICA DEL OJO I

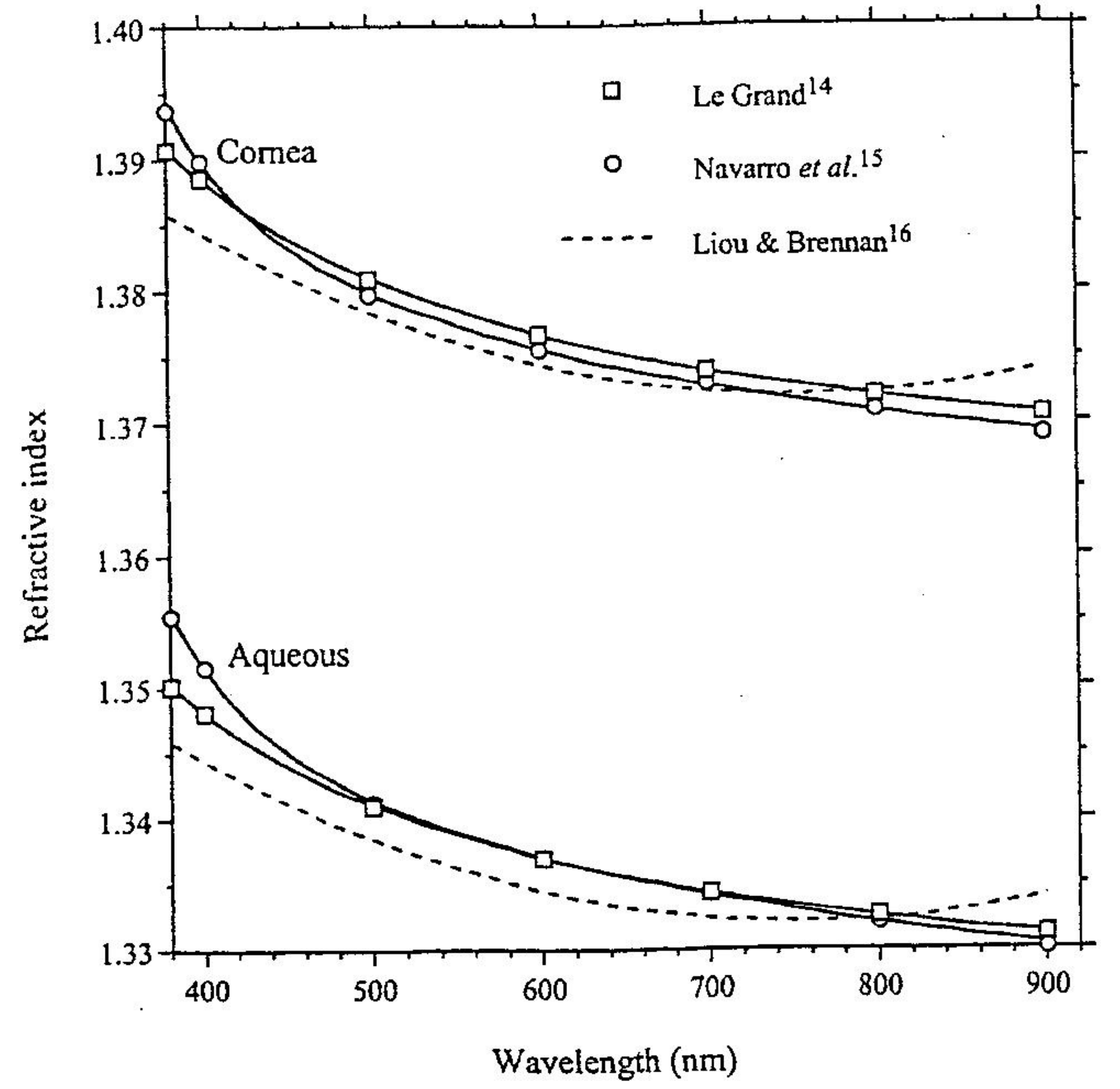


Fig. 2. Chromatic dispersions for the cornea and aqueous from studies of Le Grand,[14] Navarro *et al.*,[15] and Liou and Brennan.[16]

DISPERSION CROMATICA DEL OJO II

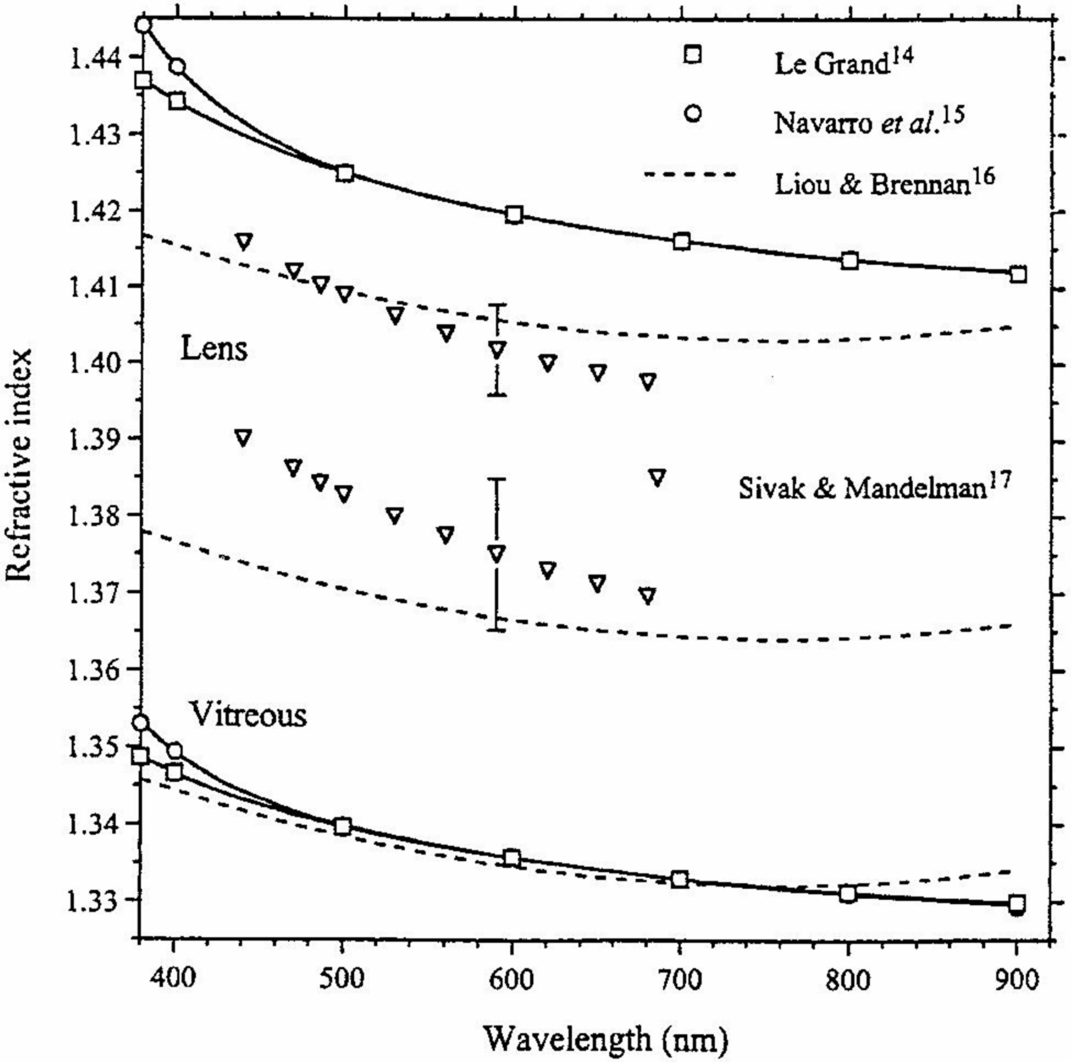


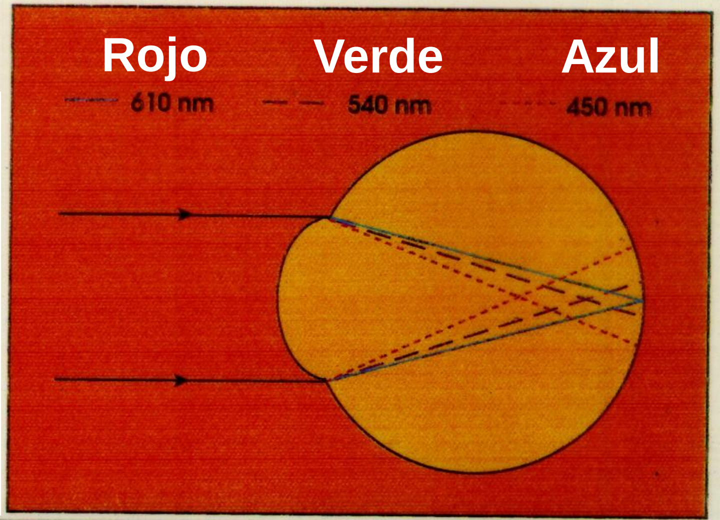
Fig. 3. Chromatic dispersions for the lens and vitreous from studies of Le Grand,[14] Navarro *et al.*,[15] and Liou and Brennan[16] and for the "high" and "low" lens from Sivak and Mandelbaum.[17]

