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- Degradation results when light rays from a given object-point fail to form a single image-point
- *It's important to recognize that aberrations are the rule, not the exception*
    - Aberration-free vision essentially never occurs

Aberrations

- Some aberrations are attributable to corrective lenses

Aberrations

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- Others are intrinsic to the eye itself

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  - Three familiar forms:

Aberrations

- Some aberrations are attributable to corrective lenses
- Others are intrinsic to the eye itself
  - Three familiar forms:
    - Spherical error (myopia/hyperopia)
    - Cylinder (astigmatism)
    - Chromatic aberration

Aberrations

- Back in the day, only three aberrations were addressed by clinicians:

  1)

  2)

  3)

Aberrations

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  1) Spherical error (ie, myopia/hyperopia)
  2) Regular astigmatism

  3) Irregular astigmatism

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     - *Regular* meaning
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Essentially, *irregular astigmatism* was a wastebasket term for aberrations that:

1) could not be measured in the clinic; and
2) could not be corrected (by glasses) even if they had been measureable

Aberrations

Old Lingo

Sphere

Myopia
Hyperopia

‘Regular Astigmatism’ — **Cylinder**

‘Irregular Astigmatism’ — Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses

This is how we thought of aberrations back in the day

Aberrations

- two words did away with the first problem

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Aberrations: Wavefront Analysis

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Aberrations: Wavefront Analysis

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  - Allows clinicians to identify/quantify many of the refractive problems previously consigned to the irregular-astigmatism wastebasket

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    The *Hartmann-Shack wavefront sensor*

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Aberrations: Wavefront Analysis

How does the Hartmann-Shack wavefront sensor (HSWS) work?

current clinical practice:

The ***Hartmann-Shack wavefront sensor***

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Aberrations: Wavefront Analysis

How does the Hartmann-Shack wavefront sensor (HSWS) work?
Essentially, by reversing the function of the eye. Instead of treating the eye as a light-gathering device, it treats the eye as a light-**emitting** device. It then analyzes the wavefront of light emitted by the eye with respect to how ‘pure’ (ie, how uniform and free of warpage) it is.

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How does the HSWS turn the eye into a light-emitting device?

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How does the HSWS turn the eye into a light-emitting device?
By firing a low-power laser into the eye that reflects off the fovea. The reflected light then passes through the focusing structures of the eye (ie, the lens and cornea), and leaves the eye.

current clinical practice:

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OK, so the HSWS turns the eye into a flashlight of sorts. How does this allow for identification and quantification of aberrations?
The HSWS contains an array of sensors that measure the 'emitted' light. If the refracting structures of the eye were perfect (ie, aberration-free), the wavefront of the emitted light would be perfectly flat--any deviation from flatness represents aberration, which in turn reflects imperfections in the eye's focusing structures.

current clinical practice:

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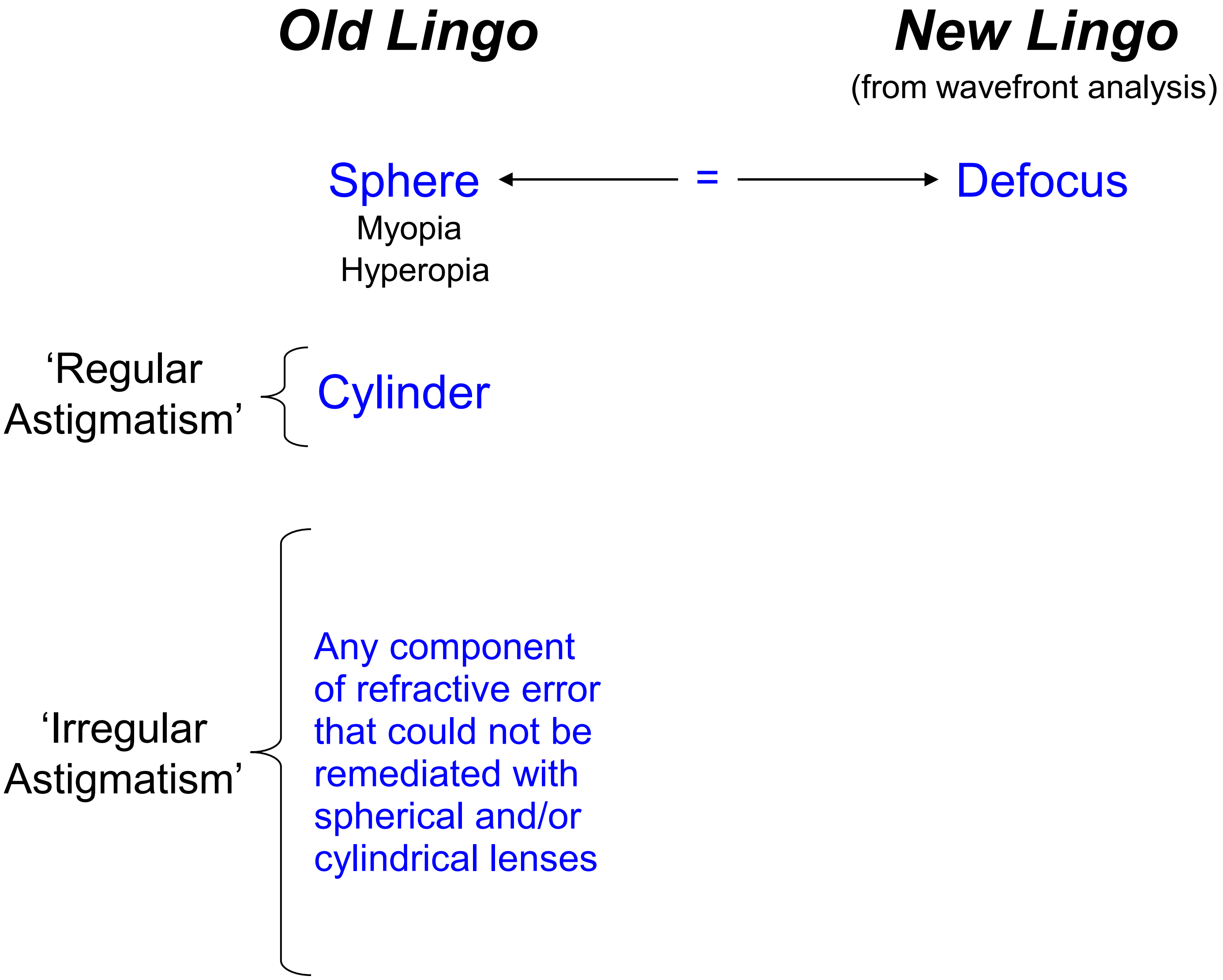
Aberrations



Old Lingo

New Lingo
(from wavefront analysis)

Sphere ← = → Defocus
Myopia
Hyperopia

'Regular Astigmatism' { Cylinder

'Irregular Astigmatism' { Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses

Aberrations

Old Lingo		***New Lingo*** (from wavefront analysis)
Sphere	← = →	Defocus
Myopia	← = →	+ vs (-) defocus
Hyperopia	← = →	+ vs (-) defocus

‘Regular Astigmatism’ { Cylinder

‘Irregular Astigmatism’ { Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses

Aberrations

Old Lingo

New Lingo

(from wavefront analysis)

Sphere ← = → Defocus

Myopia ← = → *Positive* defocus

Hyperopia ← = → *Negative* defocus

To remember which is which, note that each is the same as the ***error lens*** *responsible for each status*

'Regular Astigmatism' { Cylinder

'Irregular Astigmatism' { Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses

Aberrations

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‘Regular Astigmatism’ { Cylinder ⟷ = ⟷

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Aberrations

Old Lingo **_New Lingo_**
(from wavefront analysis)

Sphere ← = → Defocus
Myopia ← = → *Positive* defocus
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'Regular Astigmatism' { Cylinder ← = → Cylinder

'Irregular Astigmatism' { Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses

