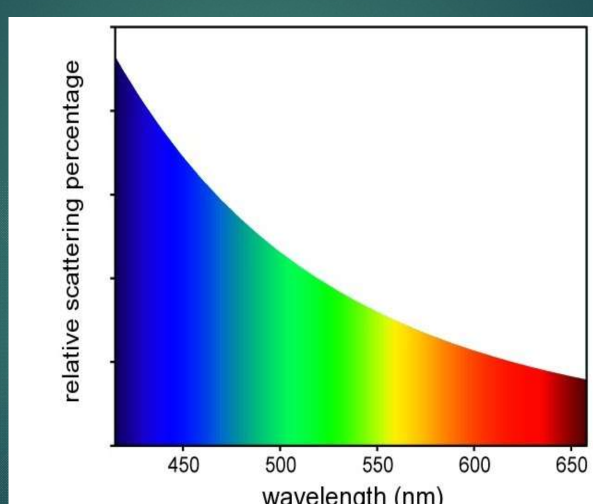
Ocular Scatter

- The are several sources of stray light in the eye including the cornea, transmission through the iris and the crystalline lens.
- Cornea tends to have Rayleigh Scatter
- Lens follows inverse power law, but not quite $1/\lambda^4$
- Scatter can be quantified as the ratio of the unwanted scattered light to the desirable non-scattered light. Usually given in log units.

Rayleigh Scattering



http://woelen.scheikunde.net/science/physics/exps/scattering/rayleigh_scattering.jpg

Scatter

Scatter creates a large halo around the PSF that can reduce contrast of a scene.

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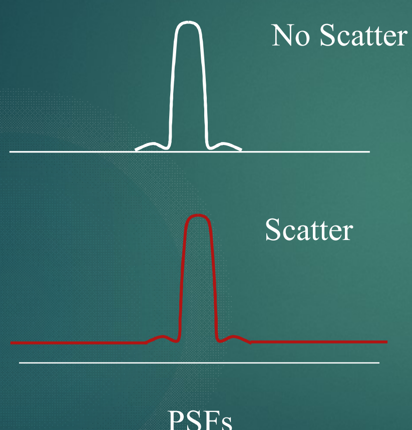
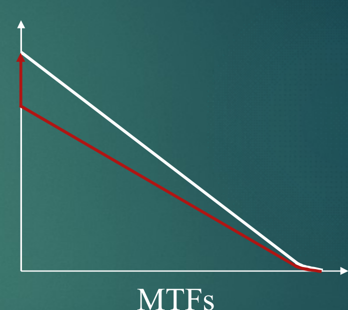
PSF and MTF with Scatter





The scattered light act like a dc offset to the PSF, which turns to a delta function in frequency space. Contrast is reduced at all spatial frequencies

Scatter

Defocus - VA 20/50 | Normal | Log(s)=1.47

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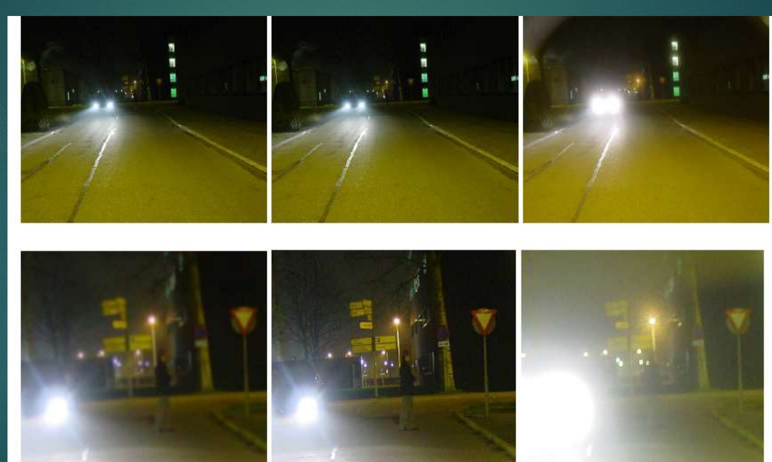
Scatter

Defocus - VA 20/50 | Normal | Log(s)=1.47



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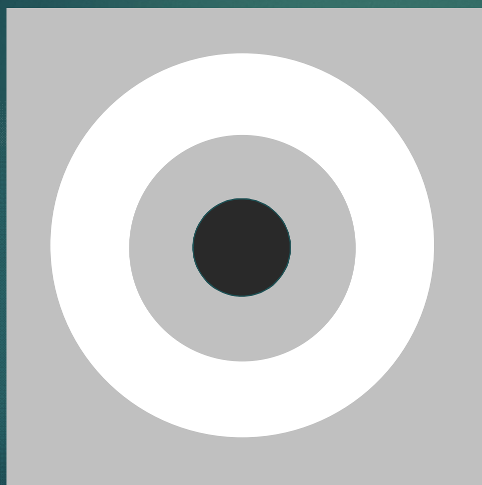
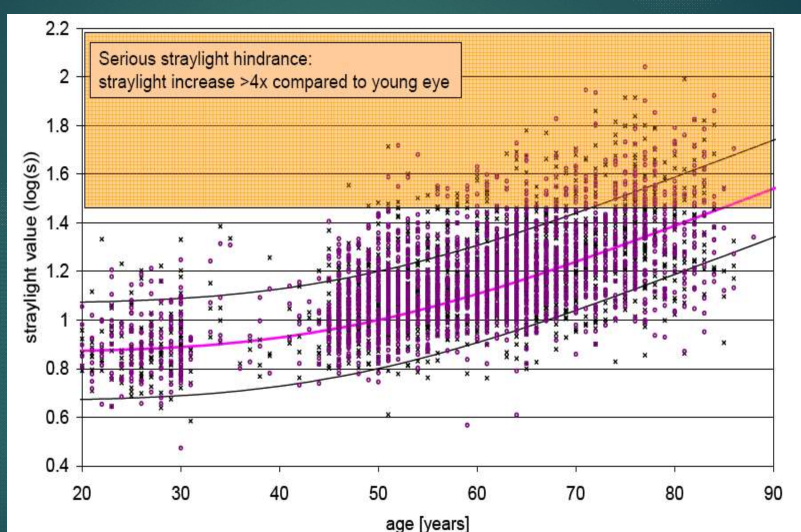
Scatter Measurement



White ring source surrounds a dark target. Ring source flickers, so that stray light falling on the target makes the target appear to flicker.

Adjusting the target with a counter-phased flicker can eliminate the intensity variation.

Scatter



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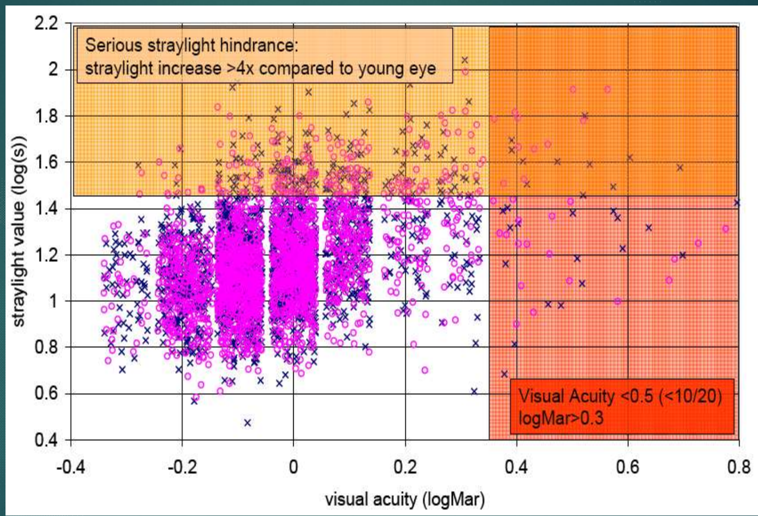
Scatter



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Cataract

Cataracts are an opacification of the crystalline lens in the eye. Early stages cause reduce light levels and scatter. Advanced stages cause (preventable) blindness.

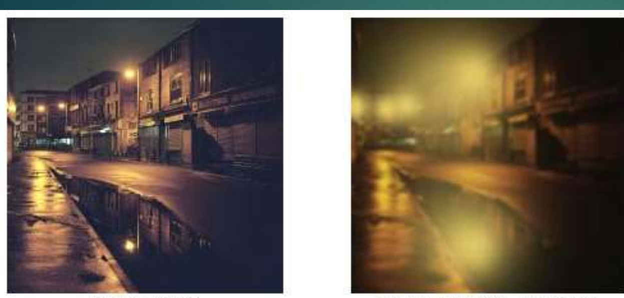
Cataract extraction with intraocular lens implantation is the most widely performed surgery in the US.