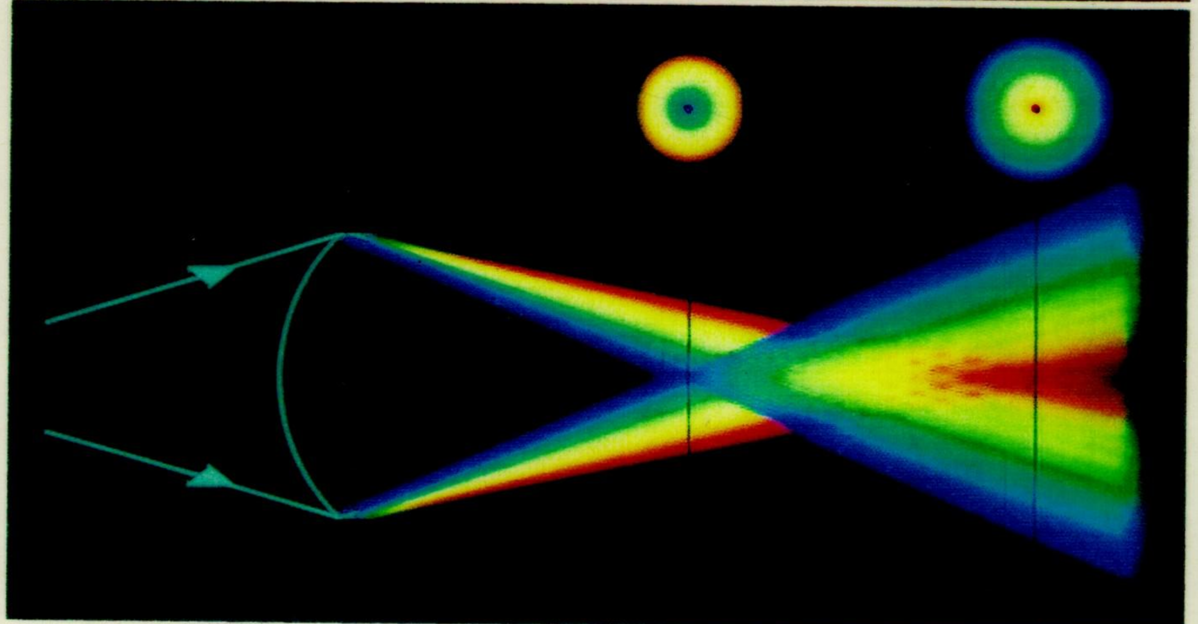
ABERRACION CROMATICA DEL OJO HUMANO I

Aberración cromática del ojo humano

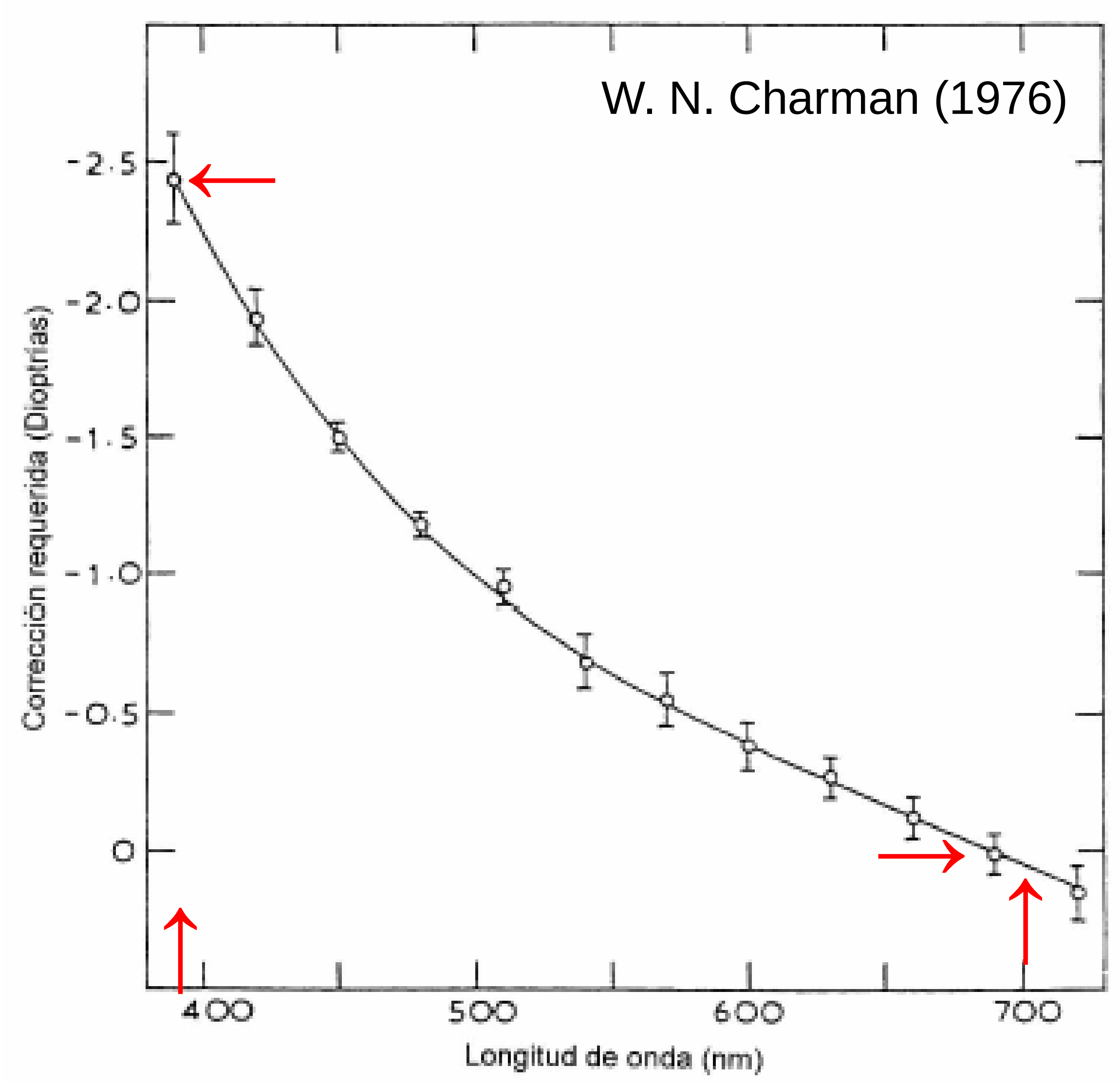
> 2,5 D

Aberración cromática longitudinal y PSF antes y después del foco verde





ABERRACION CROMATICA DEL OJO HUMANO II



IMAGENES DE PURKINJE Y ACOMODACION

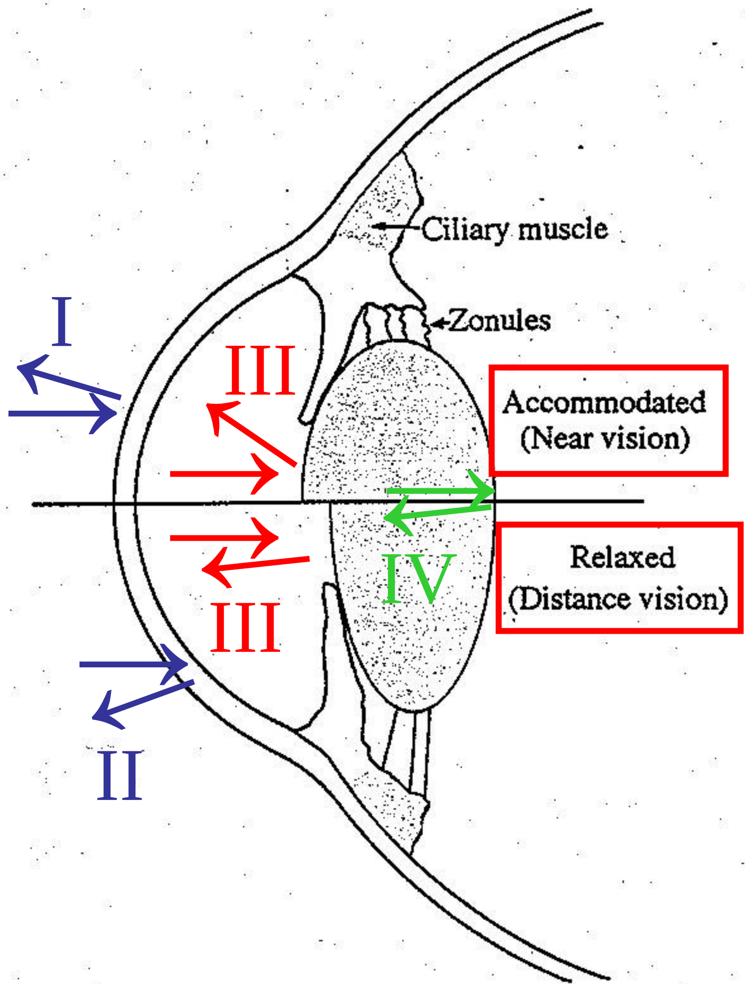
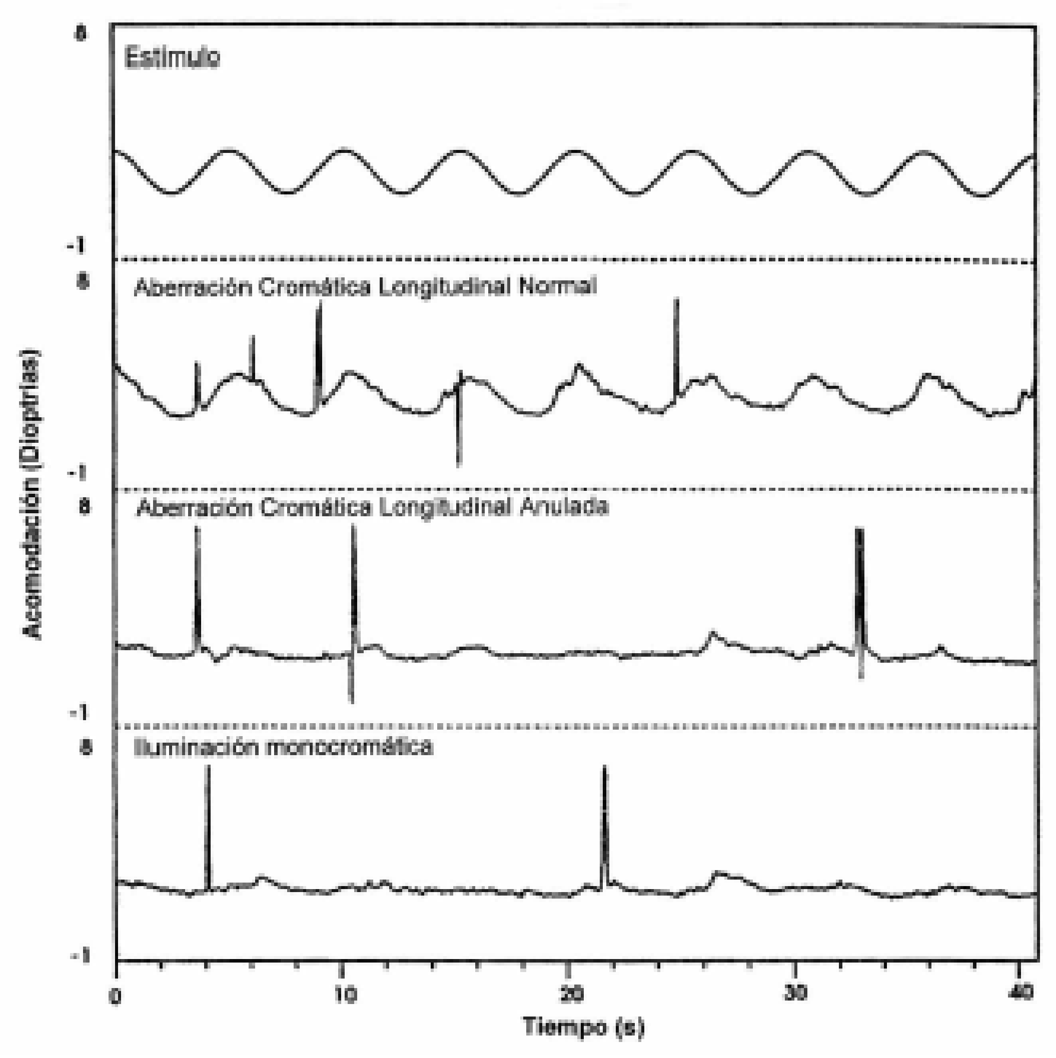