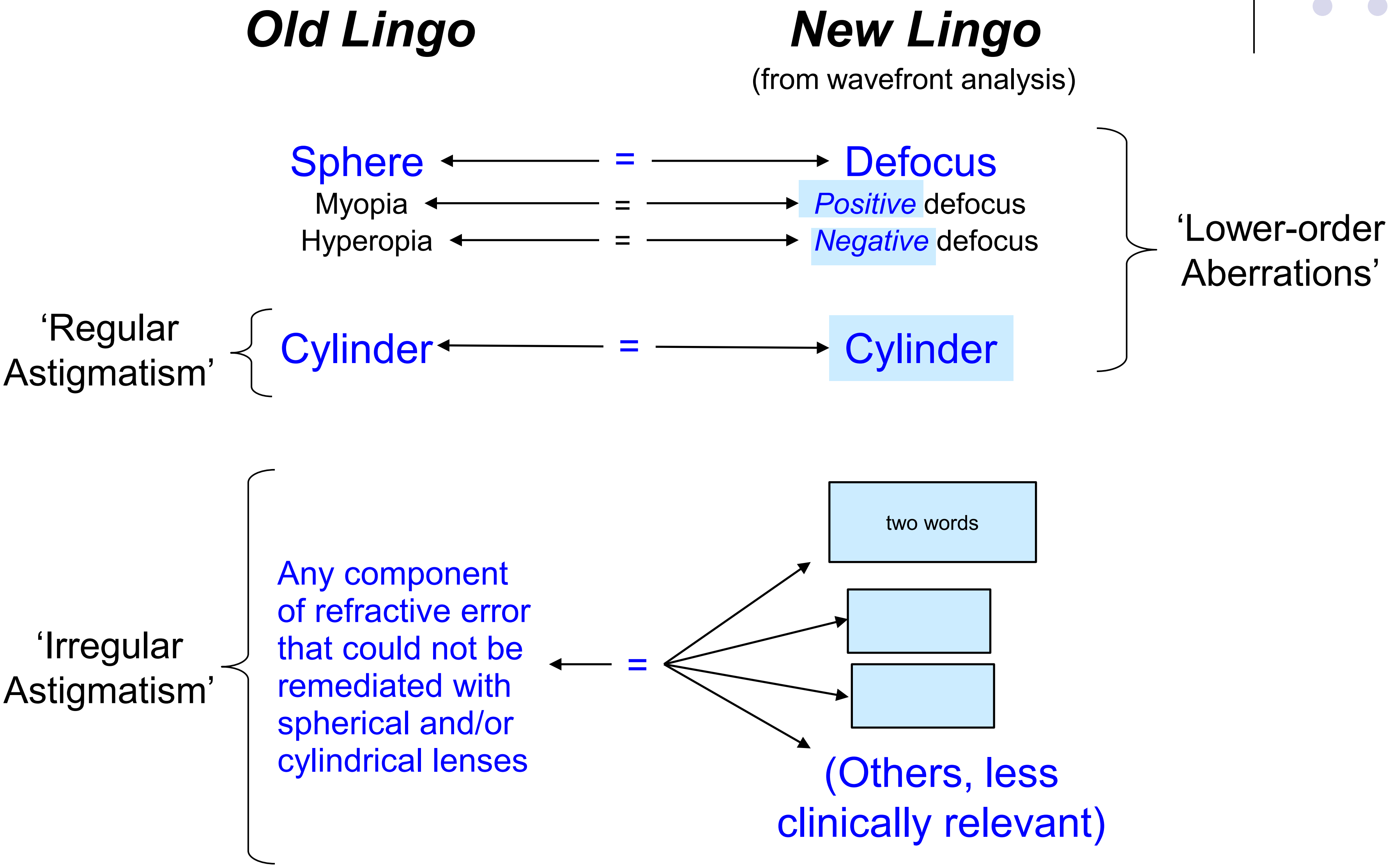
Aberrations

	Old Lingo		***New Lingo*** (from wavefront analysis)	
	Sphere	← = →	Defocus	‘Lower-order Aberrations’
	Myopia	← = →	*Positive* defocus	
	Hyperopia	← = →	*Negative* defocus	
‘Regular Astigmatism’	Cylinder	← = →	Cylinder	

‘Irregular Astigmatism’

Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses

Aberrations



Old Lingo

New Lingo
(from wavefront analysis)

Sphere ← = → Defocus
Myopia ← = → *Positive* defocus
Hyperopia ← = → *Negative* defocus

‘Regular Astigmatism’ Cylinder ← = → Cylinder

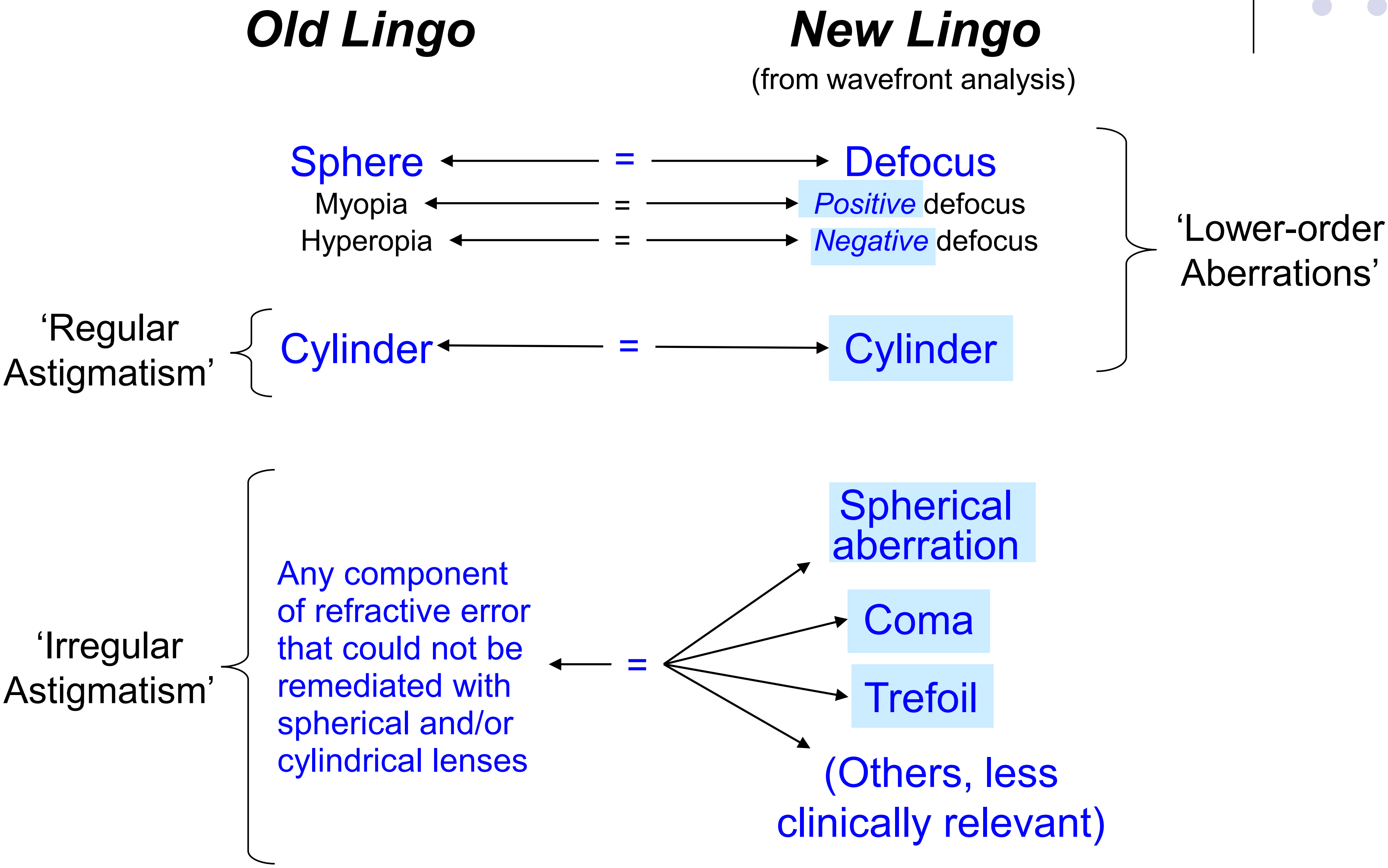
‘Lower-order Aberrations’

‘Irregular Astigmatism’ Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses ← =

two words

(Others, less clinically relevant)

Aberrations



Old Lingo

New Lingo

(from wavefront analysis)

Sphere ← = → Defocus

Myopia ← = → *Positive* defocus

Hyperopia ← = → *Negative* defocus

‘Regular Astigmatism’