Cataract Types

Cortical - opacities in the periphery working towards the lens center.
Nuclear - opacities in the center of the lens working outwards.
Subcapsule - opacities on the surface of the lens.

•Secondary cataract: Cataracts can from eye surgery, diabetes and steroid use.
•Traumatic cataract: Cataracts can develop after an eye injury.
•Congenital cataract: Some babies are born with cataracts or develop them in childhood, often in both eyes.
•Radiation cataract. Cataracts can develop after radiation exposure.

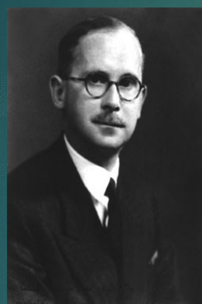
Cataract Symptoms



Normal vision — The same seen as viewed by a person with a cataract

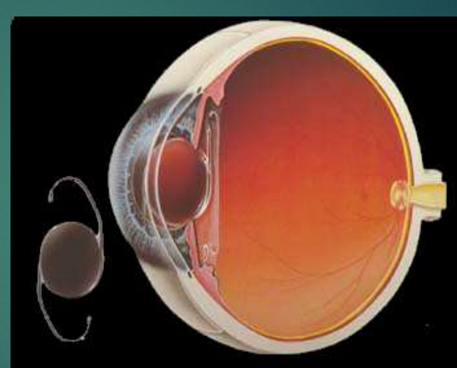
•Cloudy or blurry vision.
•Colors seem faded.
•Glare. Headlights, lamps, or sunlight may appear too bright. A halo may appear around lights.
•Poor night vision.
•Double vision or multiple images in one eye. (This symptom may clear as the cataract gets larger.)
•Frequent prescription changes in your eyeglasses or contact lenses.

Harold Ridley



Ridley noticed that shards from the canopy (PMMA) of RAF pilots lodge in their eyes did not get rejected by the body's immune system. Proposed making an implantable lens out of the material.

Intraocular Lenses



Need to calculate the power of the iol that needs to go into the eye.

SRK Formula

The SRK formula is essentially a linear regression formula. It is widely used because it is easy to memorize and can be calculated quickly. It is inaccurate for “non-normal” patients.

$$A - 0.9K - 2.5L = \phi_{iol}$$

A = A constant (Fudge factor provided by the manufacturer

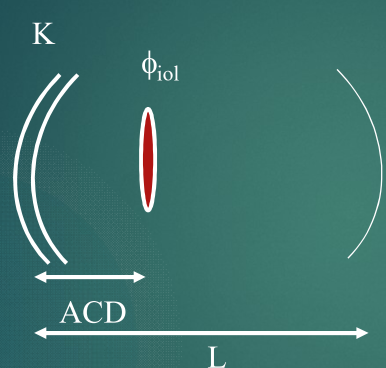
K = Average corneal power in diopters

L = Axial length of the eye

Example: A = 118, K = 42 D and L = 24 mm

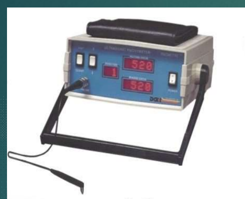
ϕ_{iol} = 20.2 D

Theoretical Formulas



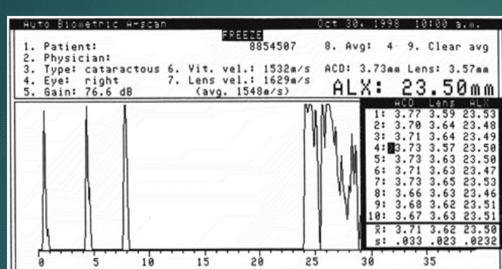
$$\phi_{IOL} = \frac{n\left(\frac{n}{K} - L\right)}{(L - ACD)\left(\frac{n}{K} - ACD\right)}$$

Pachymetry



A pachymeter is an ultrasound device for designed specifically to measure the thickness of the cornea. It was important in RK to determine blade depth settings and it used in laser refractive surgery to determine safe limits of tissue removal.

Ultrasound A-Scan



Ultrasound can also be used to determine the position of the lens within the eye and the length of the eye. This technique is routinely used for determining IOL power.

Frequencies are typically 10-20 MHz

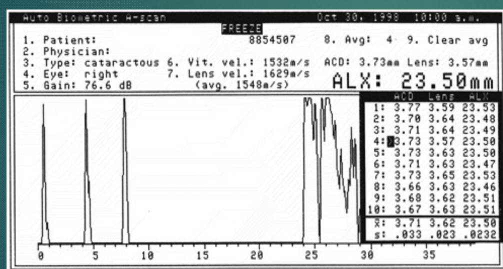
Assumes velocities of 1532 m/s in cornea, aqueous and vitreous

1629 m/s in the lens

Resolution 50 μm

Theoretical Formulas

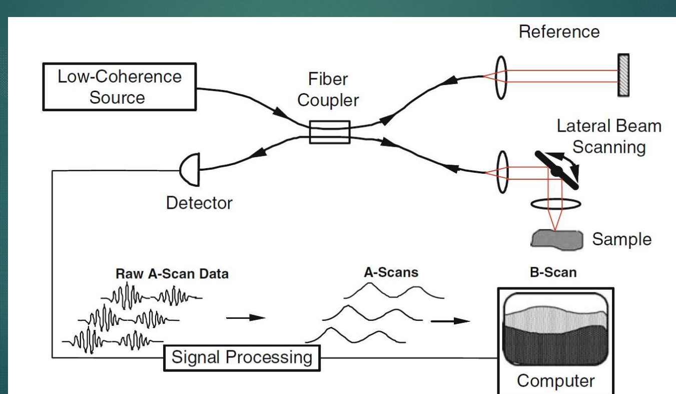
- Can usually measure K fairly accurately (Keratometry), L and ACD are more difficult.



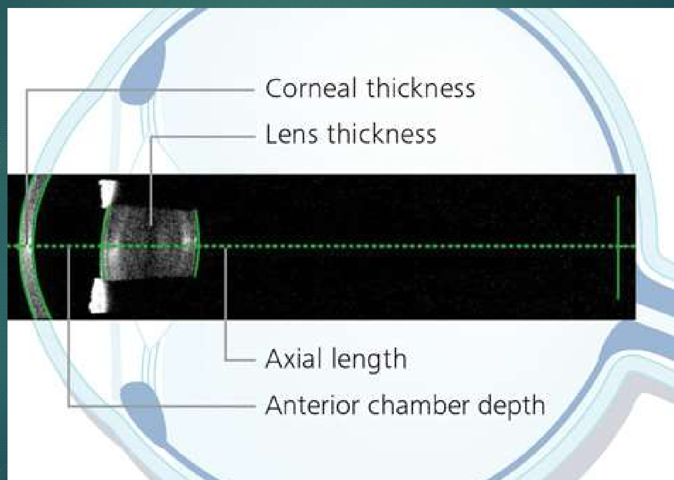
A-scan gives L and ACD for existing lens. The A constant essentially describes where the lens sits with the region of the cataractous lens.

Optical Coherence Tomography (OCT)

A low coherence light source is used

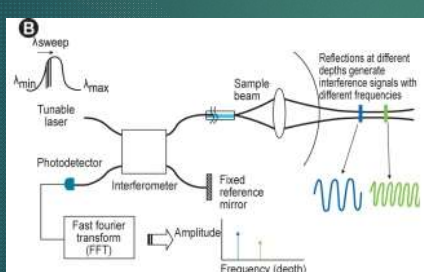


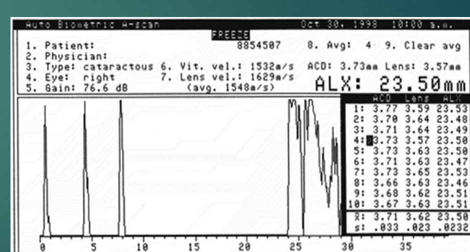
IOLMaster 700



SS-OCT vs. Ultrasound

Axial length measurement with a Swept-Source OCT is accurate to ~10µm. Axial length measurement with traditional ultrasound units are accurate to ~100µm.