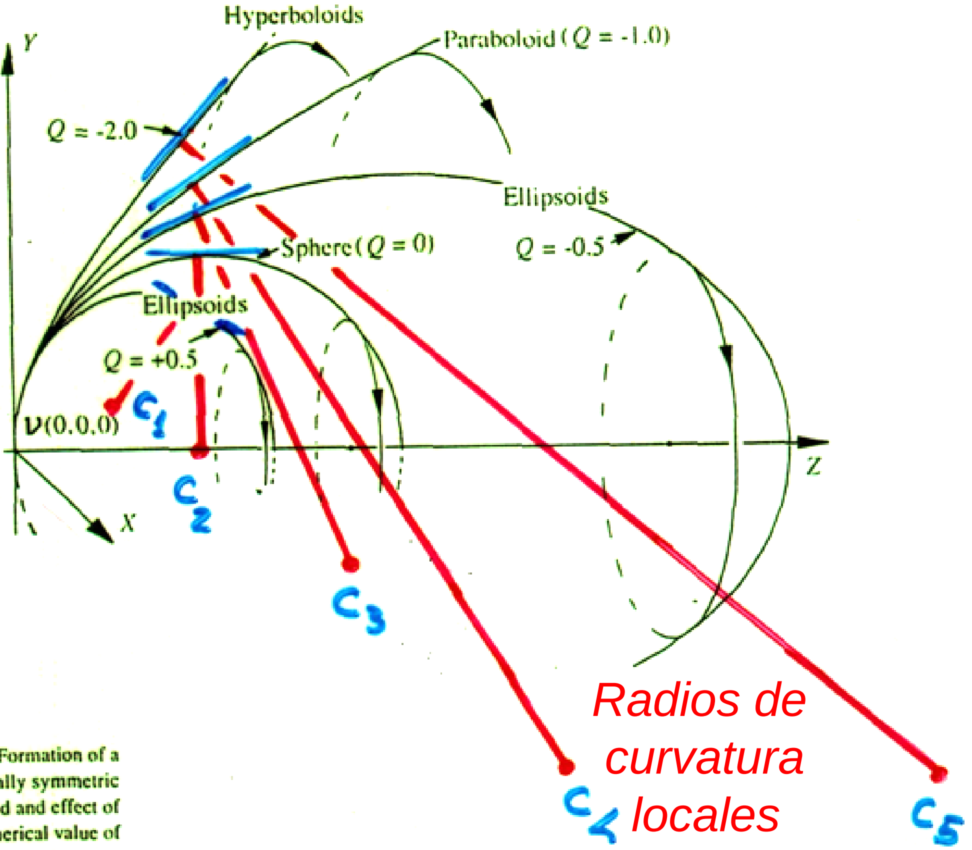
Fig. 13.2: Changes in the lens shape and position with accommodation.

