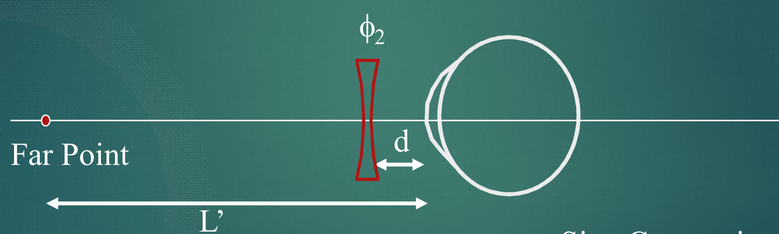
# Spherical Refractive Error

For myopia, a negative lens is needed to image a point at infinity to the eye's far point. The far point is conjugate to the retina.



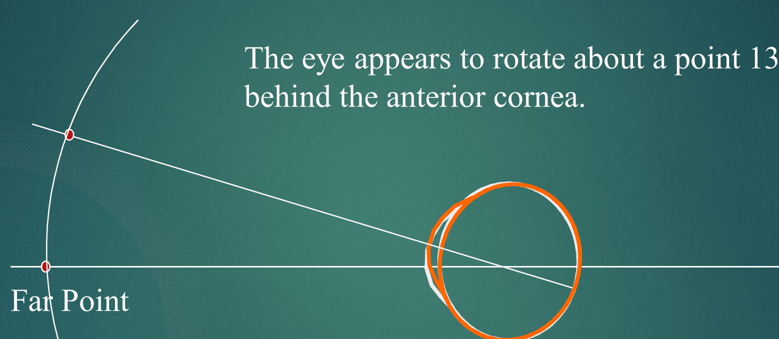

$$\frac{1}{L'+d} = \phi_2$$

Sign Convention:
L'<0

d is typically 14 mm

# Rotation of the Eye

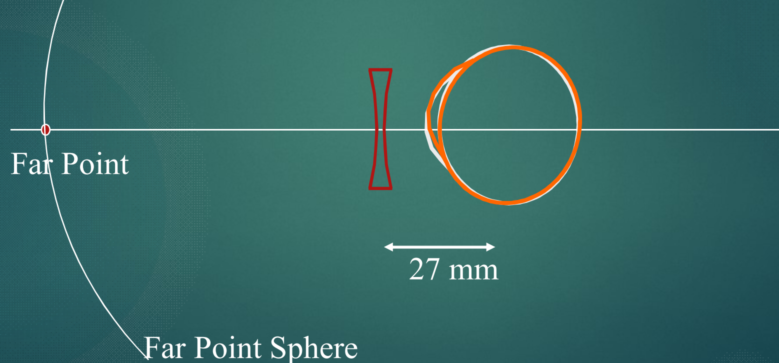
The eye appears to rotate about a point 13 mm behind the anterior cornea.




The far point traces out a sphere centered on the center of rotation of the eye.

# Far Point Sphere

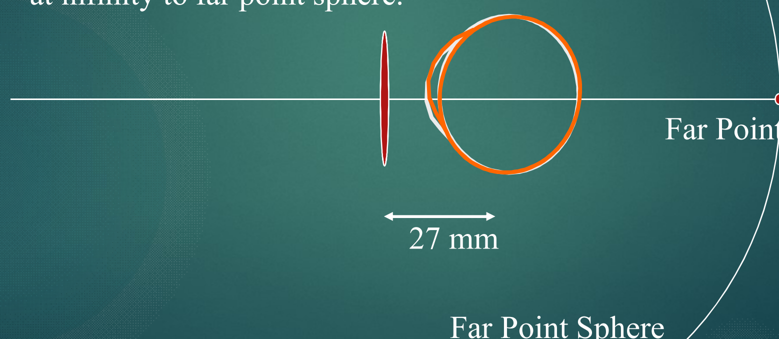
Want the power of the lens to image points at infinity to the far point sphere regardless of direction of gaze.




# Far Point Sphere

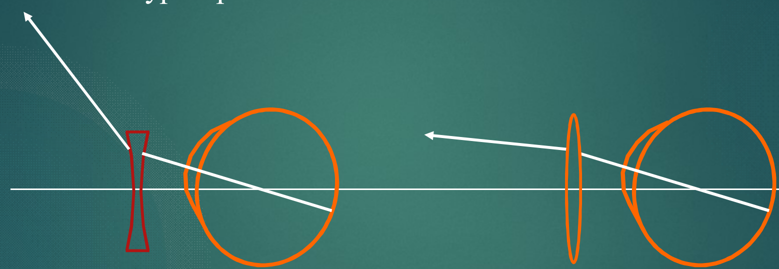
For hyperopia, the far point sphere lies behind the head.