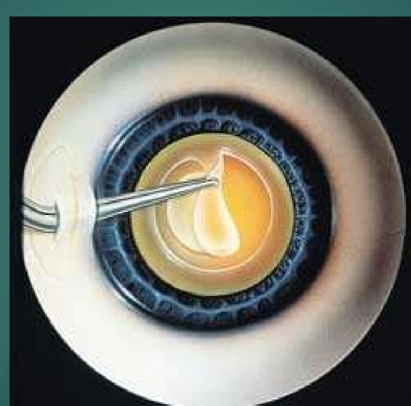




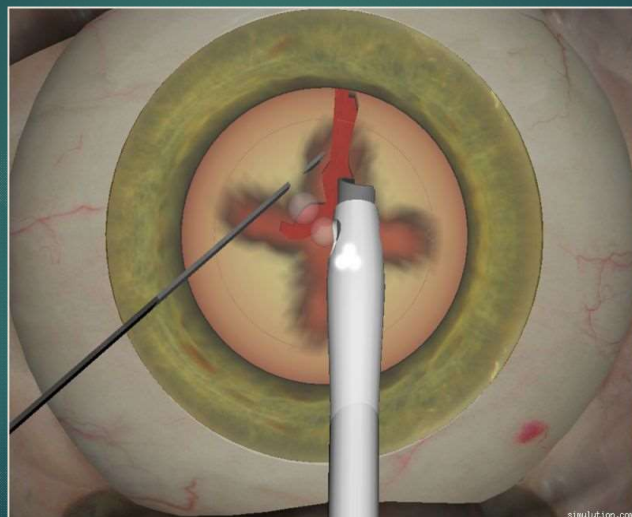
Definitions

- Aphakia – without lens. Older patients did not get implants, so they had to wear extreme hyperopic corrections. Uncommon these days.
- Pseudophakia – Fake lens. IOL implant following cataract extraction.
- Phakic Lens – Lens implant while leaving crystalline lens intact.

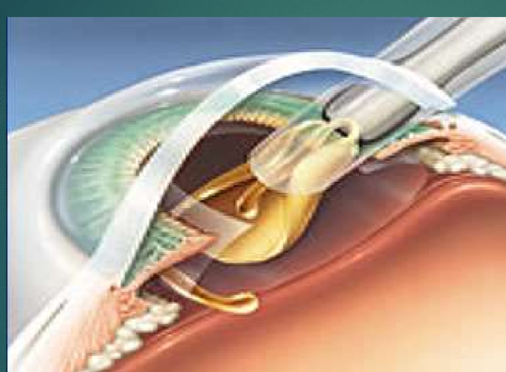
Capsulorhexis



Phacoemulsification



Lens Injection

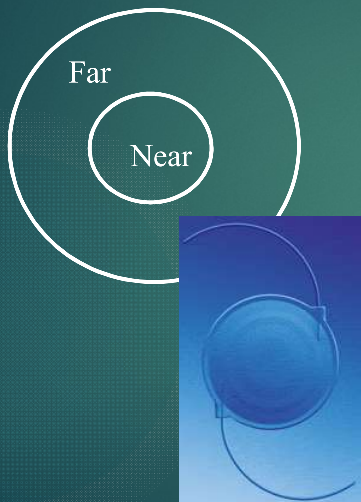


Lenses are rolled up and injected through the small incision. They unroll as they exit the injector. The surgeon then adjusts the IOL position to ensure proper placement inside the capsule and behind the iris.

Posterior Capsule Opacification

YAG Capsulotomy

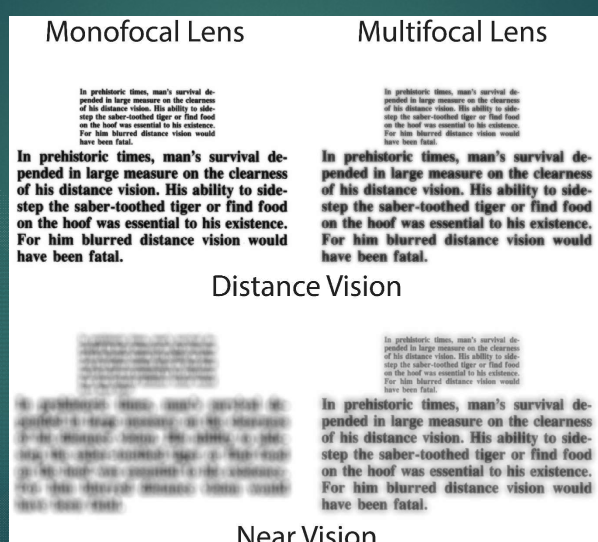
Multifocal IOLs and Contacts



Multifocal come in a variety of forms, but the basic concept is to have two different powers simultaneously on a single lens. One power allows for distance vision, while the other allows for near vision.

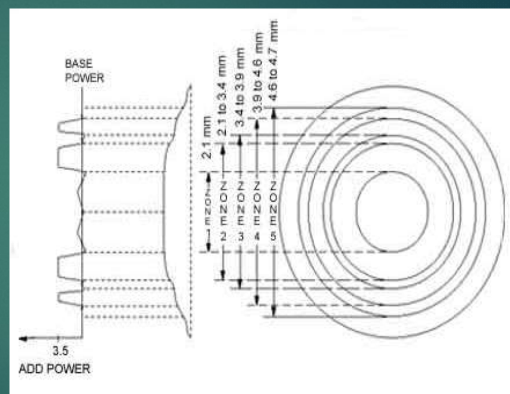
Variations in zone size, number of zones, power distribution, progressives, aspherics and diffractives all exist.

Simulated Images



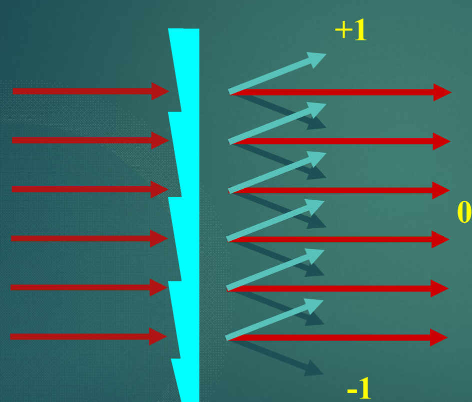
Refractive Multifocal Optics

- A refractive lens has alternating zones of varying refractive power.
- The zones of a refractive multifocal lens are typically the same size and width and act as independent annular refractive lenses.



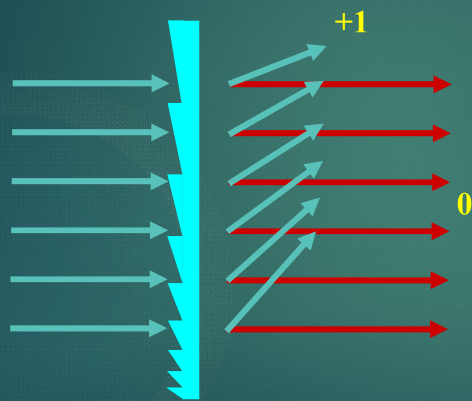
AMO ARRAY®

Blazed Grating



- Triangular steps of transparent material.
- Light diffracts from the steps and is primarily split into three beams.
- Angle of step shifts the amount of energy in each order.

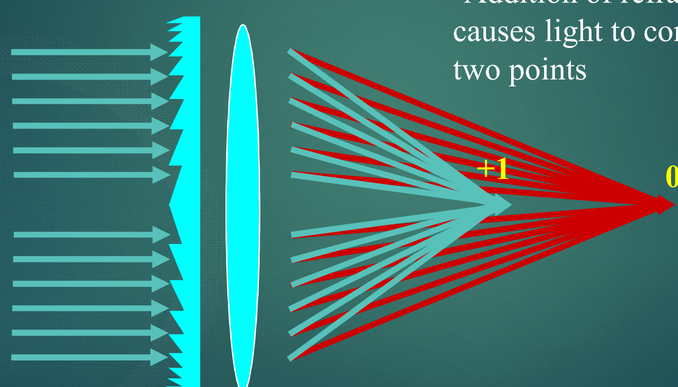
Chirped Grating



• Spacing between steps changes across grating.

• Diffraction angle changes with step spacing.

Diffractive Lens

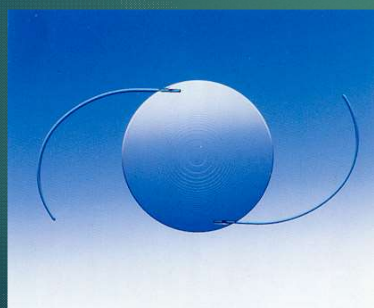


•Addition of refractive lens causes light to converge to two points

Full Aperture Diffractive IOLs

• Step heights set so that roughly 40% in near focus and 40% in distance focus.
• Relative energy does not change with pupil size.
• Remainder of light diffracted into other orders.