ABERRACION CROMATICA DEL OJO HUMANO IV



A. van Meeteren, *Optica Acta* **21**, 395-412 (1974)

LENTES ASFERICAS CON SIMETRIA ROTACIONAL Y DE FOCO VARIABLE

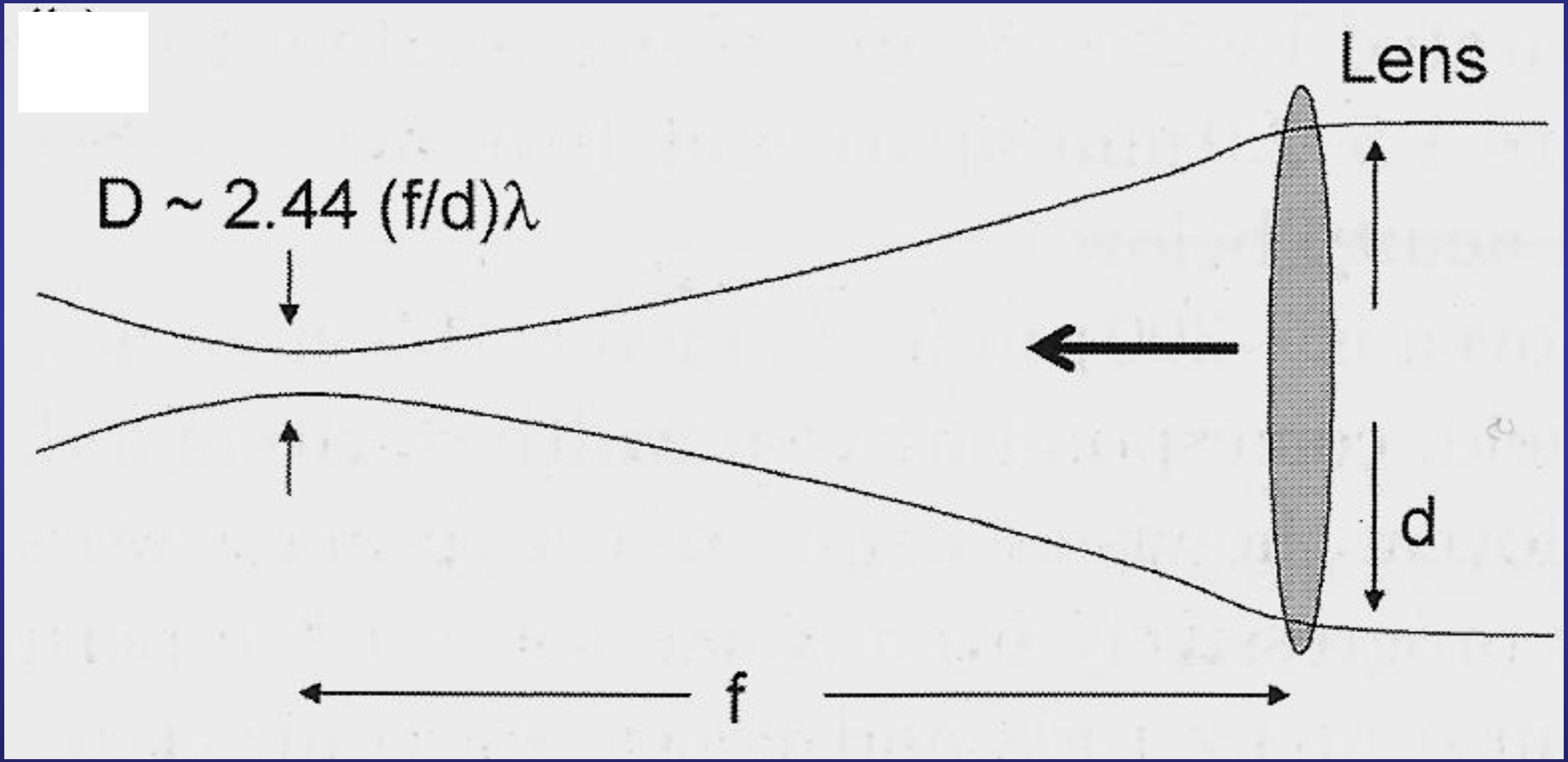


Radios de curvatura locales

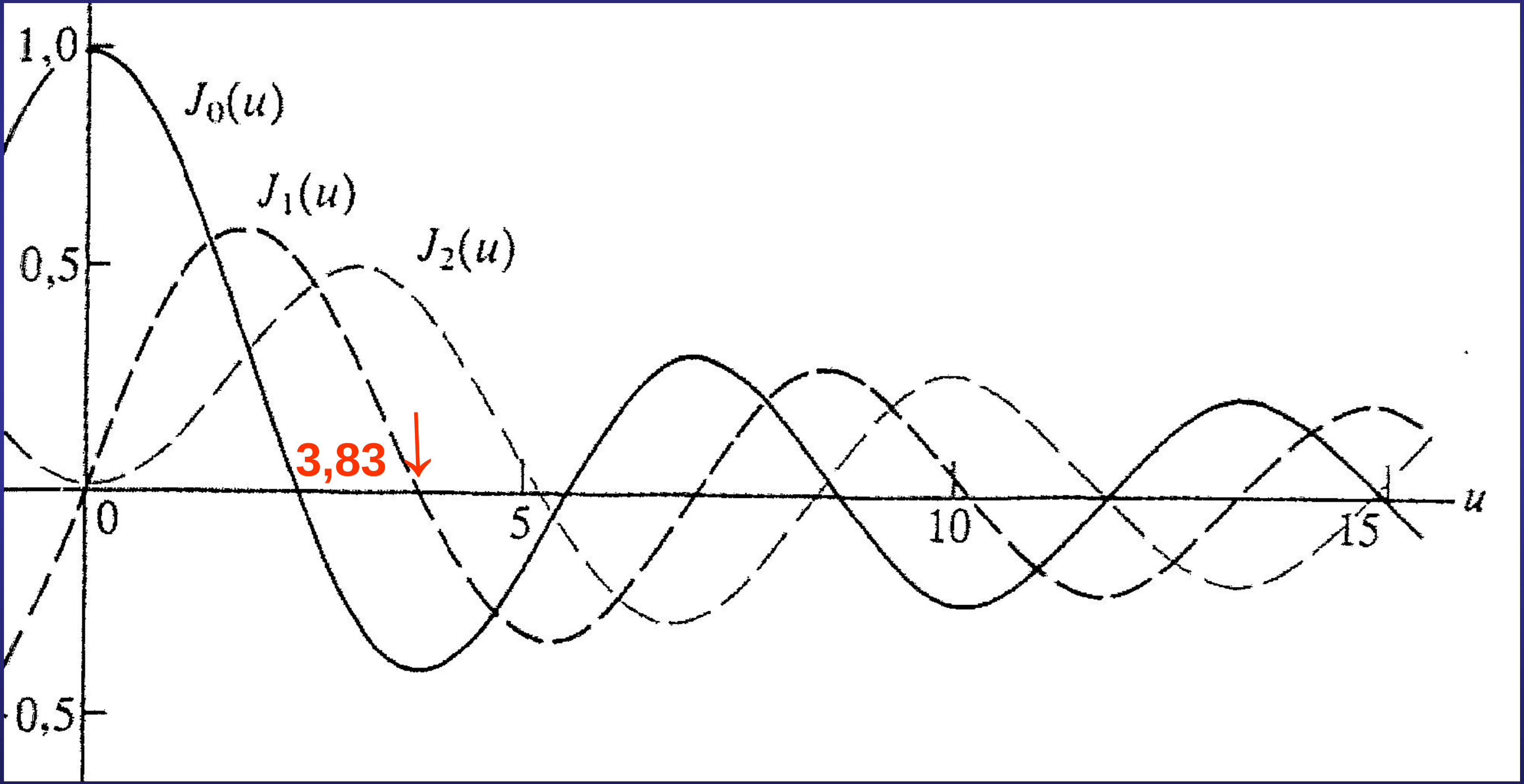
Fig. 5.14: Formation of a rotationally symmetric conicoid and effect of numerical value of asphericity Q on the shape of a conic. All curves have same curvature at vertex V.

c_i : centros de curvatura locales
c_1 : Elipsoide Prolado
c_2 : Esfera
c_3 : Elipsoide Oblado
c_4 : Paraboloide
c_5 : Hiperboloide

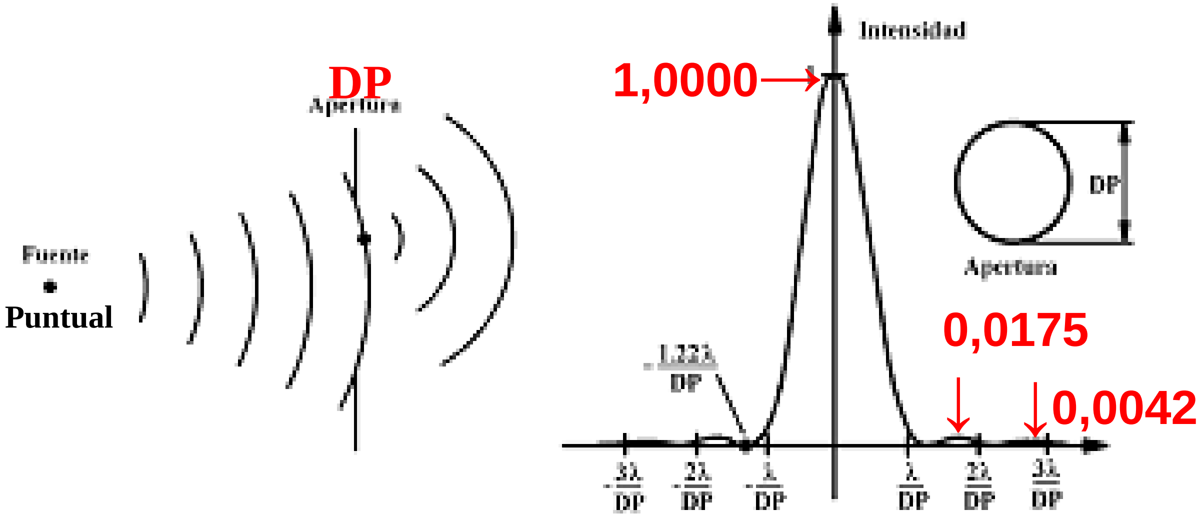
DIFRACCION POR LA APERTURA CIRCULAR DE UNA LENTE

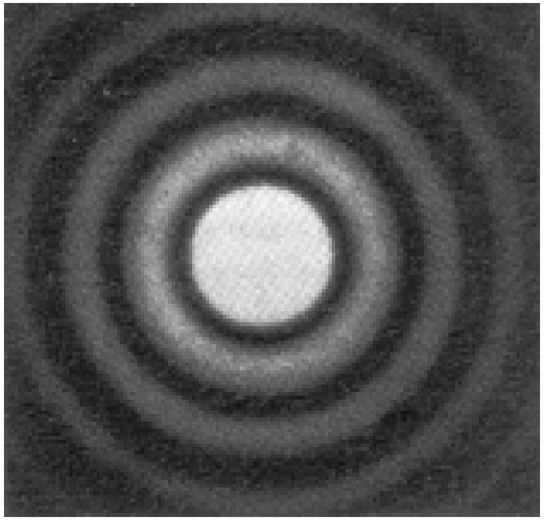


DIFRACCION POR LA APERTURA CIRCULAR DE UNA LENTE Y LA FUNCION DE BESSEL J_1



DIFRACCION POR UNA PUPILA CIRCULAR



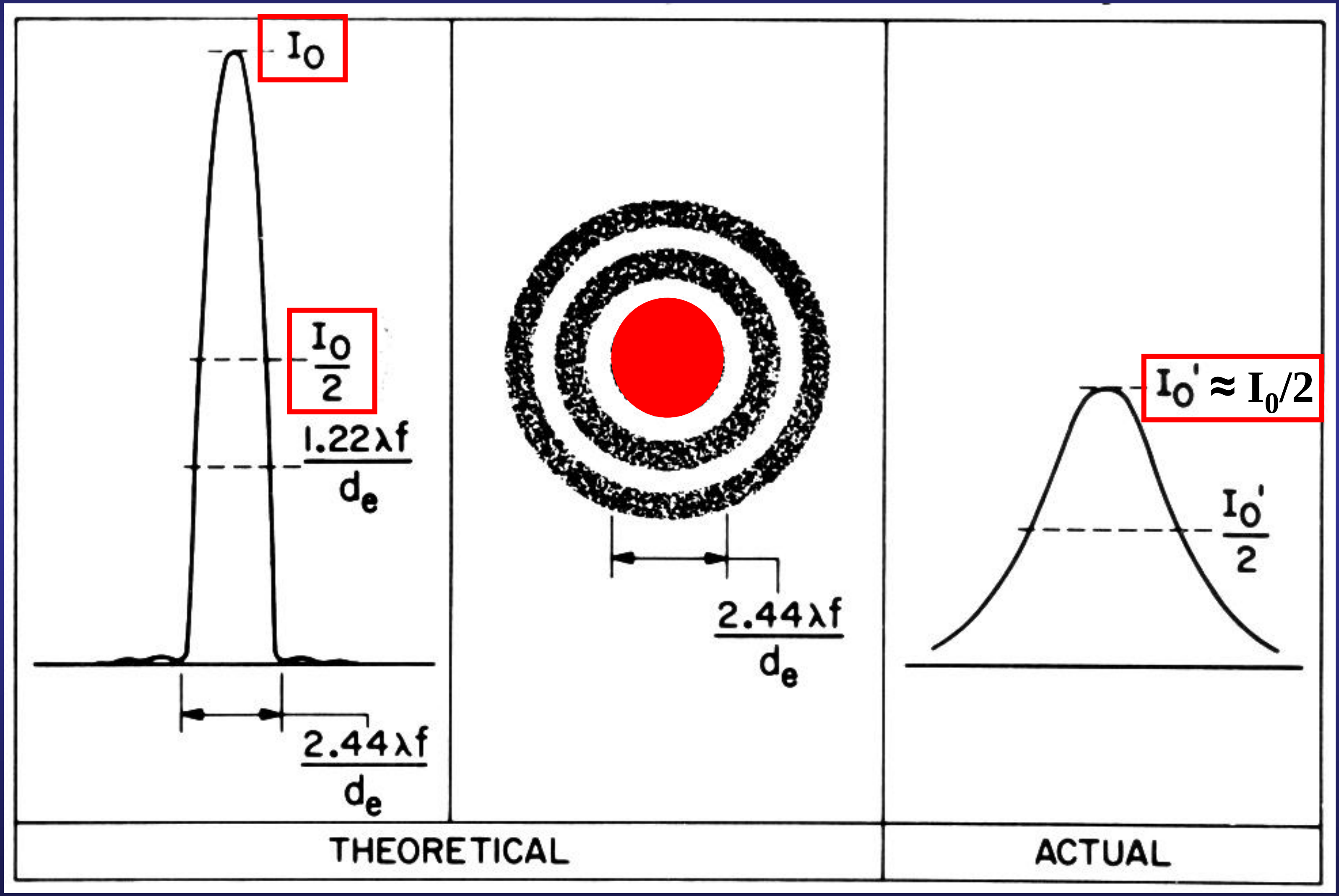


Difracción de la luz en una pupila circular de diametro DP para ángulos de incidencia nulo.