Want a plus lens to focus objects at infinity to far point sphere.



# Line of Sight

Myopes have a expanded field of vision, whereas hyperopes have a contracted field of vision.



# Spectacle Lenses

- The power of the spectacle lens is fixed by the patient's refractive error.
- This leaves limited degrees of freedom for aberration correction.
  - Front radius of curvature
  - Back radius of curvature
  - Index of refraction

What aberration should be corrected in eyeglasses?

Astigmatism

because the eye looks through different portions of the lens

## Spectacle Lens Design

- Point Focal (Punktal) - Lens surfaces are bent so that the tangential and sagittal surfaces coincide (ie oblique astigmatism is eliminated). Petzval surface does not necessary coincide with Far Point Sphere resulting in spherical error with gaze angle.
- Minimum Tangential Error - Lens surfaces are bent so that the tangential surface coincides with the Far Point Sphere. Small levels of astigmatism with gaze angle.
- Percival - Lens is bent so that Petzval surface coincides with the Far Point sphere. No spherical error with gaze, but astigmatism remians. People see the circle of least confusion.

## Tscherning’s Ellipse

$$\phi_1^2(n+2)-\phi_1\left[\frac{2}{q'}(n^2-1)+\Phi(n+2)\right]+n\left[\Phi+\frac{n-1}{q'}\right]^2=0$$

Tscherning derived the above expression for the requirement to have a spectacle lens with zero astigmatism (thin lens approximation).

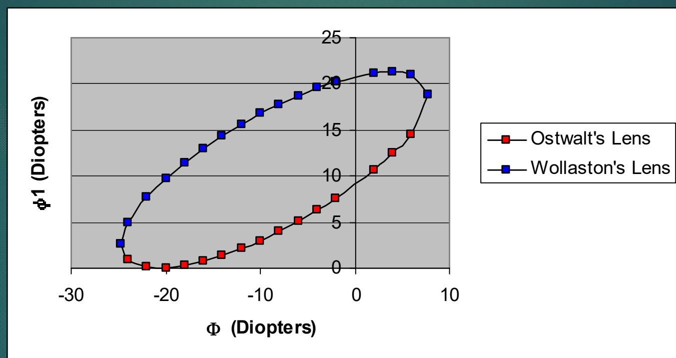
$\phi_1$ = the power anterior surface of the lens

$\Phi$ = total power of the lens

n = index of refraction of the lens

q’ = distance from back of lens to center of rotation of the eye (~27mm)

# Tscherning's Ellipse




More

Curve

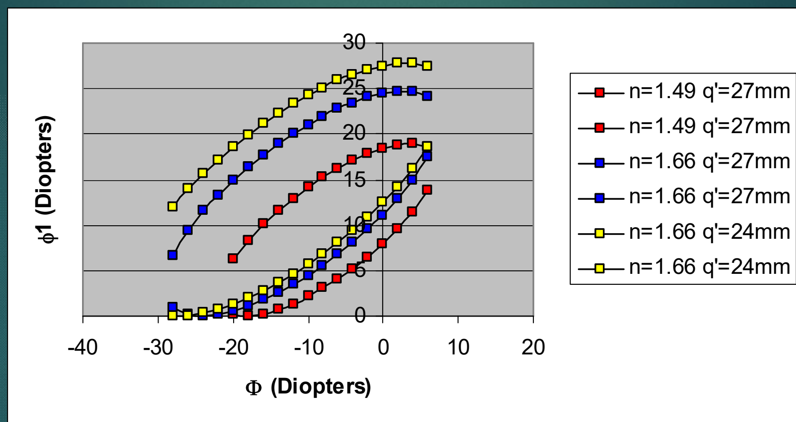
Less

Wollaston in 1804 recommended meniscus lenses to minimize astigmatism. Ostwalt in 1898 showed two solutions above, but had incorrect q'. Tscherning in 1904 did exact derivation shown above.