3M Diffractive

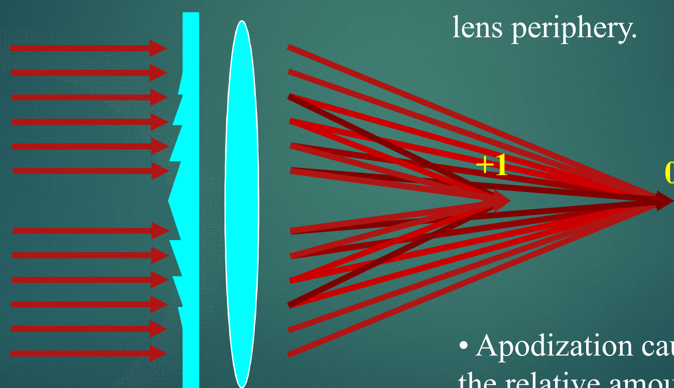


Pharmacia Multifocal

Diffractive vs. Refractive Multifocals

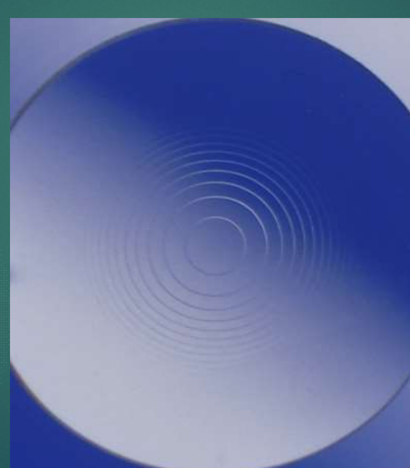
Apodized Diffractive Lens

• Reduce blaze angle towards lens periphery.



• Apodization causes a shift in the relative amounts of energy in each focus.

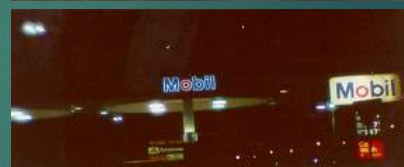
Alcon Restor



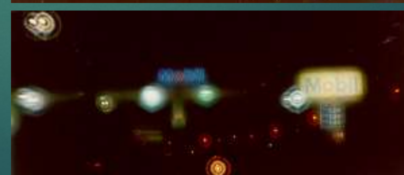
Comparative Nighttime Images (5 mm Aperture, IOL in Wet Cell)

Monofocal

AcrySof ReSTOR

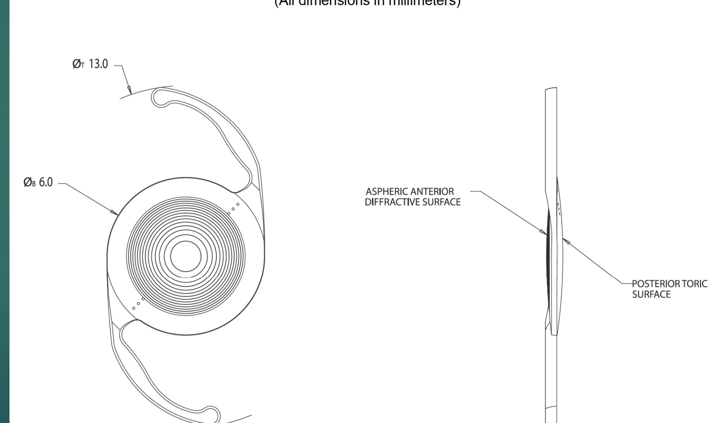


AMO Array



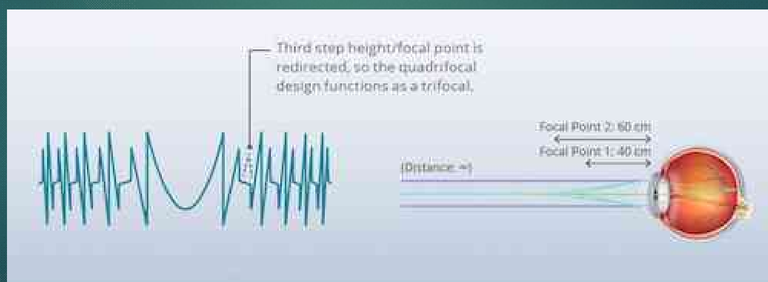
PanOptix Toric

Figure 1: Physical Characteristics of the AcrySof* IQ PanOptix* Toric Presbyopia Correcting IOL
(All dimensions in millimeters)



PanOptix Trifocal

- Frustrated quadrafocal (i.e. diffraction efficiency of one of the four foci is negligible)
- Foci for 0D (Distance) 2.17D (Intermediate) and 3.25D (Near) . Translates to roughly 40 cm and 60 cm from the eye.



Defocus Transfer Function

- Optical Transfer Function (OTF) of rotationally symmetric systems
- Relationship to the Defocus Transfer Function
- Applications to techniques for treating presbyopia.
- Examples

OTF of Rotationally Symmetric Systems

If the pupil function is given by $P(x,y) = P(r)$

Then the OTF is related to the autocorrelation of the pupil function

$$OTF(\rho) = \iint P\left(x - \frac{\rho}{2}, y\right) P^*\left(x + \frac{\rho}{2}, y\right) dxdy$$

Suppose, we want to look at the performance of this pupil function for different levels of defocus.

$$P(x,y)\exp\left(\frac{i2\pi}{\lambda} W_{20} r^2\right)$$

OTF of Rotationally Symmetric Systems

In this case,

$$OTF(\rho) = \iint P\left(x - \frac{\rho}{2}, y\right) \exp\left(\frac{i2\pi}{\lambda} W_{20}\left(x^2 - \rho x + \frac{\rho^2}{4} + y^2\right)\right)$$

$$\times P^*\left(x + \frac{\rho}{2}, y\right) \exp\left(\frac{-i2\pi}{\lambda} W_{20}\left(x^2 + \rho x + \frac{\rho^2}{4} + y^2\right)\right) dxdy$$

which reduces to

$$OTF(\rho) = \iint P\left(x - \frac{\rho}{2}, y\right) P^*\left(x + \frac{\rho}{2}, y\right) \exp\left(i2\pi\left(\frac{-2W_{20}\rho}{\lambda}\right)x\right) dxdy$$

Defocus Transfer Function (DFT)

Define the 2-D function

$$\mathrm{DTF}(\rho, z) = \iint P\left(x - \frac{\rho}{2}, y\right) P^{*}\left(x + \frac{\rho}{2}, y\right) \exp(i2\pi z x)\, dx\, dy$$

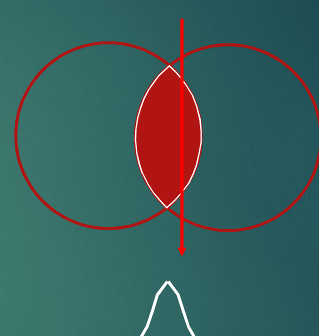
then the OTF is given by

$$\mathrm{OTF}(\rho) = \mathrm{DTF}\left(\rho, \frac{-2W_{20}}{\lambda}\rho\right)$$

In other words, the OTF for a given level of defocus is simply a slice through the DTF at an angle $-2W_{20} / \lambda$.