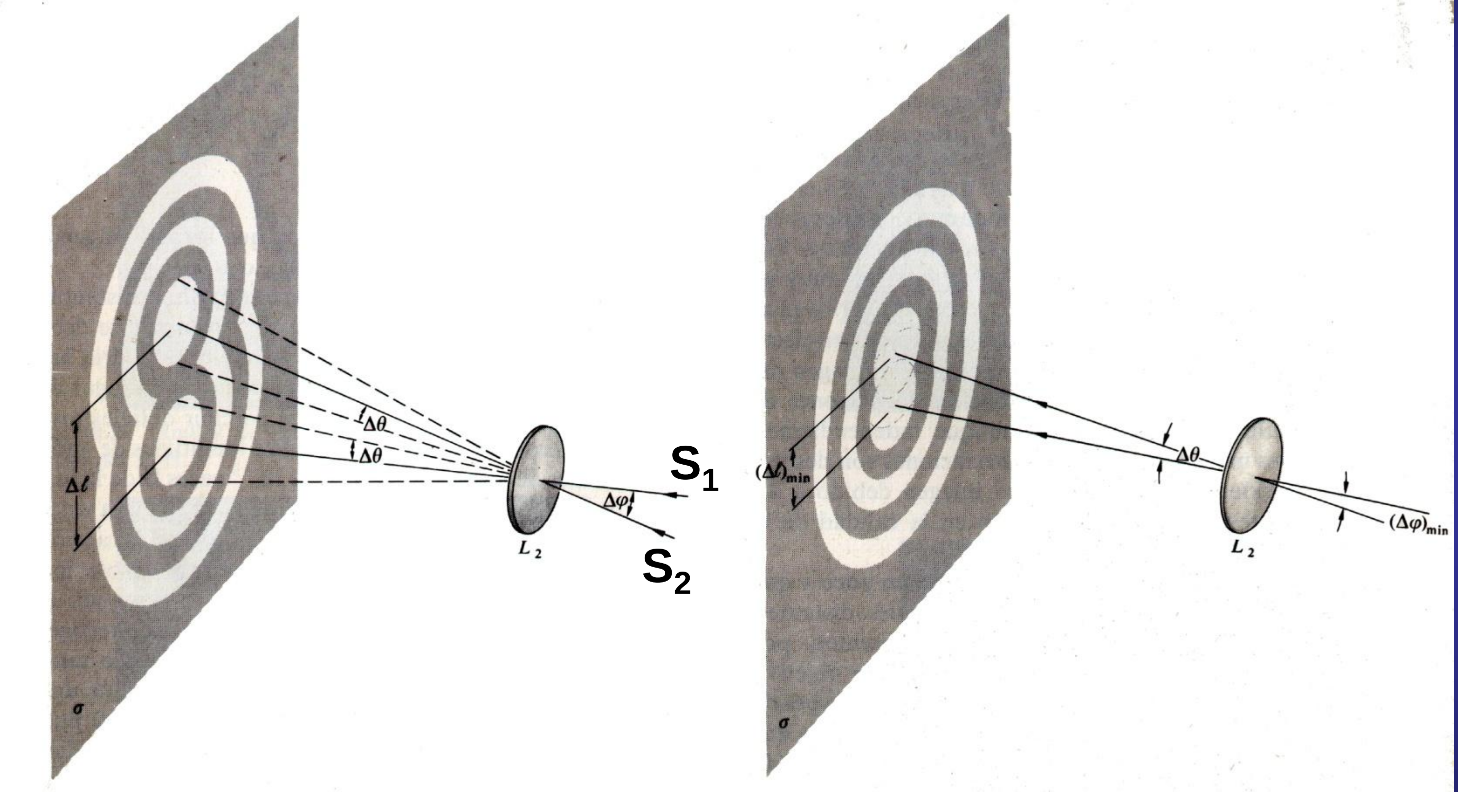
Distribución de Airy o *Point Spread Function* (PSF)

o Función de Punto Difractado

IMAGEN DE LA PSF EN LA RETINA

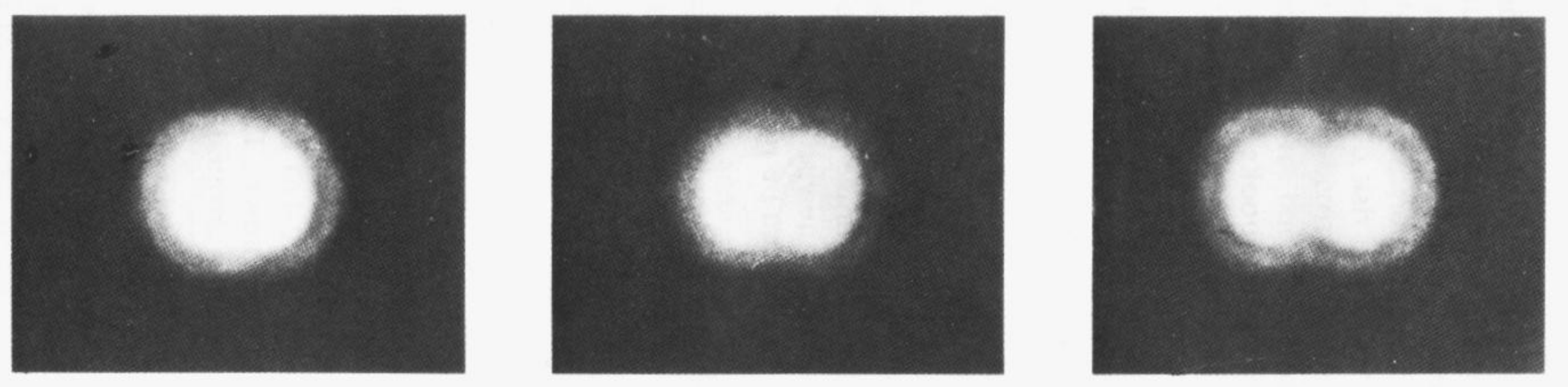


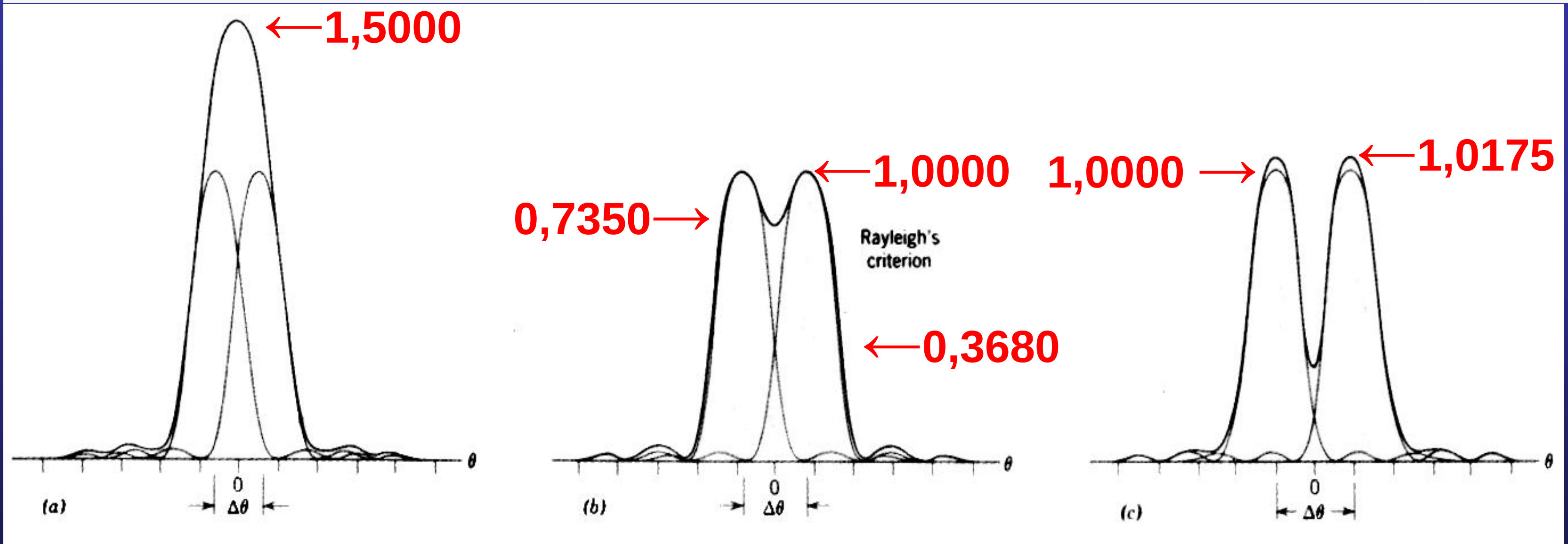
CRITERIO DE RESOLUCION DE Lord RAYLEIGH I



Superposición de dos Funciones de Airy o dos PSF producidas por dos fuentes luminosas S_1 y S_2 con diferentes separaciones angulares.