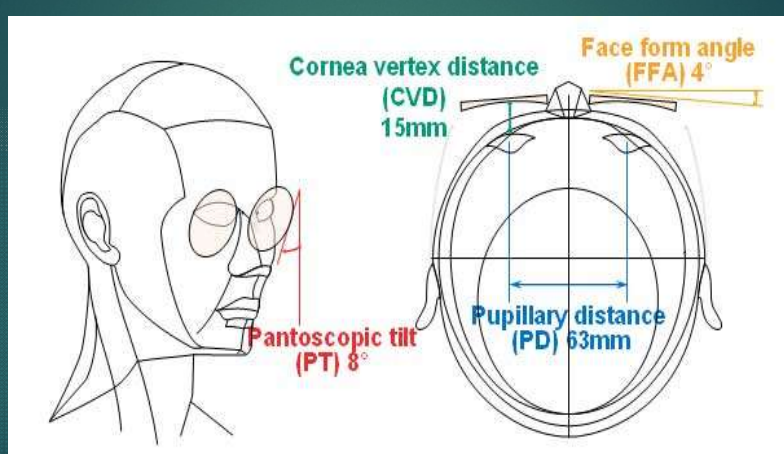
# Ostwalt vs. Wollaston

Ostwalt lenses are flatter and are regarded as more "cosmetically appealing". Wollaston lenses are more curved and have a reduced distortion with gaze angle.

# Tscherning's Ellipse



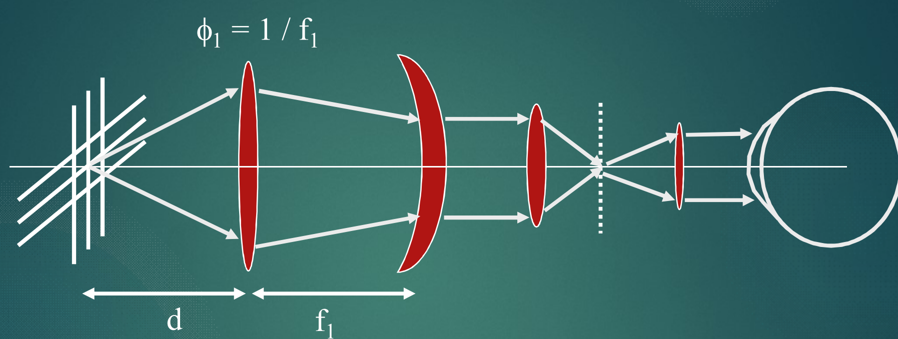

# Spectacle Ergonomics



# Lensmeters (Focimeters)

Lensmeters are devices that measure the prescription of a spectacle lens. There are manual and automated devices. For bifocal and multifocal lenses, different regions within the lens can be measured.

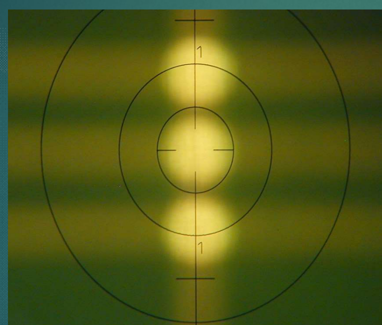
# Lensmeter

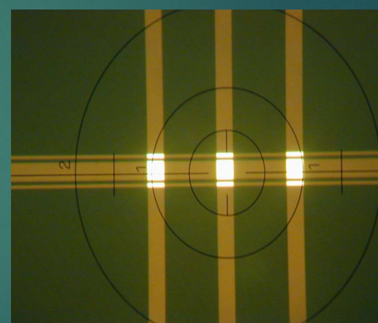



$$\phi_{spec} = \frac{d - f_1}{f_1^2}$$

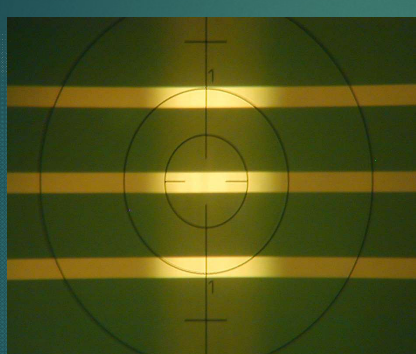
The spectacle lens is placed at the back focal point of lens $\phi_1$. The distance d is varied until observer sees target in focus on reticle.