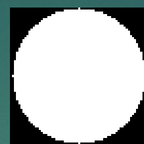
DTF Algorithm

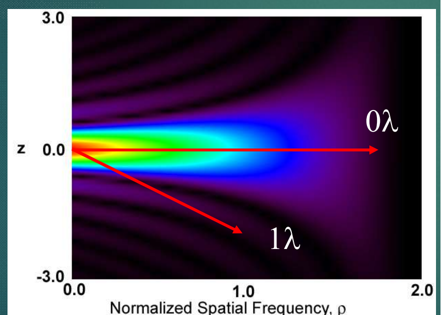
- Pick a value of $\rho = \rho_o$
- Integrate along the y axis.
- 1-D Fourier transform result
- Store in DTF(ρ_o , z)
- Repeat for new value of ρ_o

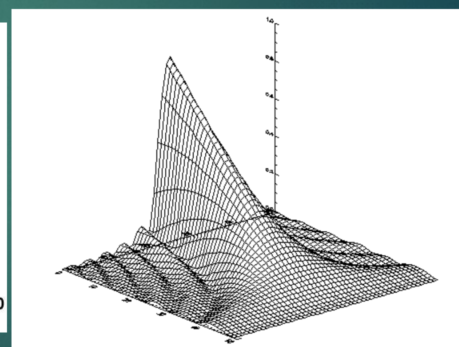


Example - Aberration-Free System

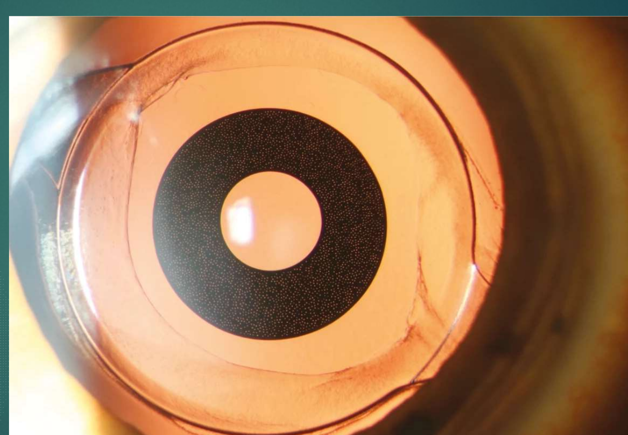
Slope = $-2W_{20} / \lambda$



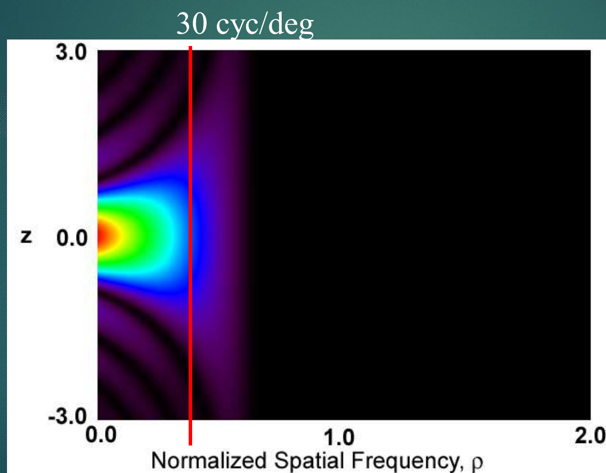


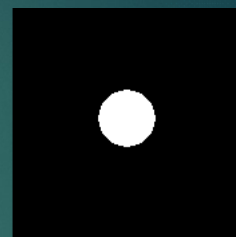


Pinhole Implant



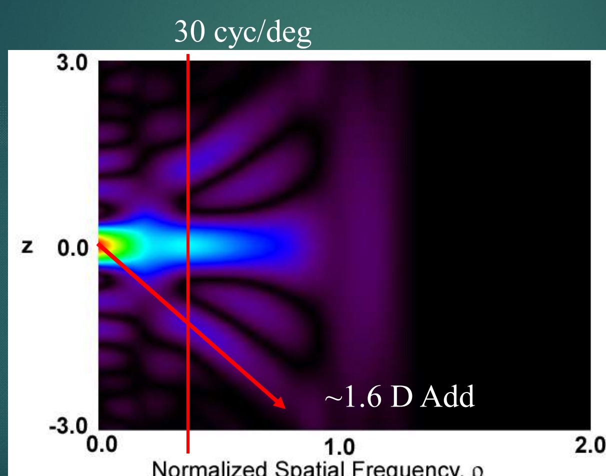
Annulus with 3 mm Pupil



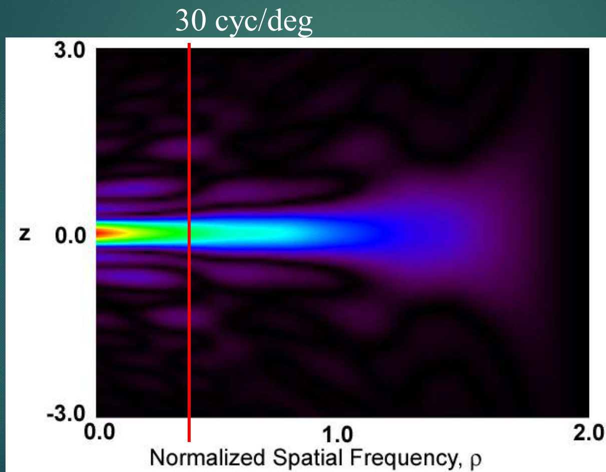


Effectively a
2 mm pupil.
Pinholing!!

Annulus with 4 mm Pupil



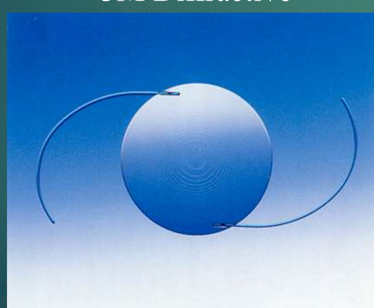
Annulus with 6 mm Pupil



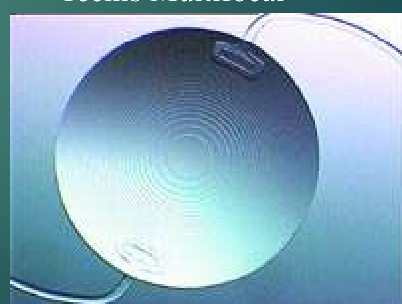
Full Aperture Diffractive IOLs

- Step heights set so that roughly 40% in near focus and 40% in distance focus.
- Relative energy does not change with pupil size.
- Remainder of light diffracted into other orders.