Cylinder ← = → Cylinder

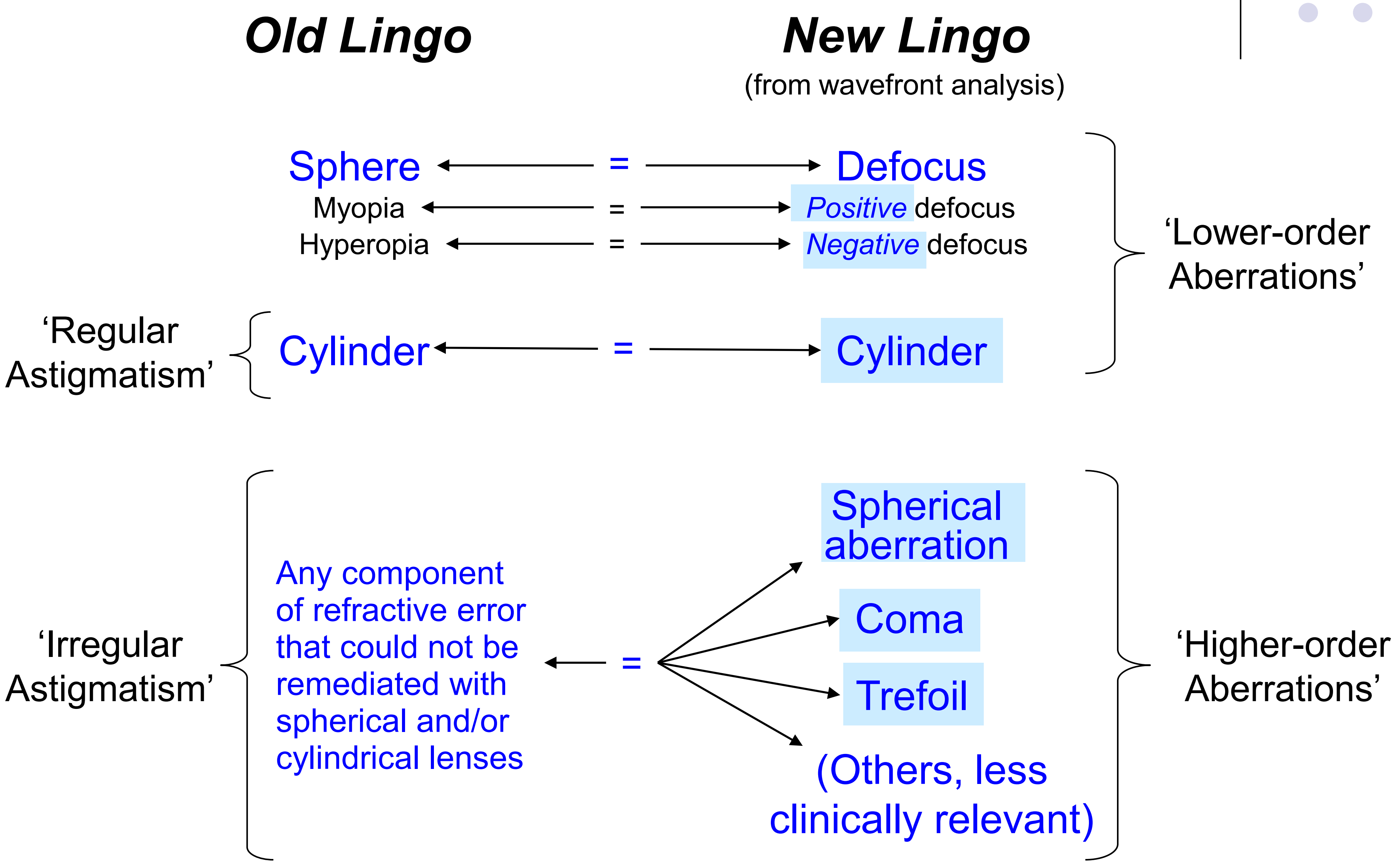
‘Lower-order Aberrations’

‘Irregular Astigmatism’

Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses ← = →

- Spherical aberration
- Coma
- Trefoil
- (Others, less clinically relevant)

Aberrations



Old Lingo

New Lingo

(from wavefront analysis)

Sphere = Defocus

Myopia = *Positive* defocus

Hyperopia = *Negative* defocus

'Regular Astigmatism'

Cylinder = Cylinder

'Lower-order Aberrations'

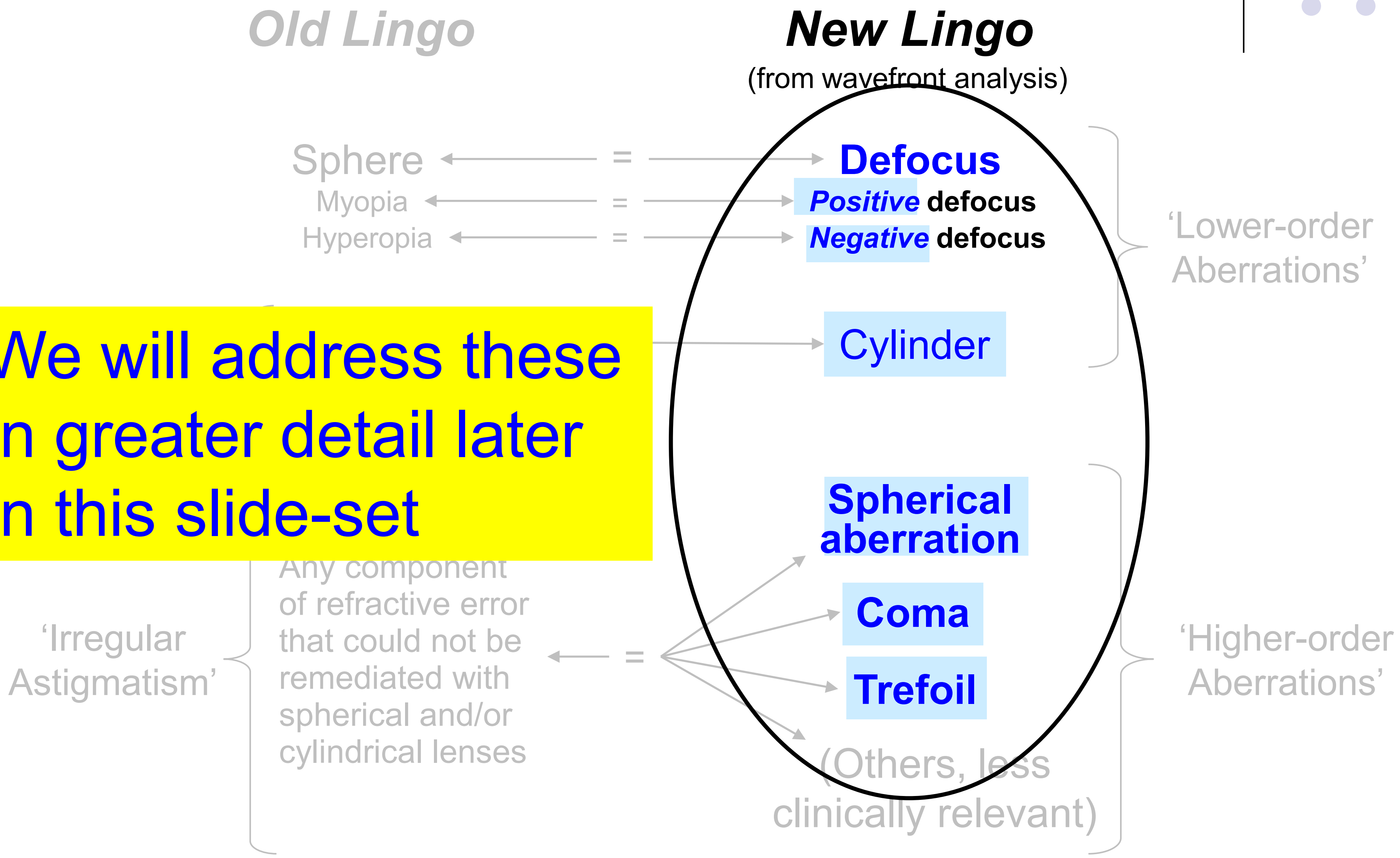
'Irregular Astigmatism'

Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses =

- Spherical aberration
- Coma
- Trefoil
- (Others, less clinically relevant)

'Higher-order Aberrations'

Aberrations



Old Lingo

New Lingo

(from wavefront analysis)

Sphere = **Defocus**

Myopia = ***Positive* defocus**

Hyperopia = ***Negative* defocus**

Cylinder

Spherical aberration

Coma

Trefoil

(Others, less clinically relevant)

‘Lower-order Aberrations’

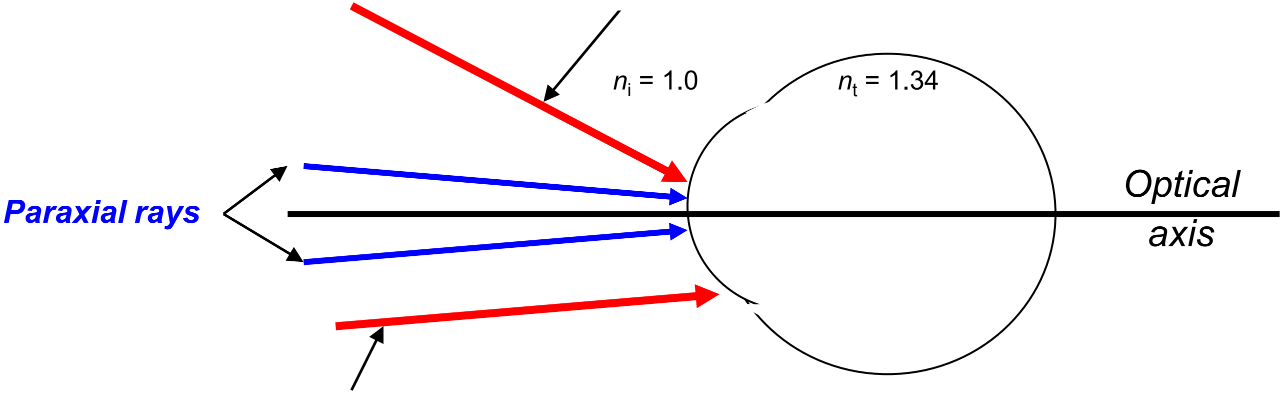
‘Irregular Astigmatism’