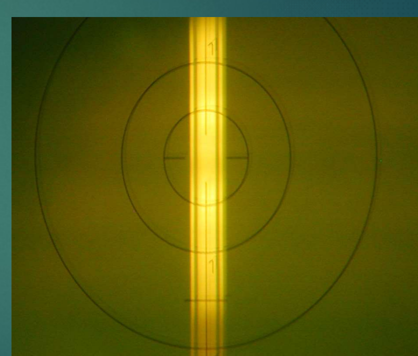
# Spherical Lens



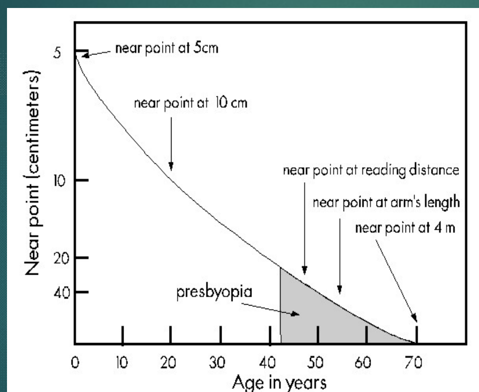


# Spherocylinder Lens





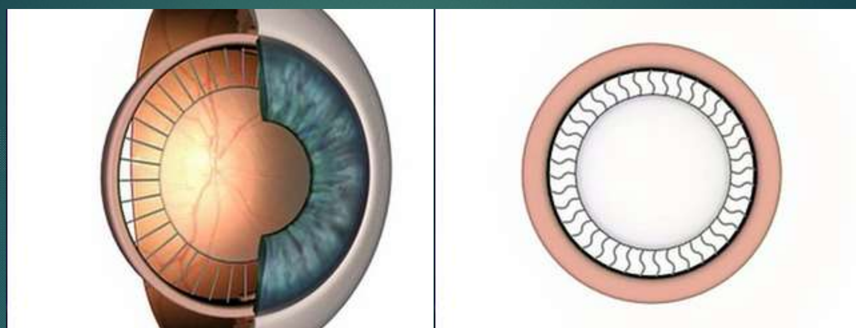
# Presbyopia




Your ability to accommodate reduces steadily with age. Typically, you don't notice the effects until it affects your ability to read comfortably. This is presbyopia.

# Presbyopia

# Accommodation

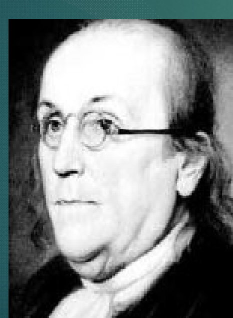


Relaxed ciliary muscle pulls zonules taut an flattens crystalline lens.

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

# Bifocals

Bifocals were invented by Benjamin Franklin in 1775. He simply cut two lenses in half and mounted them together in a frame.



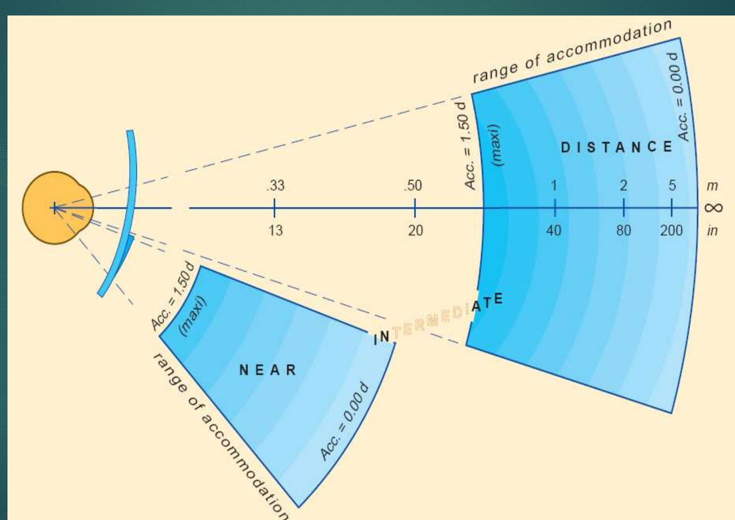
# Bifocals

Main lens contains the distance correction, while a second smaller lens is implanted to add additional power to allow for comfortable reading.  The add power is typically 3D – 0.5(residual accommodation).

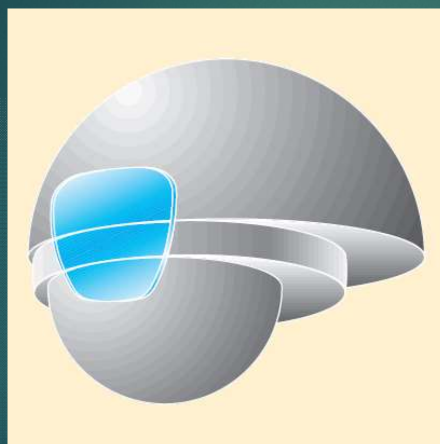
Bifocals have cosmetic drawbacks for some people.

Image jump across boundary.