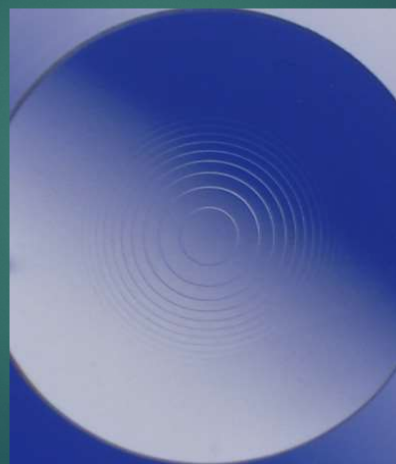
3M Diffractive



Tecnis Multifocal



Apodized

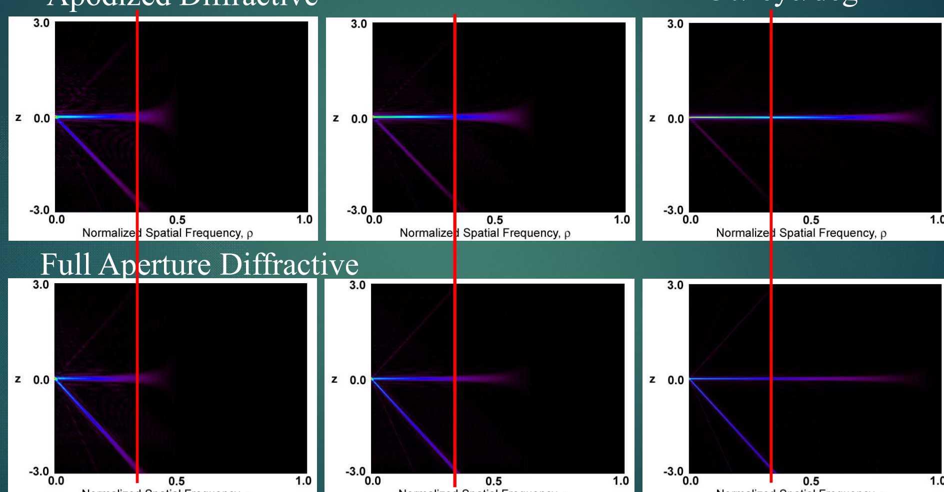


Alcon ReStor

Apodized vs. Full Aperture

Apodized Diffractive

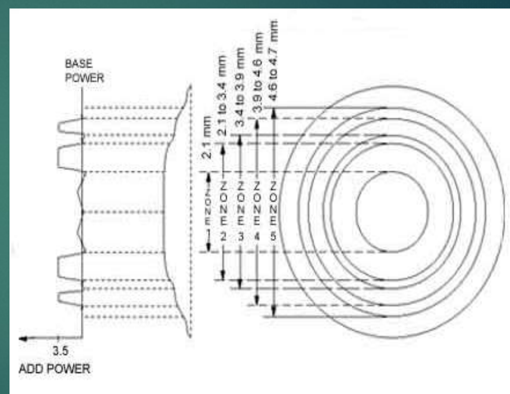
30/ cyc/deg



3mm Pupil 4mm Pupil 6mm Pupil

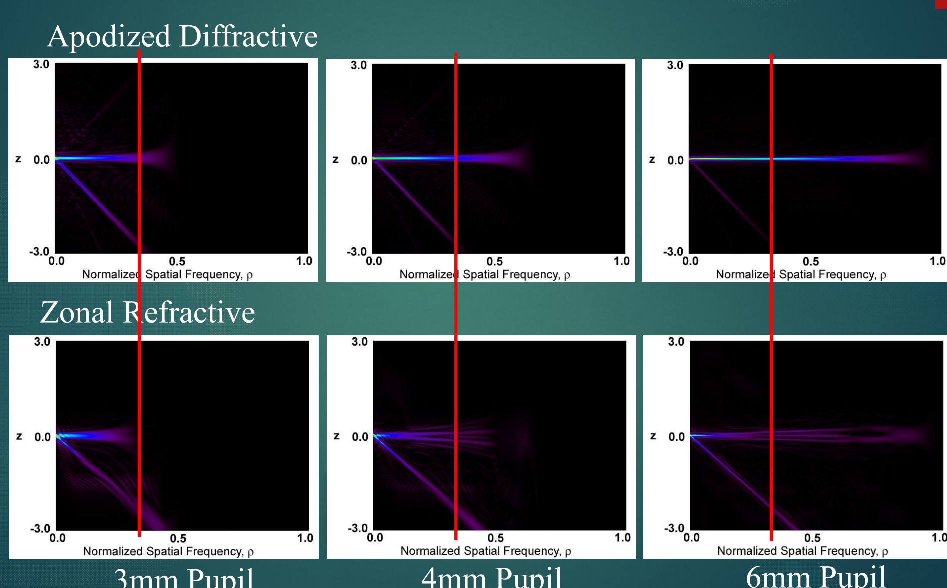
Zonal Refractive Multifocals

- A refractive lens has alternating zones of varying refractive power.
- The zones of a refractive multifocal lens are typically the same size and width and act as independent annular refractive lenses.



AMO ARRAY®

Zonal Refractive



Polychromatic DTF

- Four Chromatic Issues to take into account
  - Phase introduced by step heights depends on λ.
  - Ocular Longitudinal Chromatic Aberration
  - Cutoff Frequency of OTF depends on λ.
  - Spectral Sensitivity of the photoreceptors.

Defocus Transfer Function (DFT)

Define the 2-D function

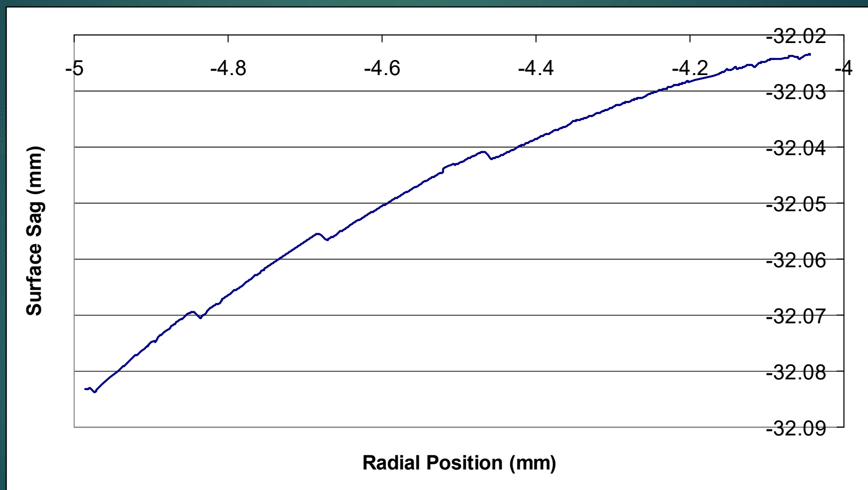
$$DTF(\rho, z) = \iint P\left(x - \frac{\rho}{2}, y\right) P^*\left(x + \frac{\rho}{2}, y\right) \exp(i2\pi zx)\, dxdy$$

then the OTF is given by

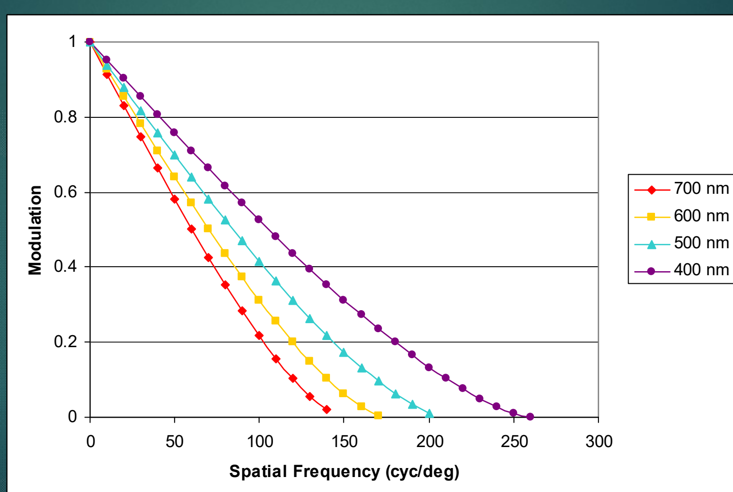
$$OTF(\rho) = DTF\left(\rho, \frac{-2W_{20}}{\lambda}\rho\right)$$

In other words, the OTF for a given level of defocus is simply a slice through the DTF at an angle $-2W_{20} / \lambda$.