Any component of refractive error that could not be remediated with spherical and/or cylindrical lenses =

‘Higher-order Aberrations’

We will address these in greater detail later in this slide-set

Aberrations



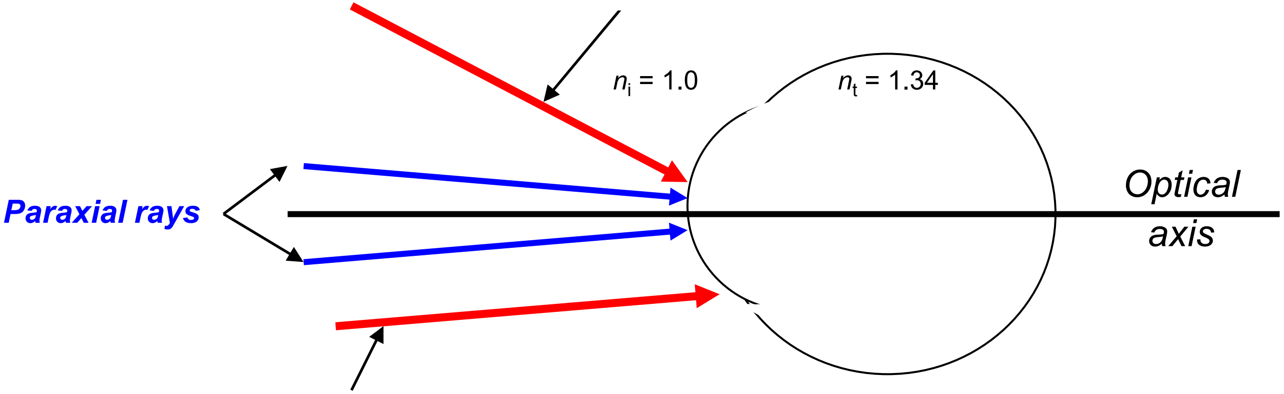
Not paraxial (close to optical axis, but not parallel to it)

Not paraxial (nearly parallel to optical axis, but not close to it)

When dealing with refraction at a curved surface, we work only with the ***paraxial rays:*** *Those that are both **close to the optical axis** and **nearly parallel to it.***

(The above was presented first in the slide-set Basic Optics, *Chapter 17. If you have no idea what it's about, consider reviewing that chapter.)*

Aberrations



Not paraxial (close to optical axis, but not parallel to it)

n_i = 1.0

n_t = 1.34

Paraxial rays

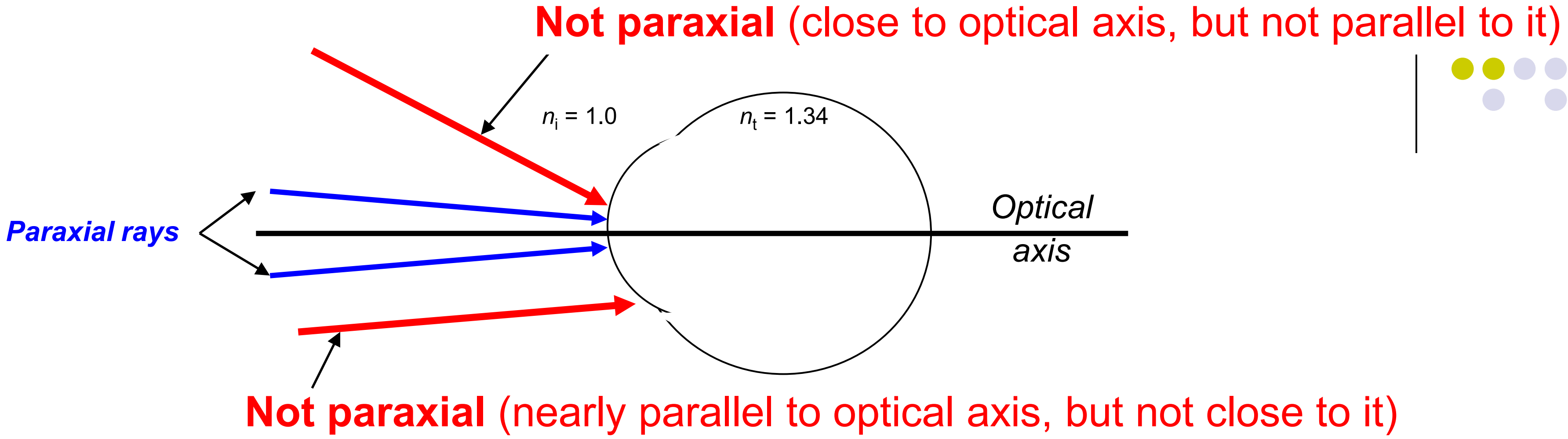
Optical axis

Not paraxial (nearly parallel to optical axis, but not close to it)

When dealing with refraction at a curved surface, we work only with the ***paraxial rays:*** *Those that are both* ***close to the optical axis*** *and* ***nearly parallel to it.***

Until now, we have focused exclusively on the optics of paraxial rays. But to understand higher-order aberrations, we have to consider the optics of nonparaxial rays.

Aberrations



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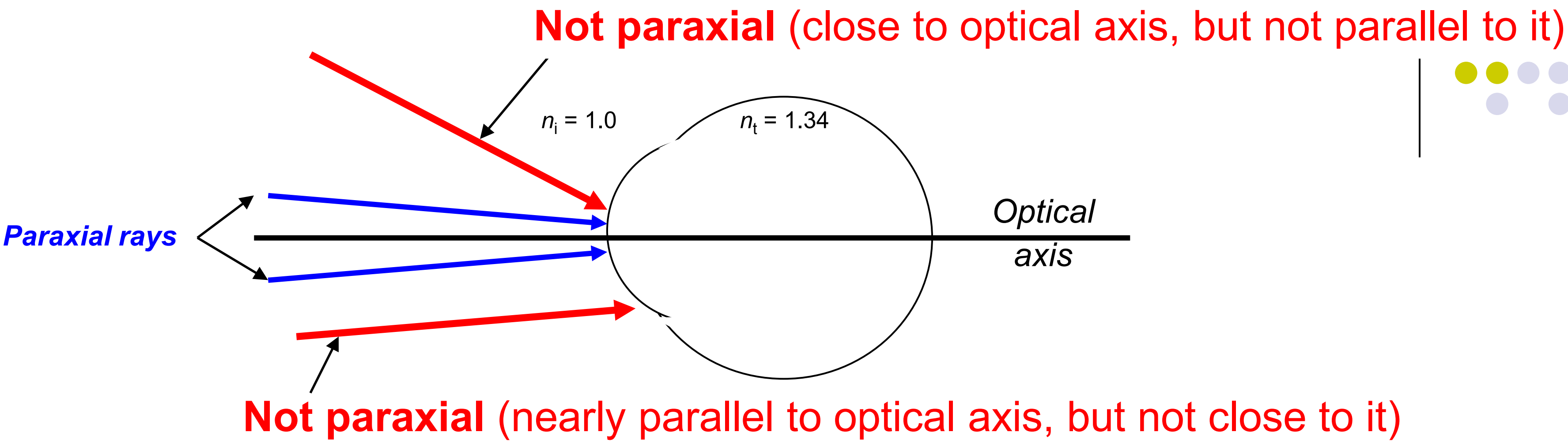
Until now, we have focused exclusively on the optics of paraxial rays. But to understand higher-order aberrations, we have to consider the optics of nonparaxial rays.

The clinically **most important** higher-order aberration stemming from nonparaxial rays is two words, so we'll discuss it first.

Aberrations



When dealing with refraction at a curved surface, we work only with the ***paraxial rays:*** *Those that are both **close to the optical axis** and **nearly parallel to it.***

Until now, we have focused exclusively on the optics of paraxial rays. But to understand higher-order aberrations, we have to consider the optics of nonparaxial rays.

The clinically **most important** higher-order aberration stemming from nonparaxial rays is *spherical aberration*, so we'll discuss it first.