# Bifocals



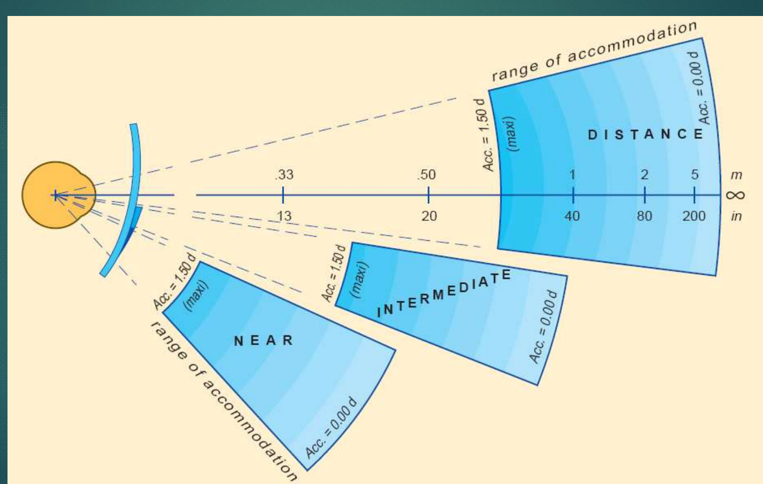
# Trifocals



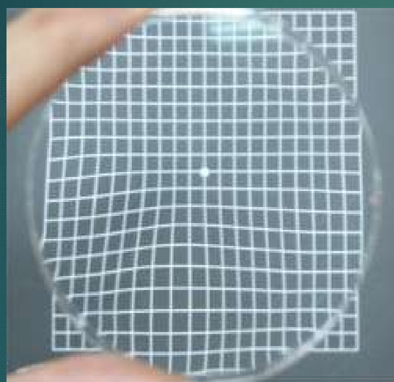
Trifocals are used to provide near, intermediate and distance vision in the same lens.

e.g. reading, computer screen, & driving.

# Trifocals



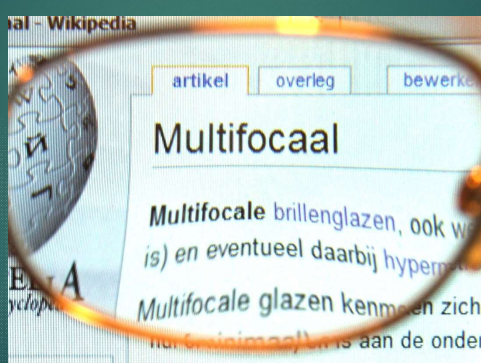
# Progressive Addition Lens



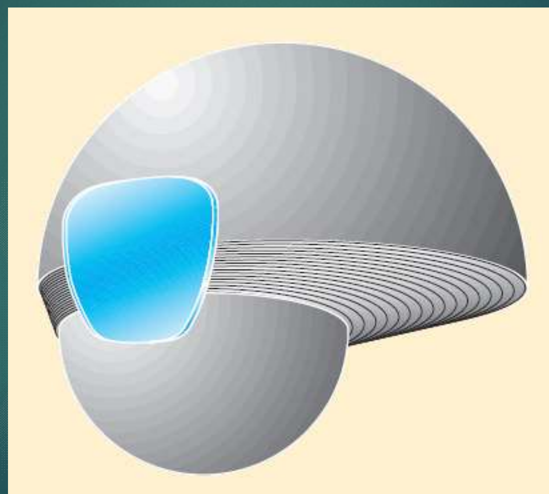
PALs have a continuous increase in power from top to bottom. Eliminates any image jump and eliminates the “line” from bifocals. Good distance vision, but near vision is restricted to a narrow channel because of astigmatism.

Requires head scanning, instead of eye scanning for reading.