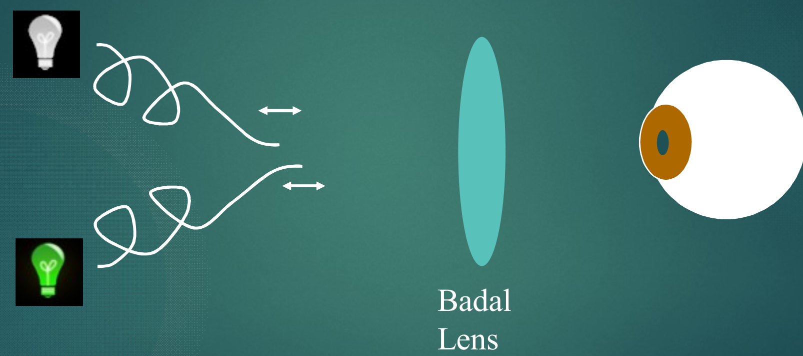
Tecnis MF Steps



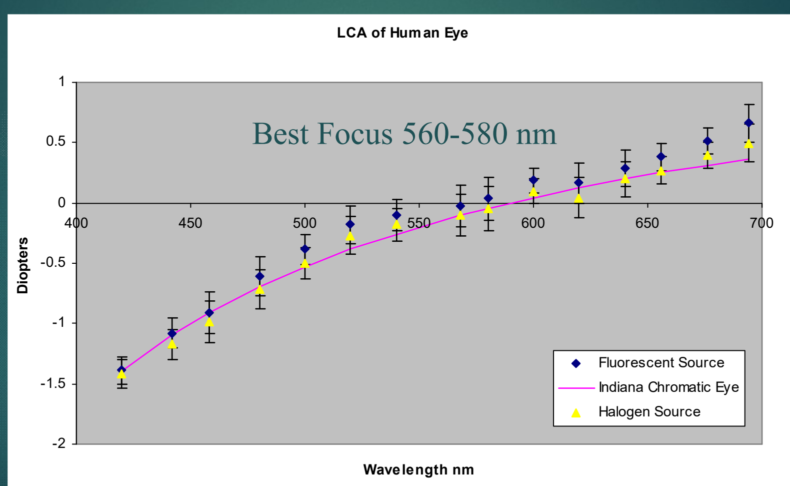
Cutoff Frequency vs. λ



Ocular Chromatic Aberration



Ocular Chromatic Aberration



Ocular Chromatic Aberration

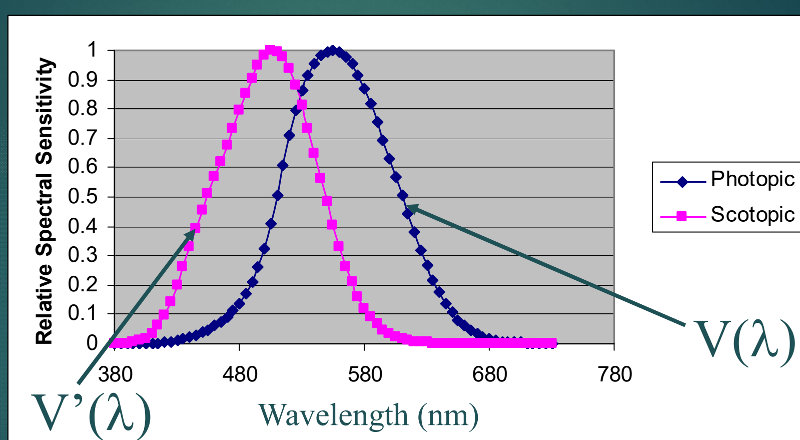
$\lambda = 400$ nm

$\lambda = 500$ nm

$\lambda = 600$ nm

$\lambda = 700$ nm

Luminosity Functions



Polychromatic OTF

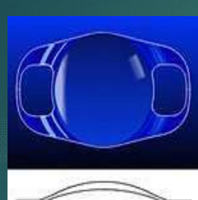
$$\mathrm{POTF}(\xi,\eta)=\frac{\sum_{\lambda}V(\lambda)\,\mathrm{OTF}(\xi,\eta;\lambda)}{\sum_{\lambda}V(\lambda)}$$

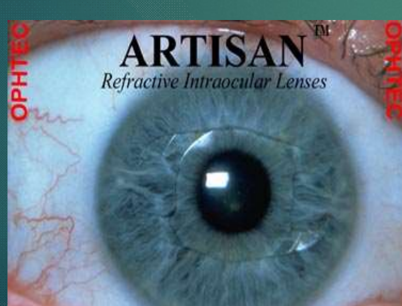
- Conventional definition of polychromatic OTF.
- Assumes single sensor with spectral sensitivity of $V(\lambda)$.
- But this is not how the eye operates.

Polychromatic Defocus Transfer

Polychromatic Defocus Transfer

Phakic IOLs

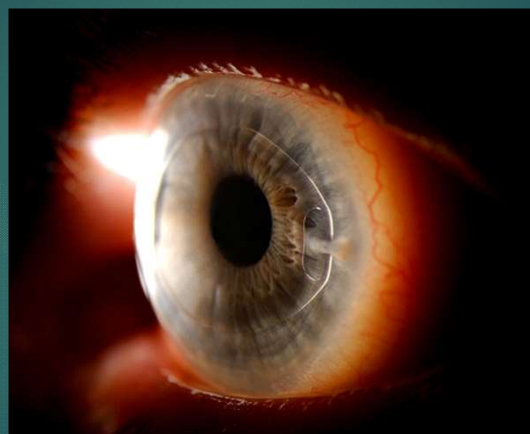




Phakic IOLs are currently in trials.
This is a means of implanting a lens
in the eye to correct for refractive error.

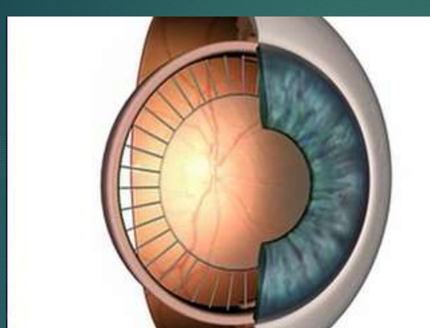
Concerns:
Damage to corneal endothelium causes
corneal opacities
Contact with crystalline lens causes
cataracts.

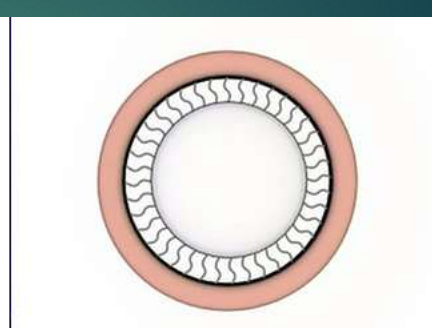
Phakic IOLs



Source: Webvision.med.utah.edu - Photograph was made by James Gilman of the Moran Eye Center.

Accommodation





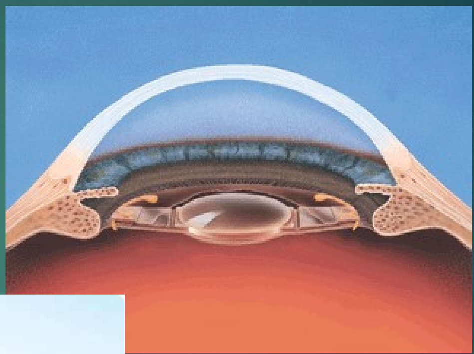
Relaxed ciliary muscle pulls zonules taut an flattens crystalline lens.

Constrict ciliary muscle releases tension on zonules and crystalline lens bulges.

Accommodating IOLs

Accommodating IOLs are based on a mechanical translation of the lens within the eye. As the ciliary muscle contacts, it presses on the hinged haptics and causes the lens to move forward.

Accommodating IOL

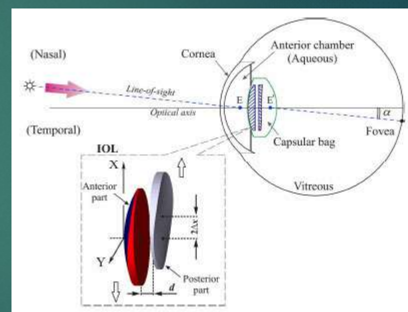


Crystalens

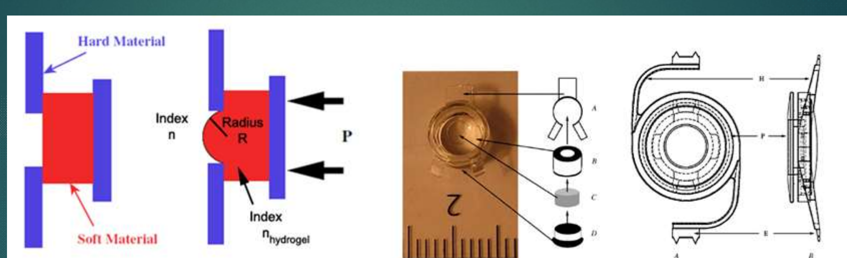
Two cases of Z syndrome with the Crystalens after uneventful cataract surgery
Leonard Yuen, MD, MRCOphth, MPHAuthor Vitae, William Trattler, MD, Brian S. Boxer Wachler, MD
Journal of Cataract & Refractive Surgery Volume 34, Issue 11, November 2008, Pages 1986–1989

Dual Optic Accommodating IOL

Alvarez Accommodating IOL

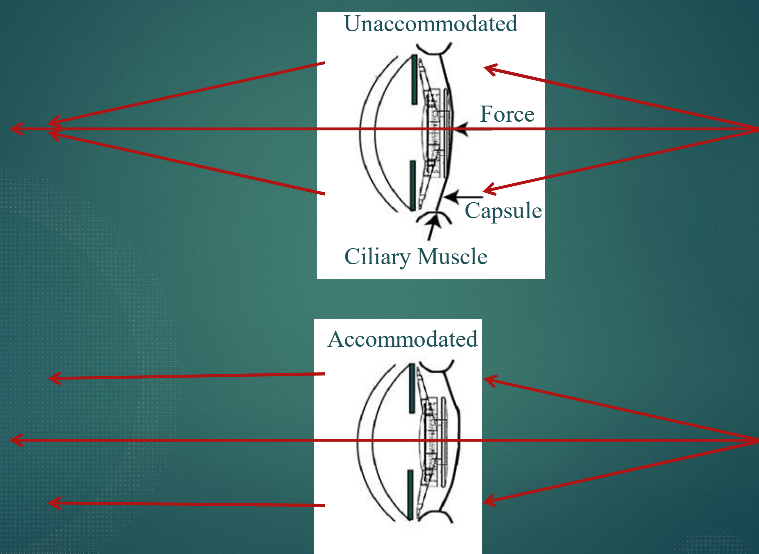


NuLens Dynacurve

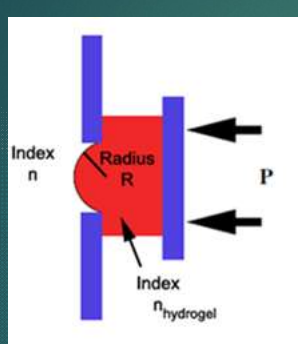


Ben-nun J, Alio JL. Feasibility and development of a high power real accommodating intraocular lens. J Cataract Ref Surg 2005; 31:1802-1808.