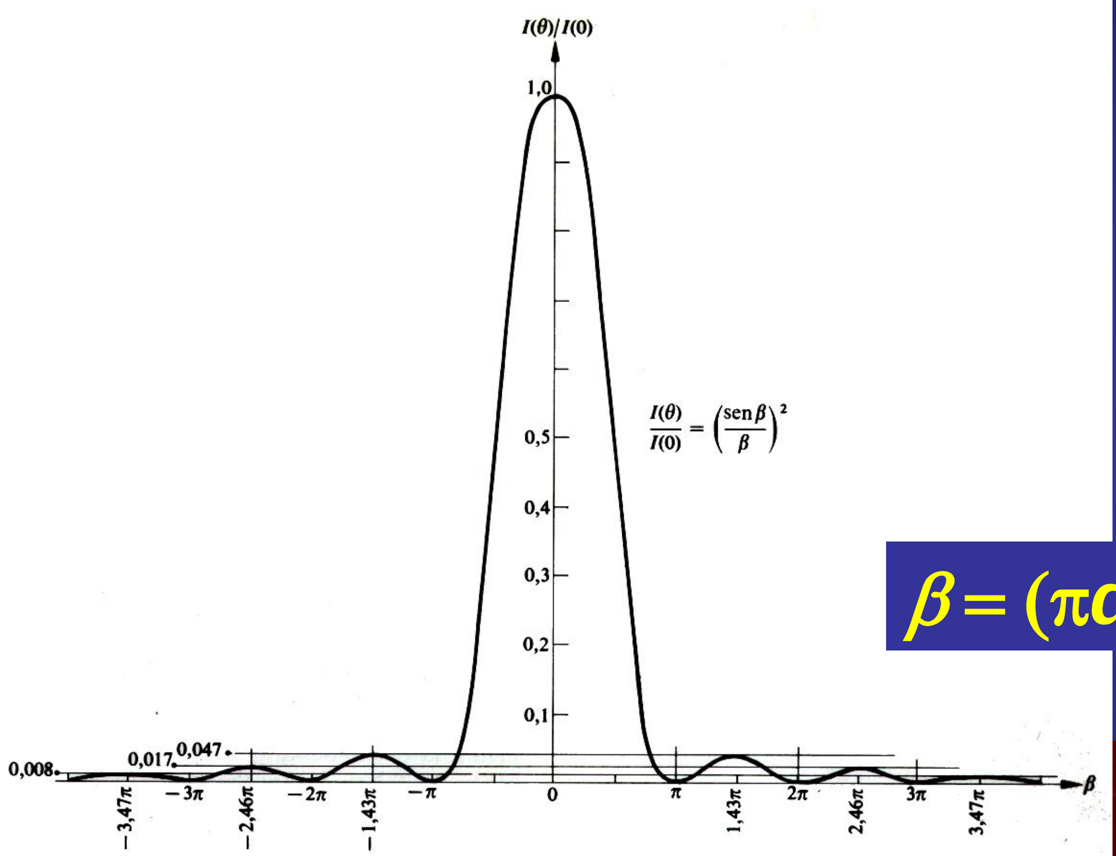
CRITERIO DE RESOLUCION DE Lord RAYLEIGH II





CRITERIO DE RAYLEIGH

DIFRACCION DE FRAUNHOFER POR UNA RANURA DE ANCHO *d* SEGUN (senc β)^2



$$\beta = (\pi d/\lambda)\,\text{sen}\,\theta_n$$

n = ... -2 -1 0 +1 +2 ...

θ_n es el ángulo de cada orden de difracción n = 0, ±1, ±2, ...

FUNCION DE LINEA DIFRACTADA (LSF) EN LA RETINA HUMANA I

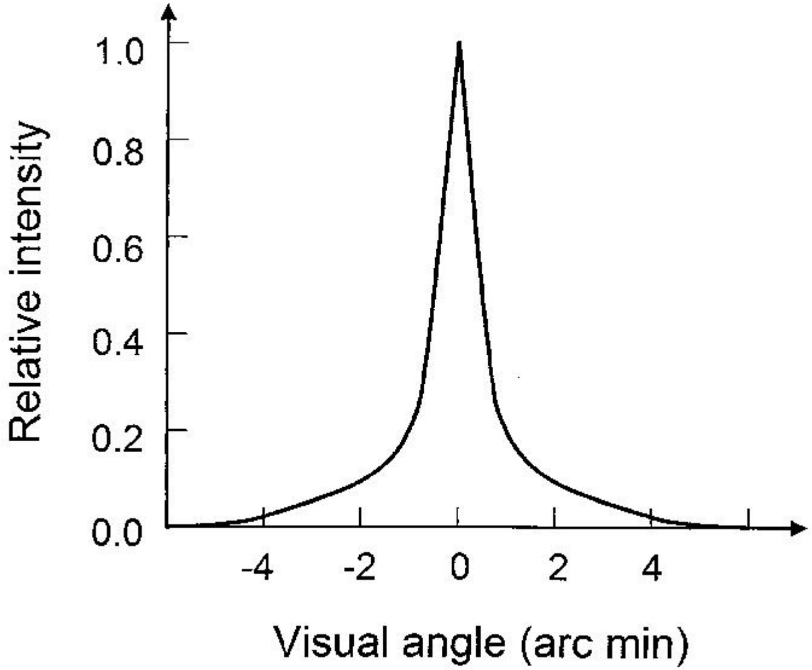


Fig. 11.30. The human line spread function for an eye with 3.0 mm pupil diameter, using a model in [561] (see Problem 11.30) that is based on experiment. (Based on [560] and [561])

FUNCION DE LINEA DIFRACTADA (LSF) EN LA RETINA HUMANA II

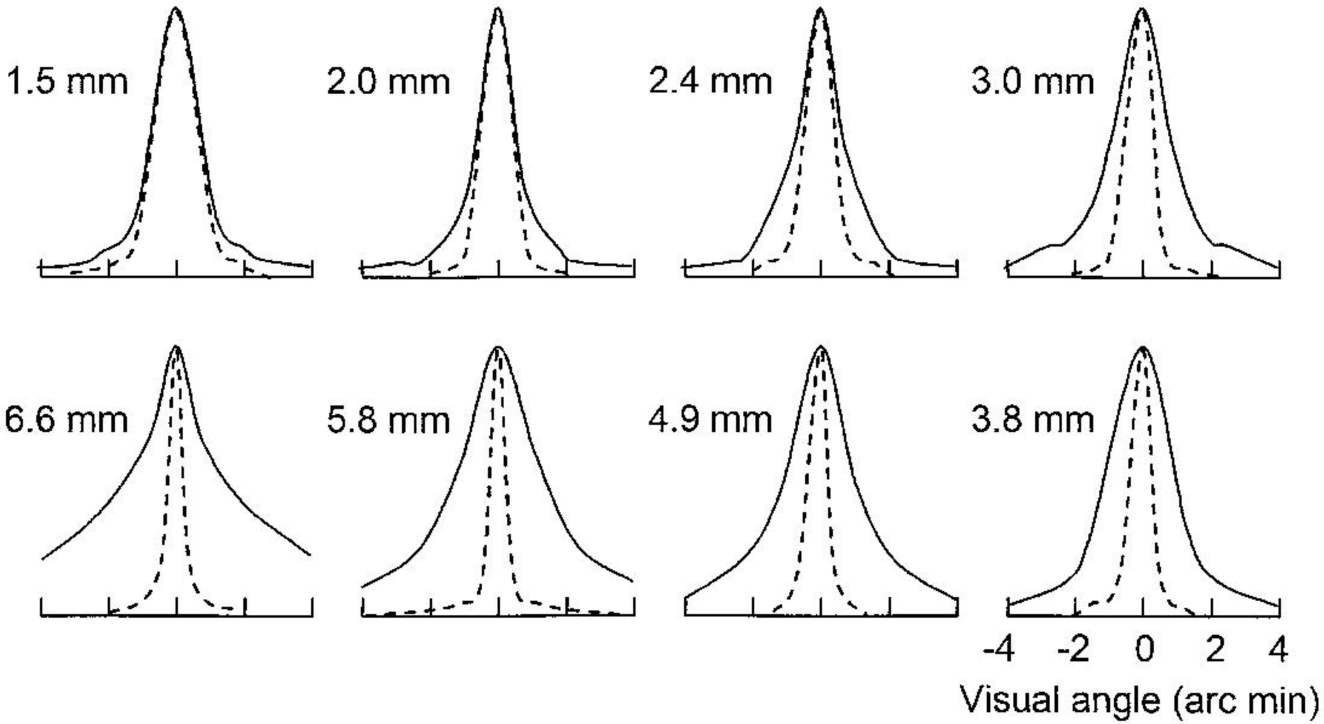
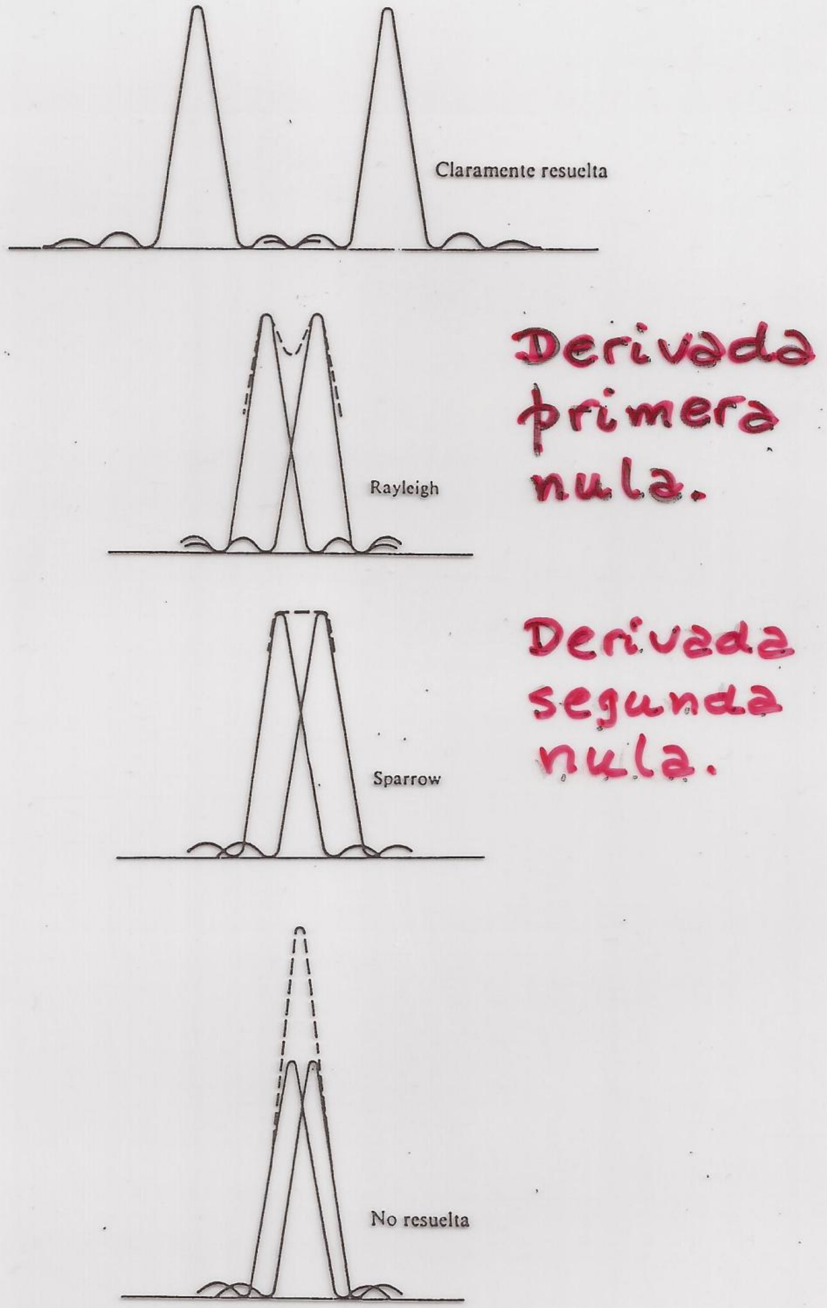