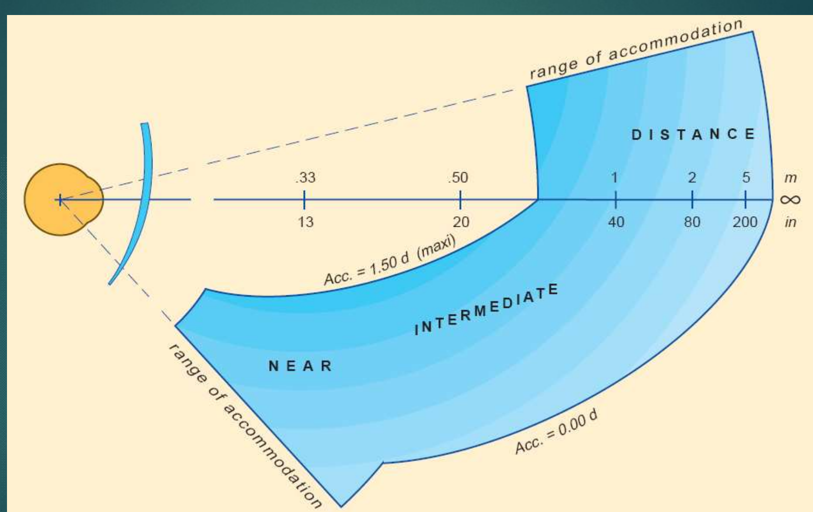
# Progressive Lens



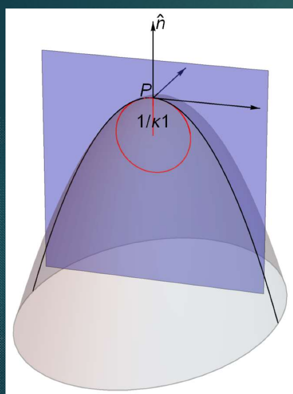
## Progressive Addition Lenses

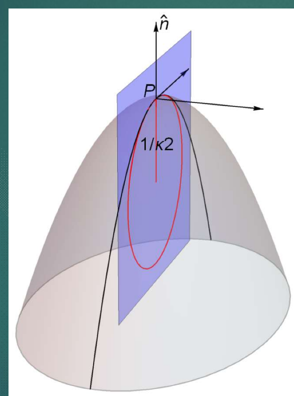


## Progressive Addition Lenses



# Differential Geometry




- Every point on a continuous surface has two Principal Curvatures.
- These curvatures represent the maximum and minimum curvature through this point and
- The principal curvatures are always along orthogonal axes.
- Calculated from the Fundamental Forms)

# PALs - Surface Feature Display

**First Fundamental Form**

$$E = 1 + \left(\frac{\partial f}{\partial x}\right)^2 \qquad F = \left(\frac{\partial f}{\partial x}\right)\left(\frac{\partial f}{\partial y}\right) \qquad G = 1 + \left(\frac{\partial f}{\partial y}\right)^2$$

**Second Fundamental Form**

$$L = \frac{\partial^2 f / \partial x^2}{\left[EG - F^2\right]^{1/2}} \qquad M = \frac{\partial^2 f / \partial x \partial y}{\left[EG - F^2\right]^{1/2}} \qquad N = \frac{\partial^2 f / \partial y^2}{\left[EG - F^2\right]^{1/2}}$$