Nulens Concept



Making Things Work the "Right" Way



Why do we assume this interface Provides positive power?

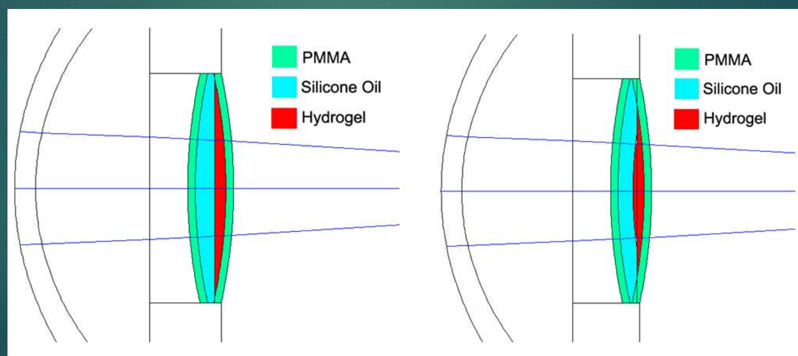
Because we assume index of hydrogel is greater than the surrounding index.

Make $n > n_{hydrogel}$ to create negative power.

Proposed Lens

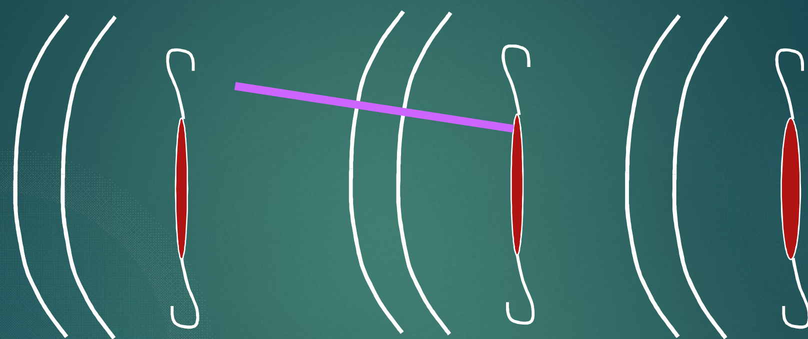
- Soft hydrogel sandwiched between to rigid elements. Hydrogel extrudes through aperture into higher index material as plates are compressed

Accommodated Unaccommodated



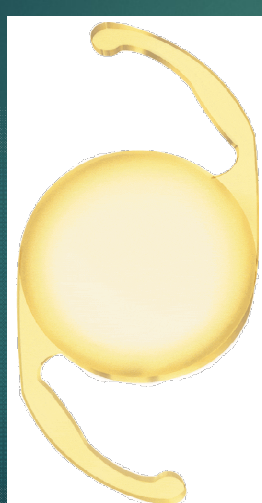
Accommodating IOL

Light Adjustable IOLs



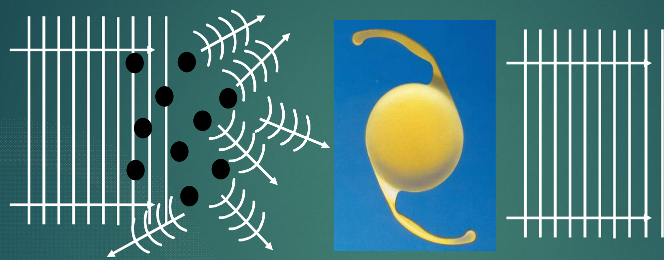
Adjustable IOLs are implanted in the eye. Several weeks following surgery, a uv beam is used to “write to” the IOL and modify its shape. The shape is then fixed, allowing for a permanent customized correction.

Blue-Light Absorbing Lenses



- Reduces amount of blue light (which can be harmful) hitting the retina
- Reduces the effects of chromatic aberration of the eye.
- Reduces scattered light within the eye.

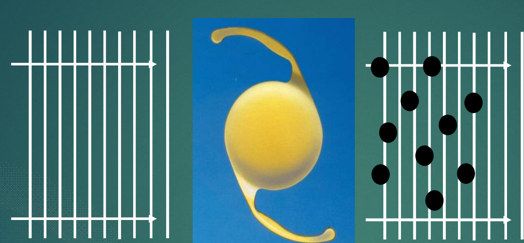
Scatter



Scattered blue light
is filtered by IOL.

Environmental conditions such as fog and haze, or corneal haze cause scatter that is blocked by the Natural chromophore, resulting in a higher contrast on the retina.

Scatter



Blue light is filtered
by IOL, so scatter is
reduced following
lens

Internal scatter in the vitreous is reduced by Natural chromophore since blue light is filtered prior to getting to scattering bodies. Aspheric optics, in addition, result in higher contrast on the retina.

Scatter Experiment

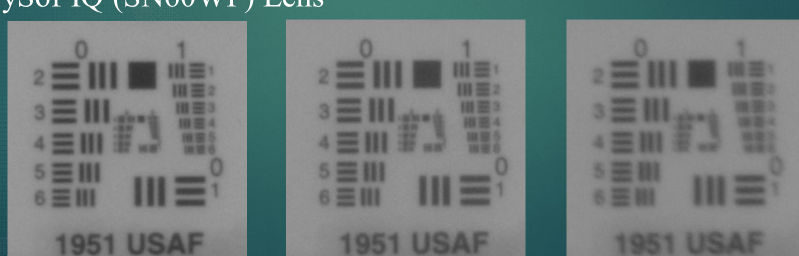
- Blue light scatters more than longer wavelengths.
- Sodium bicorbonate added to wet cell to introduce scatter.
- Concentrations of 0.0 g/L, 52.8 g/L and 105.6 g/L.
- Photographs of bar targets under white light illumination captured with model eye.

Scatter Experiment Results

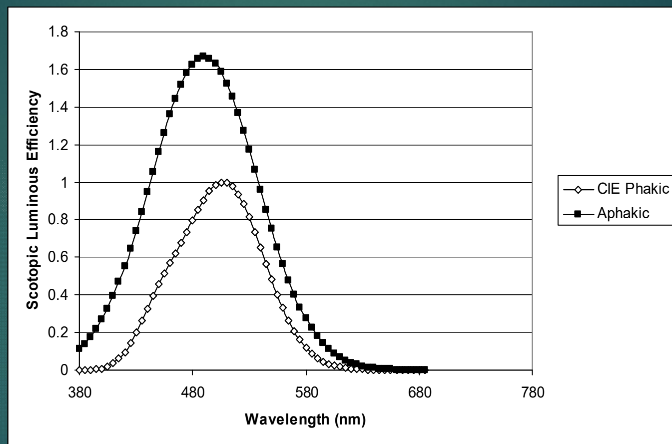
AcrySof (SA60AT) Lens

Increasing Scatter

AcrySof IQ (SN60WF) Lens

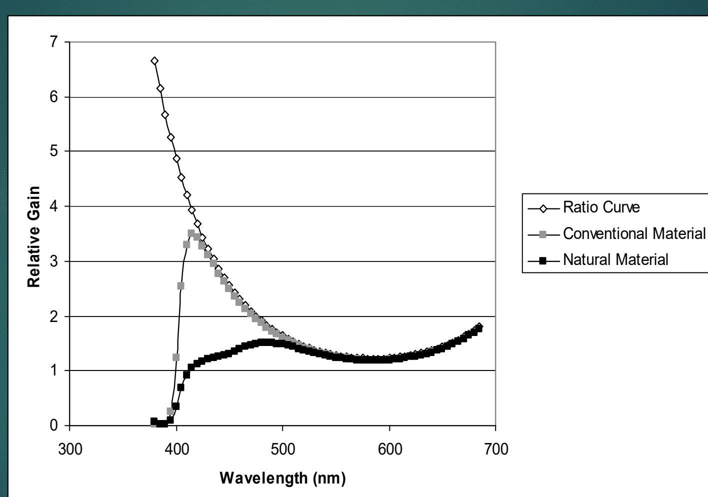


Aphakic Scotopic Response Curve



Stark WS, Tan KEWP. Ultraviolet light. Photosensitivity and other effects on the visual system. Photochemistry and Photobiology 1982; 36:371-380.

Spectral Changes



Results