Fig. 11.33. Line spread function for the human eye for different pupil diameters. The *solid curves* are the total functions. The *dashed curves* are the line spread functions for those apertures assuming diffraction-limited conditions. (Based on [517] and [560])

CRITERIO DE RAYLEIGH

CRITERIO DE SPARROW



Derivada primera nula.

Derivada segunda nula.

Imágenes puntuales superpuestas.

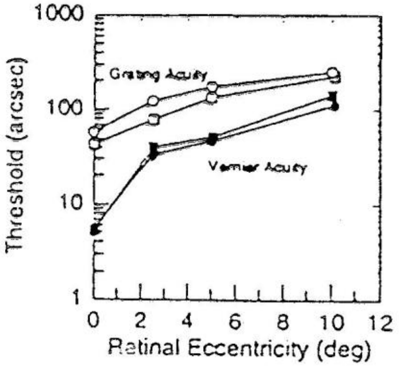
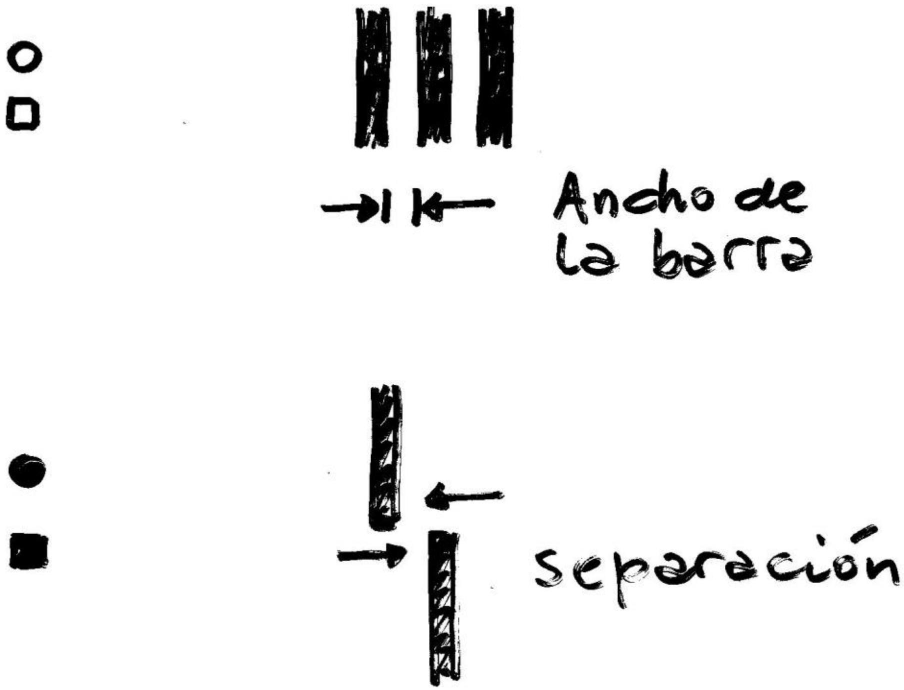
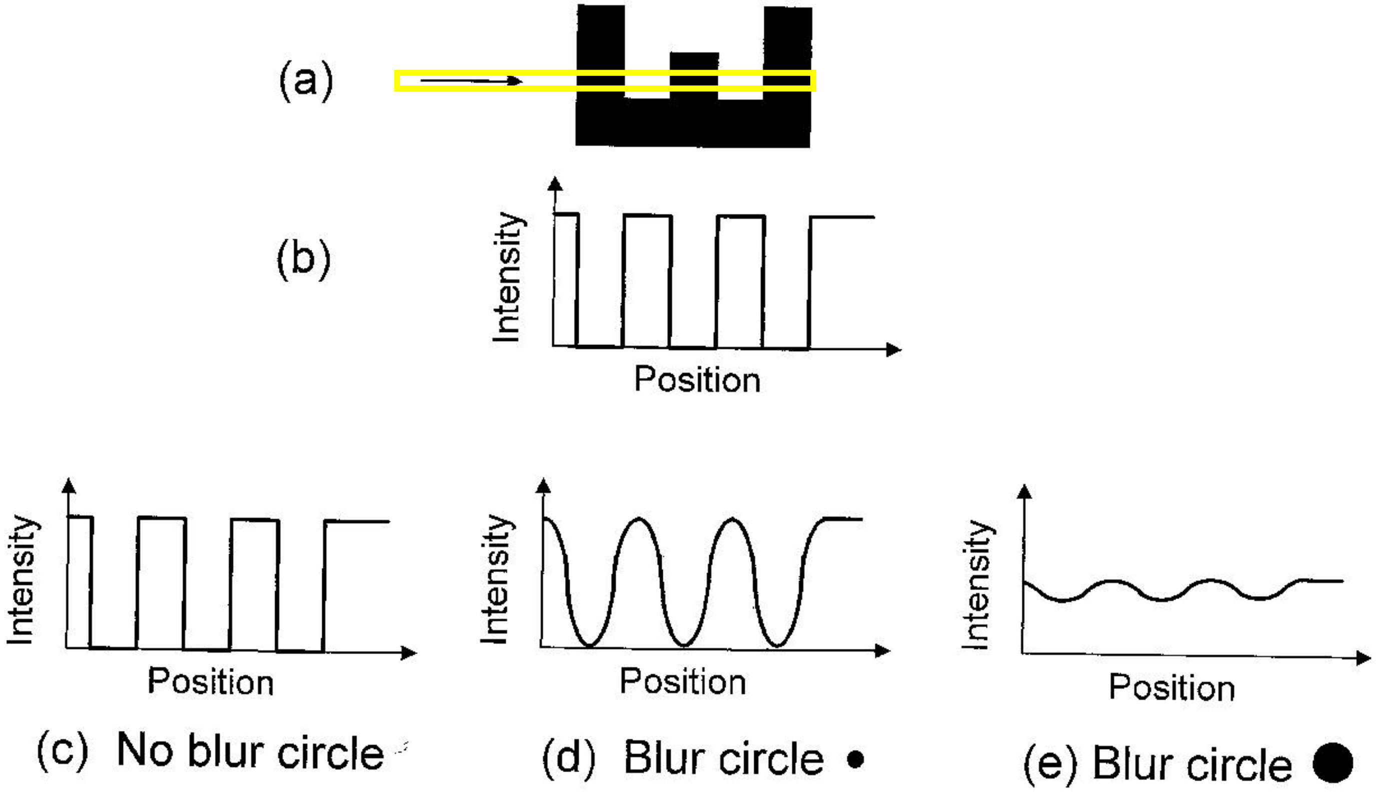


FIGURE 20 Grating and vernier acuity as a function of retinal eccentricity. The open symbols represent the smallest detectable bar widths for a high-contrast grating. The filled symbols represent the smallest detectable offset of one line segment with respect to another. Circles and squares are the data from two different observers. *(Adapted from Ref. 110.)*



AGUDEZA VISUAL PARA REDES DE PERFIL CUADRADO Y TIPO VERNIER

AGUDEZA VISUAL Y BORRONEO



(c) No blur circle (d) Blur circle • (e) Blur circle ●

Fig. 11.31. (a) The horizontal letter E on it side, and (b) the light level in the direction of the *arrow* in (a) showing a periodic square wave object. This leads to potential images on the retina for (c) ideal imaging, (d) imaging with a small blur spot, and (e) imaging with a large blur spot