**Mean Curvature**

$$H = \frac{EN + GL + 2FM}{2\left(EG - F^2\right)}$$

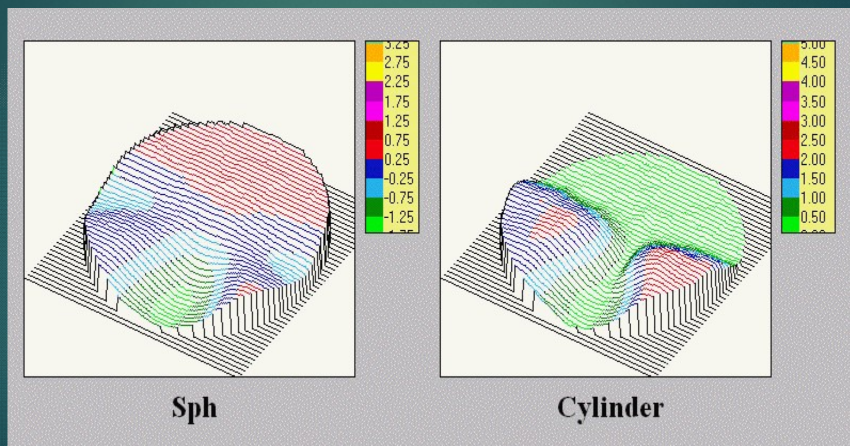
**Gaussian Curvature**

$$K = \frac{LN - M^2}{EG - F^2} = \kappa 1 \kappa 2$$

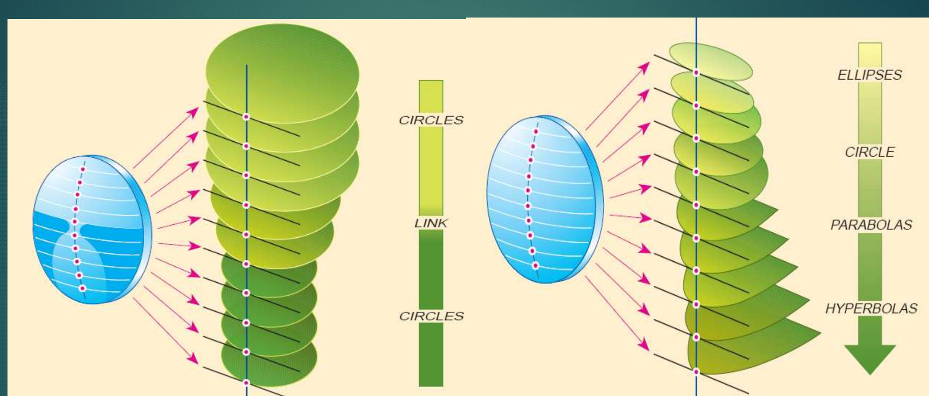
**Astigmatism**

$$A = 2\sqrt{H^2 - K}$$

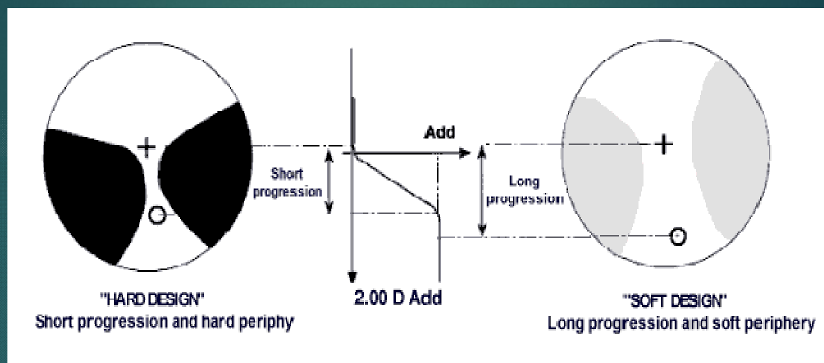
# Progressive Addition Lenses




# Reduction of Astigmatism



# Hard vs. Soft Designs




# Hard vs. Soft Designs

HARD DESIGN

CHARACTERISTICS
- Short and rapid progression
- Concentrate power on periphery

ADVANTAGES
- Large distant & near areas
- Excellent foveal vision
- Near power higher in lens

DISADVANTAGES
- High amounts of power in periphery
- Smaller intermediate field

SOFT DESIGN

CHARACTERISTICS
- Long, slow progression
- Spreads power throughout lens

ADVANTAGES
- Sharper peripheral acuity
- Wide intermediate area

DISADVANTAGES
- Near power lower in lens
- Smaller distance & near field

## Specific Gravity

- Weight is a big issue with spectacles.
- Glass has a specific gravity of ~2.5, whereas polymers ~1.3
- Specific gravity is the relative density of a material compared to water.
- 1 $cm^3$ of water equals 1 gram

## Contact Lenses

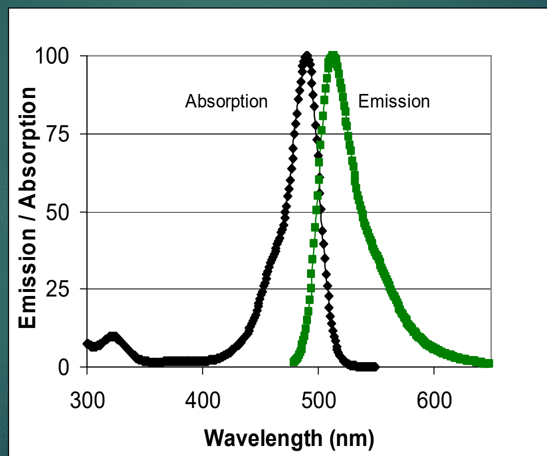
- Contact lenses come in two varieties: hard and soft
- Original hard lenses made of PMMA had poor oxygen transmission.
- Modern “hard” lenses have much better oxygen transmission and are called rigid gas permeable (RGPs) to distinguish.
- Soft lenses are polymers with large water content.