Aberrations: *Spherical*

- A spherical lens is one for which the refracting surface(s) have a single

three words

Aberrations: *Spherical*

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Aberrations: *Spherical*

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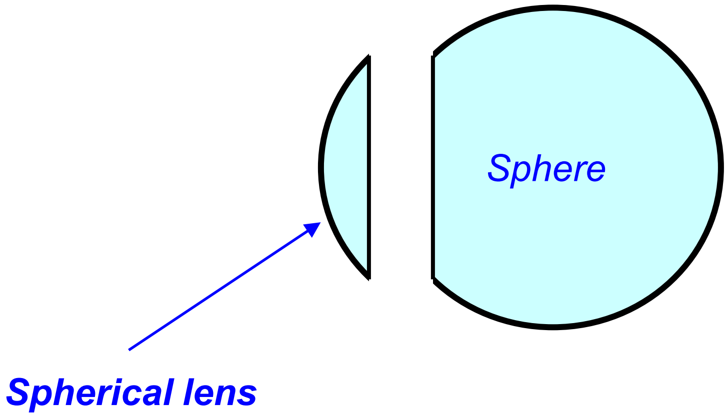
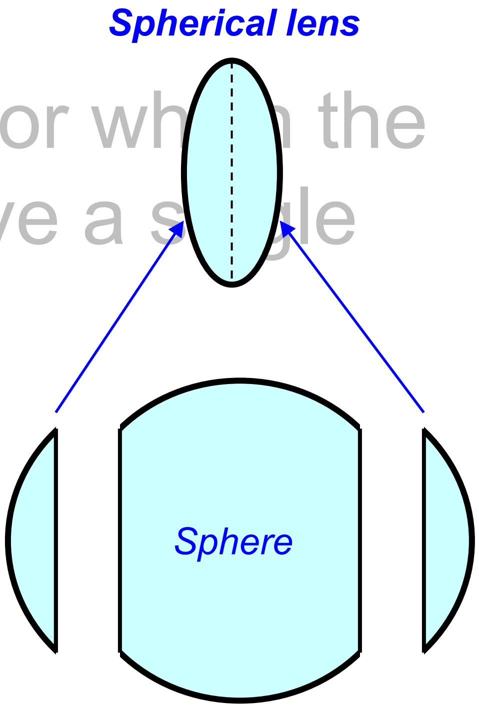


Note that a spherical lens need not be a sphere! For a lens to be 'spherical,' its refracting surface(s) must have a single radius-of-curvature—as if the lens was sliced off of a sphere.

Aberrations: *Spherical*

- A spherical lens is one for which the refracting surface(s) have a single radius of curvature



Note that a spherical lens need not have a single refracting surface.

Aberrations: *Spherical*

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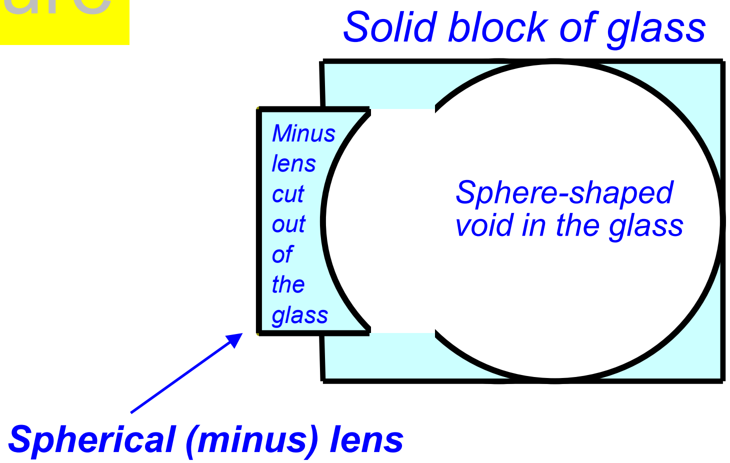
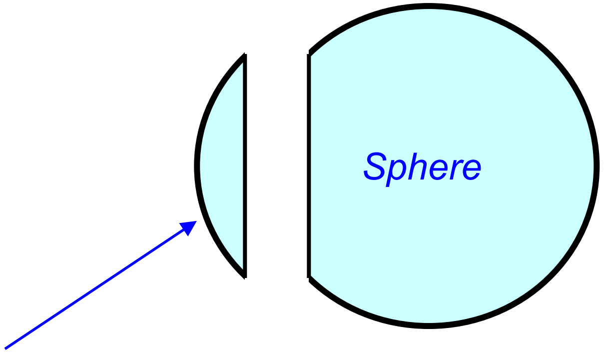


Note that a spherical lens need not be a **plus** lens, either.

Aberrations: *Spherical*

- A ~~spherical~~ ^spherocylindrical lens is one for which the refracting surface(s) have a single radius of curvature

*What about the refracting surface of a sphero**cylindrical** (S-C) lens?*



Spherocylindrical lens?

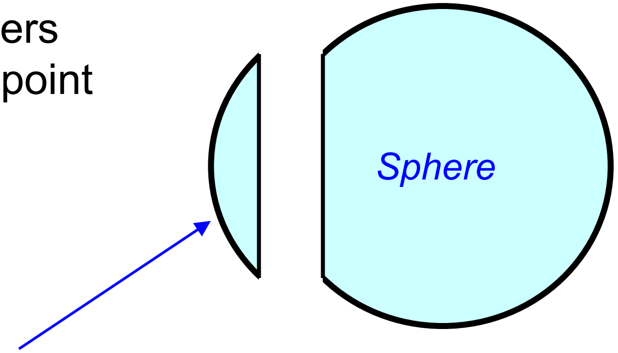
Rhetorical question—advance when ready

Aberrations: *Spherical*

- A ~~spherical~~ spherocylindrical lens is one for which the refracting surface(s) have ~~a single~~ two radi~~us~~i of curvature

*What about the refracting surface of a sphero**cylindrical** (S-C) lens?*

Recall that, by definition, a S-C lens has two different powers oriented at right angles to one another. This means every point on its surface has **two** radii—one for each power.



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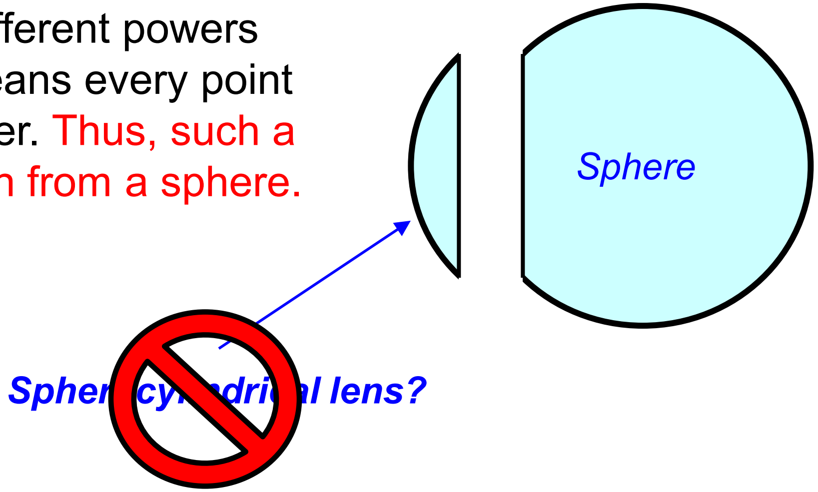
Recall that, by definition, a S-C lens has two different powers oriented at right angles to one another. This means every point on its surface has **two** radii—one for each power. Thus, such a lens could not be created by slicing off a section from a sphere.



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Can you think of an everyday (hint: and delicious) object from which a slice could be taken that would qualify as a S-C lens?

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Yes—a donut.

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Can you think of an everyday (hint: and delicious) object from which a slice could be taken that would qualify as a S-C lens? Yes—a donut. Every point on the surface of a donut has *two* radii—one determined by its distance from the center of the donut's hole, the other by its distance from the center of the part you bite into.