AGUDEZA VISUAL vs DISTANCIA A LA FOVEA

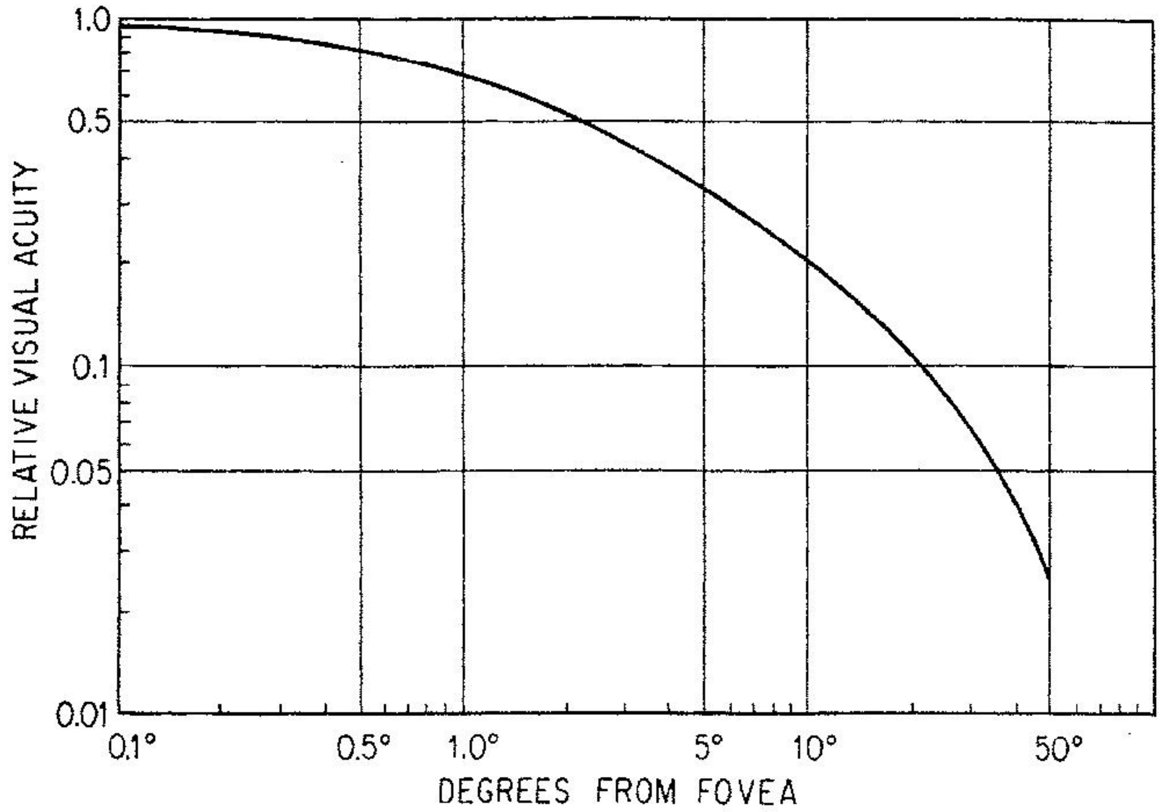


Fig. 11.25. The variation of visual acuity with retinal position relative to the fovea. (From [555]. Reprinted with permission of McGraw-Hill)

AGUDEZA VISUAL vs BRILLO

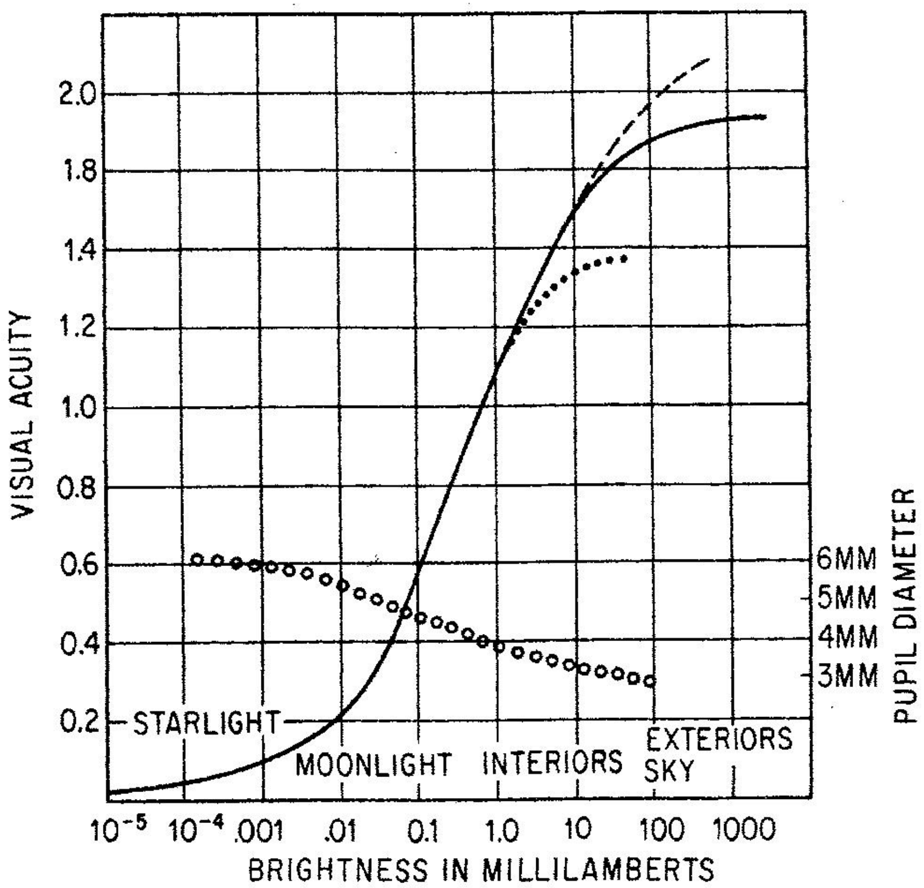


Fig. 11.37. Visual acuity (in 1/min) and pupil diameter (*circles*) as a function of object brightness. The *dashed* and *dotted* acuity lines are, respectively, for increased and decreased surround brightness of 1 milliLambert. (See Table 11.4: 1 milliLambert = 3.183 nit = 3.183 cd/m^2). (From [555]. Reprinted with permission of McGraw-Hill)

SENSITIVIDAD A LAS FRECUENCIAS ESPACIALES vs ORIENTACION

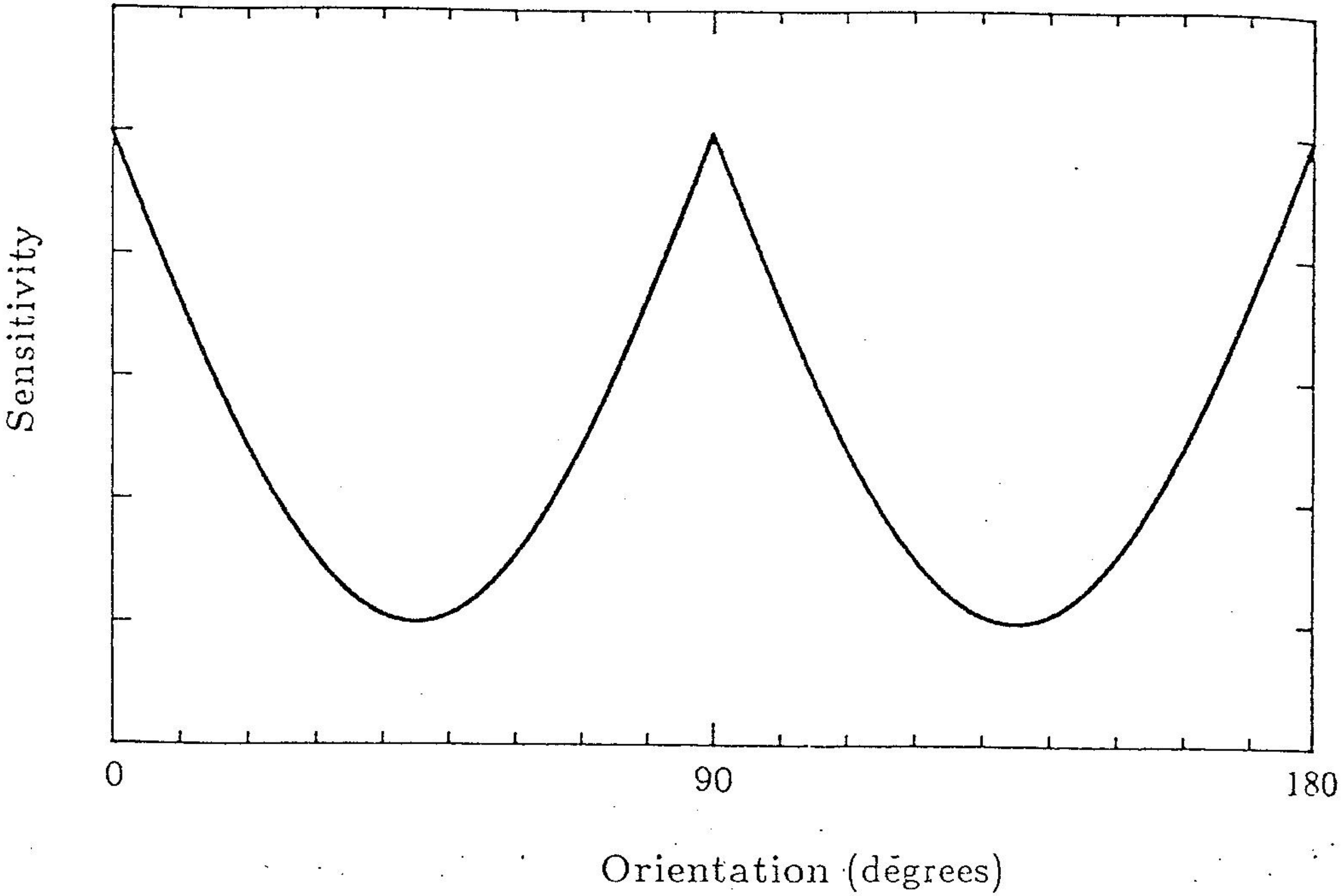


Figure 5.3: Spatial Frequency Sensitivity vs. Orientation.