# RGPs

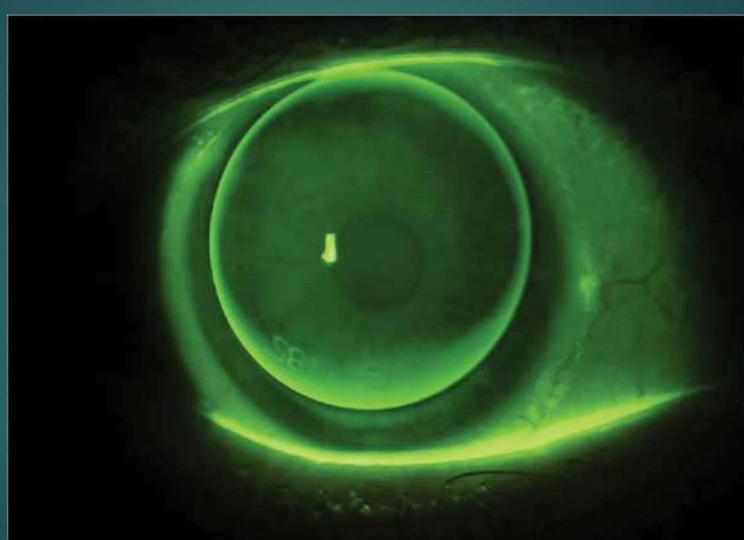
Tear film forms a "lens" underneath the RGP. This lens can change the power of the correction, can mask astigmatism and irregularities.

# Rigid Gas Permeable Lens

## Sodium Fluorescein




## Sodium Fluorescein



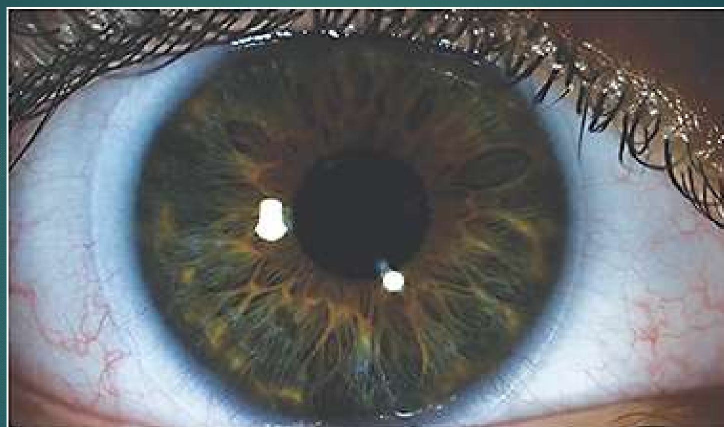
## Radiuscope

Determines the radius of curvature of the back surface of the contact lens. First focus point source on surface of lens and then focus on the cat's eye position. Distance traveled is the radius of curvature.

## Soft Contact Lens

Soft Lenses mold to the shape of the cornea. Astigmatism and irregularities are tranferred through the lens material.

# Soft Contact Lens

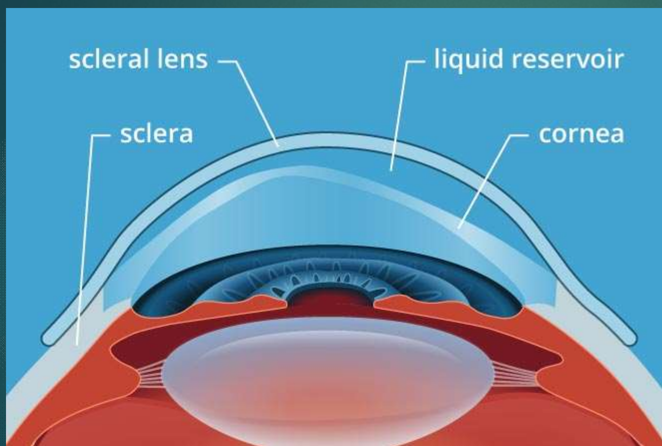


# Oxygen Permeability, Dk

The amount of oxygen diffusing through a fixed amount of material in a given time frame.

Dk/L - Oxygen transmissibility - amount of oxygen going through a lens of thickness L in the same timeframe.

# Scleral Contact Lens

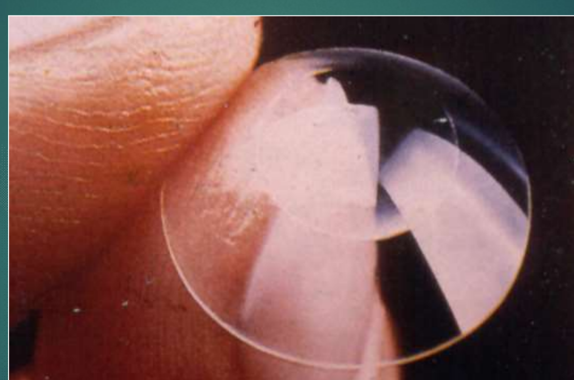



Scleral contact lenses are especially good for irregularly shaped corneas. The lens periphery rides on the sclera and the center of the lens vaults over the cornea. The space between the scleral lens and the cornea fills with fluid.

# Scleral Contact Lens

## Contact Lens Comparisons


## Hybrid Lens



# Multifocal Contact Lenses