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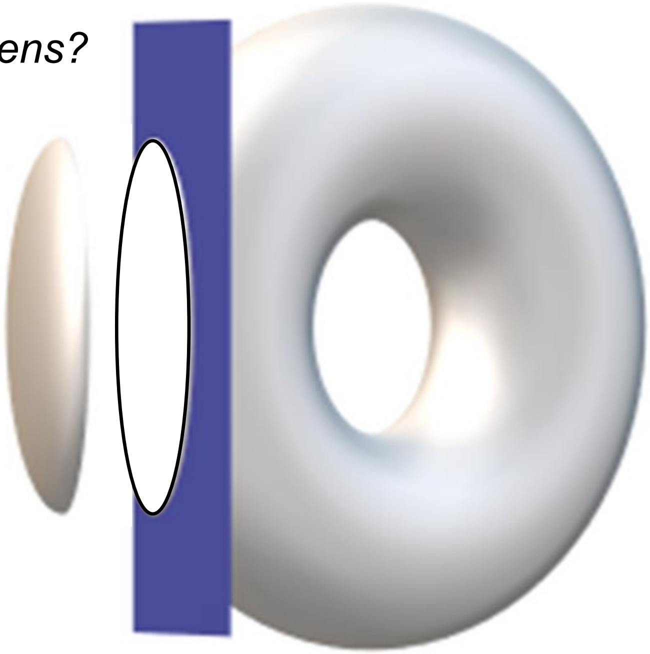

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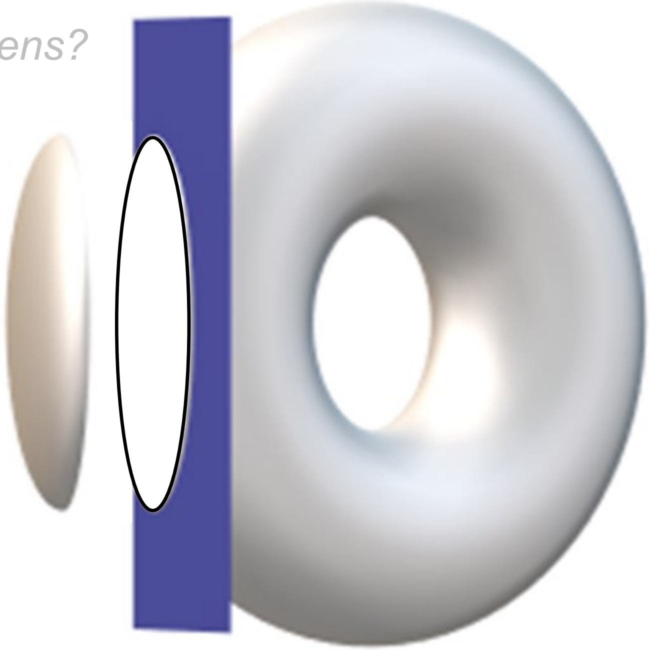
There is a more formal/precise name for the shape from which a spherocylindrical lens is sliced—what is it?

Can you
which a
Yes—a
radii—o
donut's
part
you bite into. So, just as a spherical lens is created by taking a slice off a sphere, a sphero**cylindrical** lens is created by taking a slice off a **donut**.



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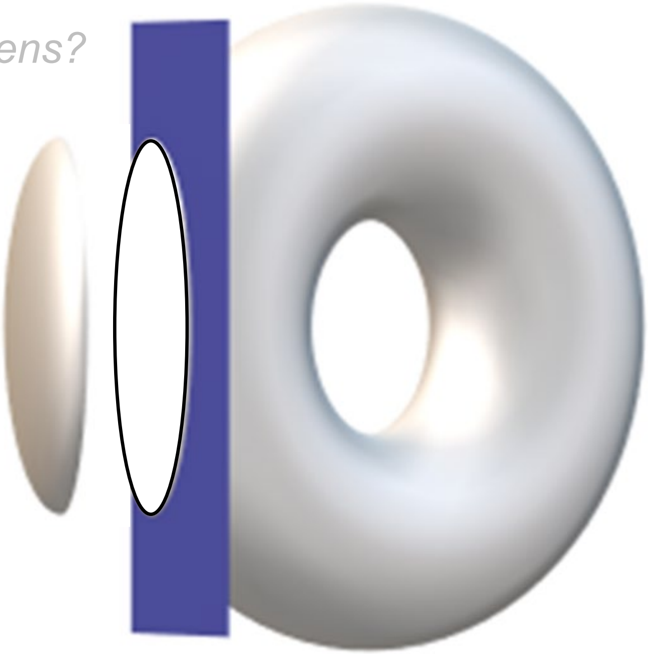
Recall that, by definition, a S-C lens has two different powers oriented at right angles to one another. This means every point on its surface has **two** radii—one for each power. Thus, such a lens could not be created by slicing off a section from a sphere.

There is a more formal/precise name for the shape from which a spherocylindrical lens is sliced—what is it?
A **torus**

Can you … *which a* … *s?*
Yes—a …
radii—o …
donut's … part
you bite into. So, just as a spherical lens is created by taking a slice off a sphere, a sphero**cylindrical** lens is created by taking a slice off a **donut**.



Aberrations: *Spherical*

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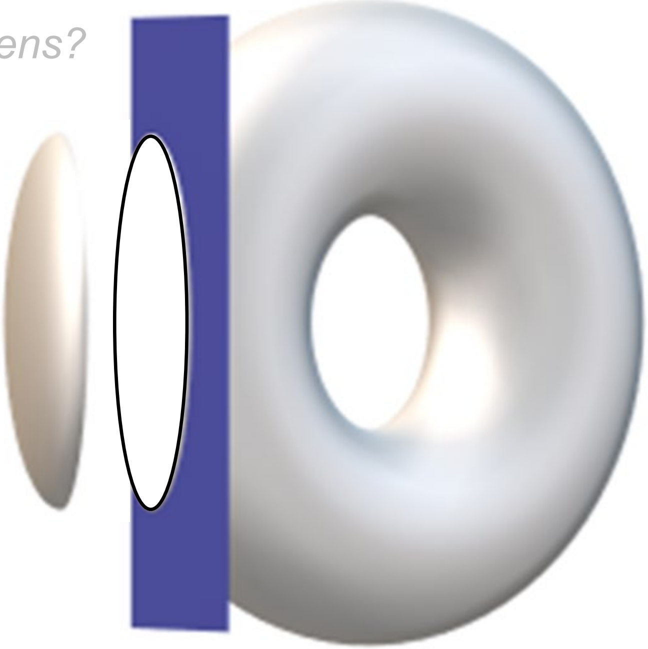
Similarly, this more-formal name gives rise to an alternate name for a spherocylindrical lens—what is it?



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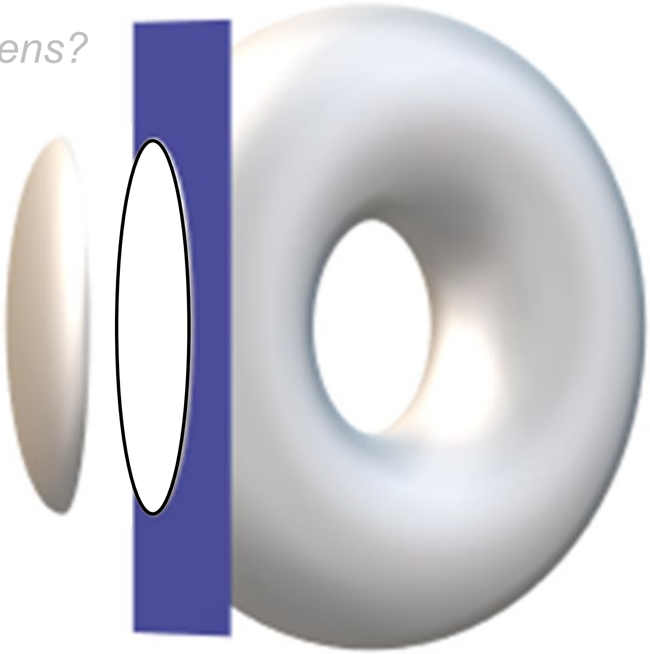
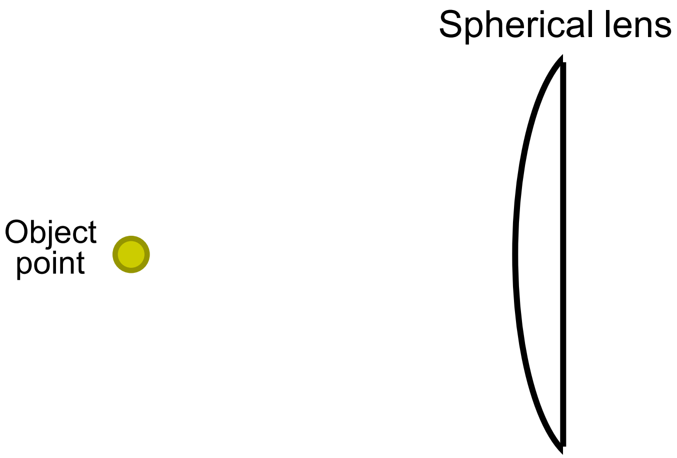


Aberrations: *Spherical*

Let’s drill down on how spherical aberration comes to pass:

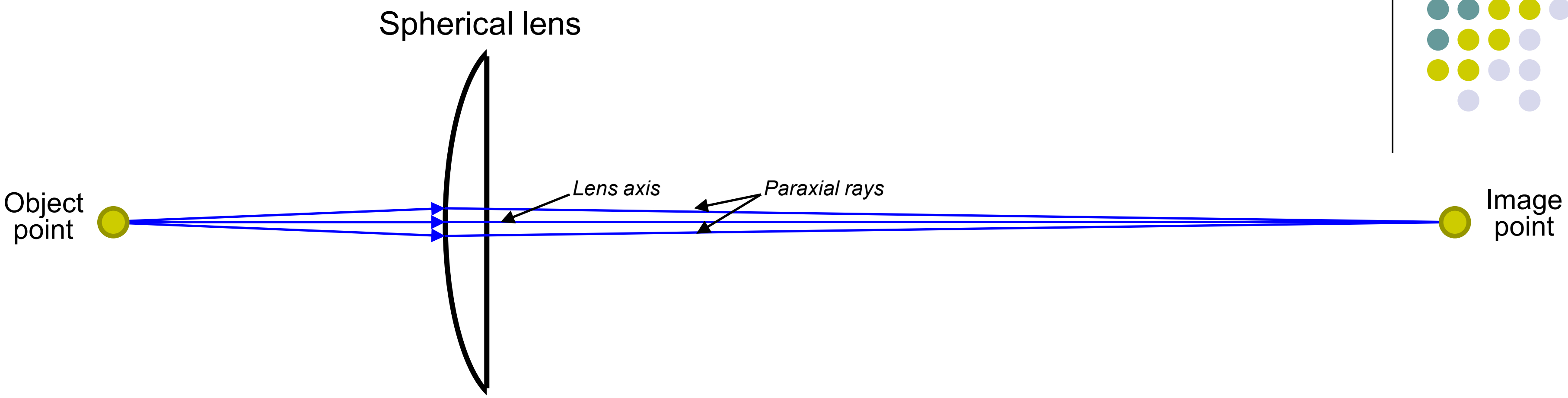
Aberrations: *Spherical*



Consider an object-lens system as above.

Let’s drill down on how spherical aberration comes to pass:

Aberrations: *Spherical*



If we deal only with the paraxial rays, we find their focus closely approximates a perfect point, as predicted by first-order optics.

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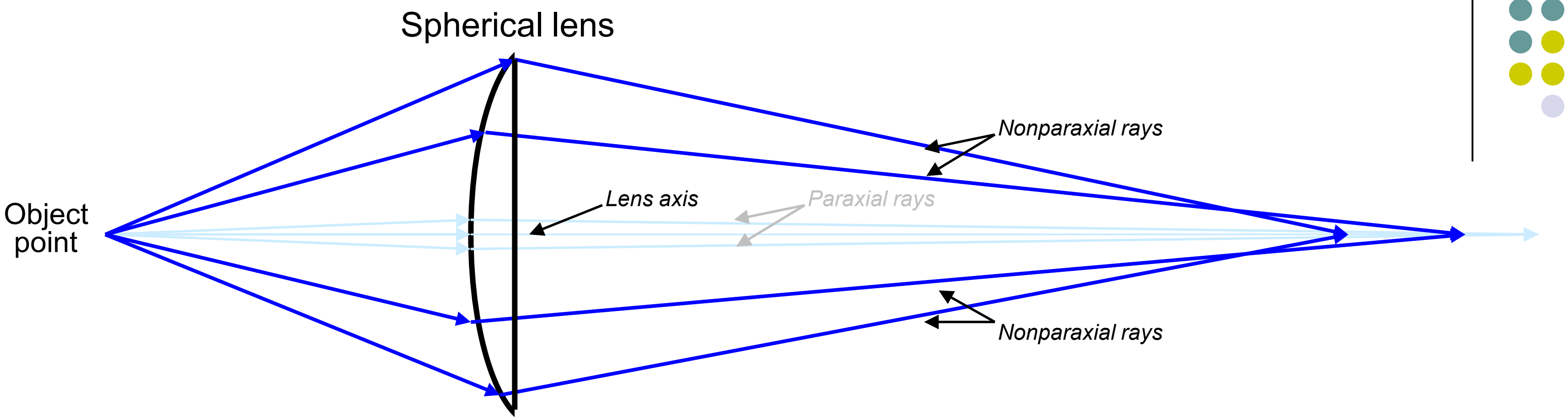

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However, when we look at the behavior of the **non**-paraxial rays, we find they do not focus at the same location as the paraxial rays; rather, because they are more sharply refracted, they focus anterior to the paraxial focal point.

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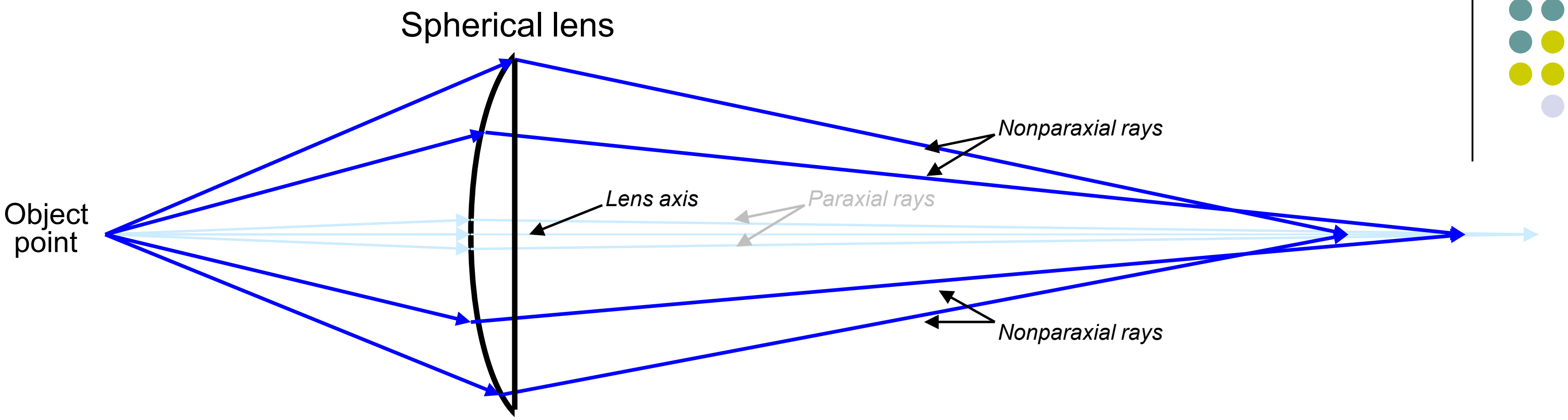

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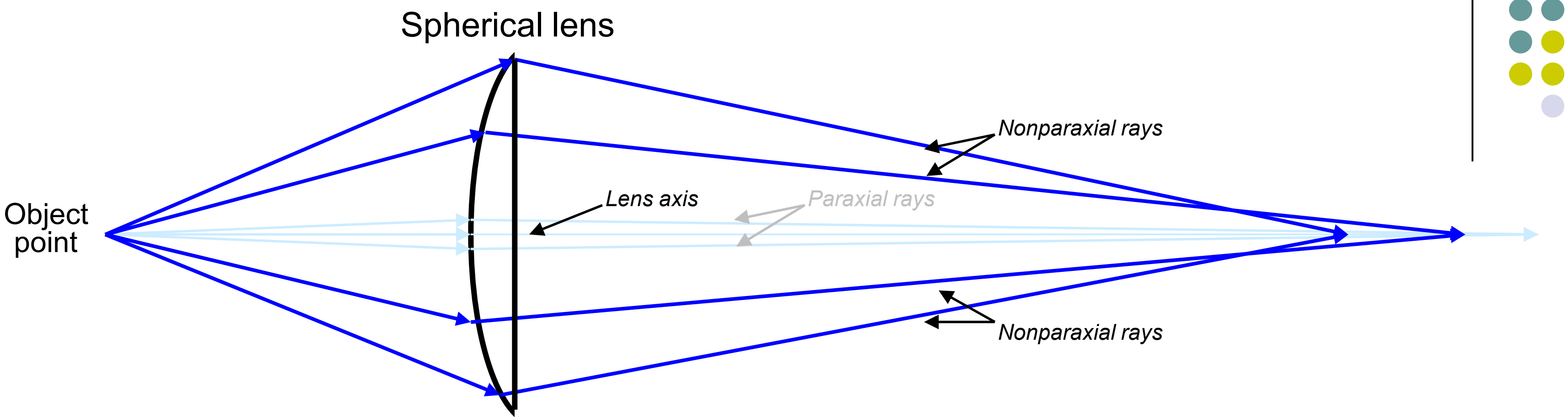
Why are nonparaxial rays refracted more than paraxial rays on a spherical lens?

Aberrations: *Spherical*



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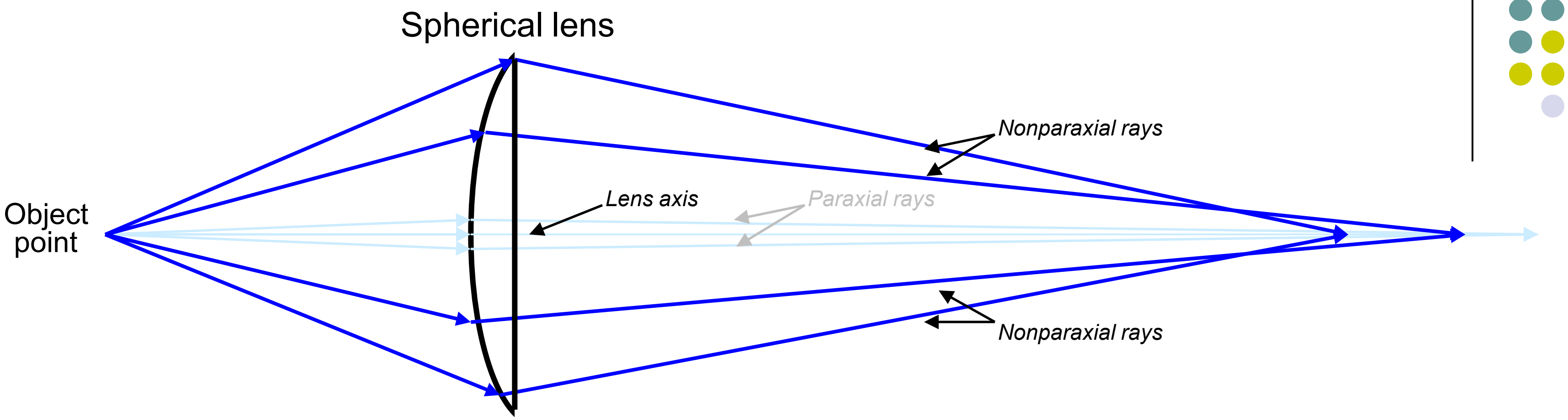
Snell's Law states that the angle of refraction is a function of the angle of incidence. For paraxial rays, the angle of incidence is determined solely by the radius-of-curvature of the lens.

Aberrations: *Spherical*



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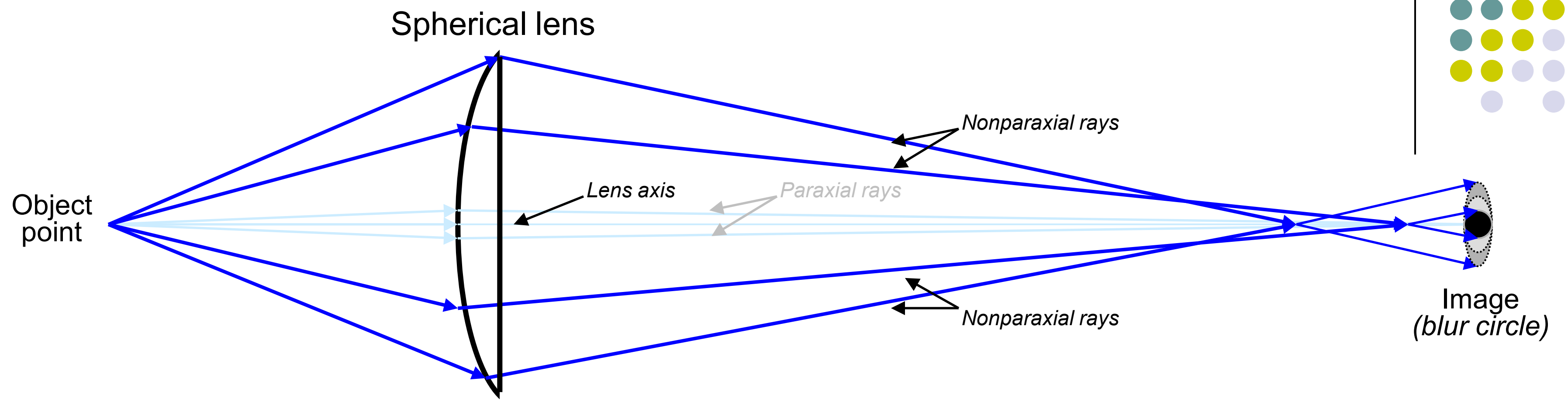
Aberrations: *Spherical*



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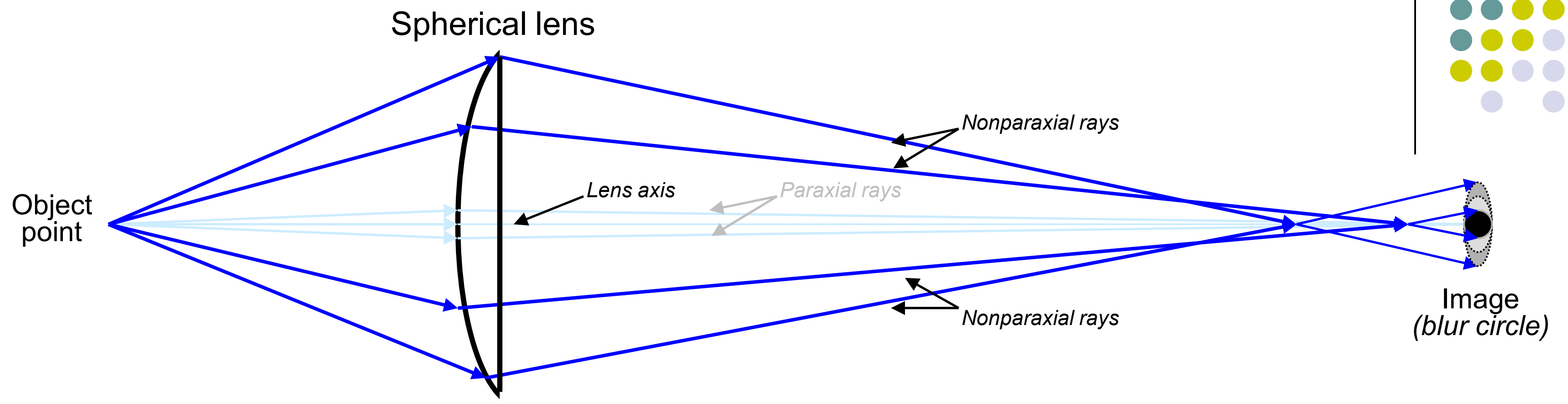
However, when we look at the behavior of the **non**-paraxial rays, we find they do not focus at the same location as the paraxial rays; rather, because they are more sharply refracted, they focus anterior to the paraxial focal point. By the time these rays reach the focal plane for the paraxial rays, they are diverging. Thus, they contribute not to a focal **point**, but rather to a somewhat defocused area called a *blur circle*.

Aberrations: *Spherical*



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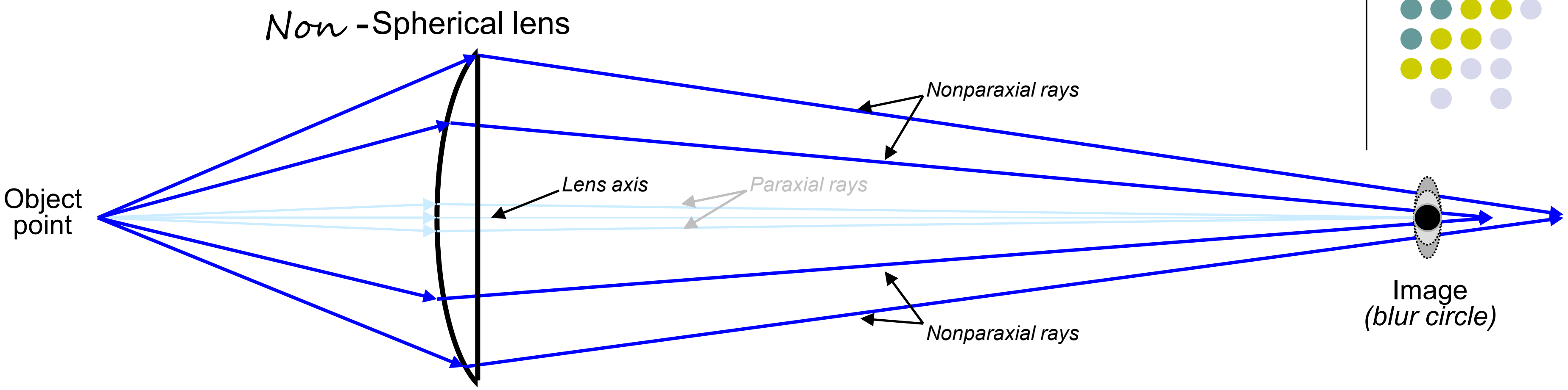
> *When progressively peripheral rays are refracted more and more sharply, the lens is said to possess* **positive** *spherical aberration.*

Aberrations: *Spherical*



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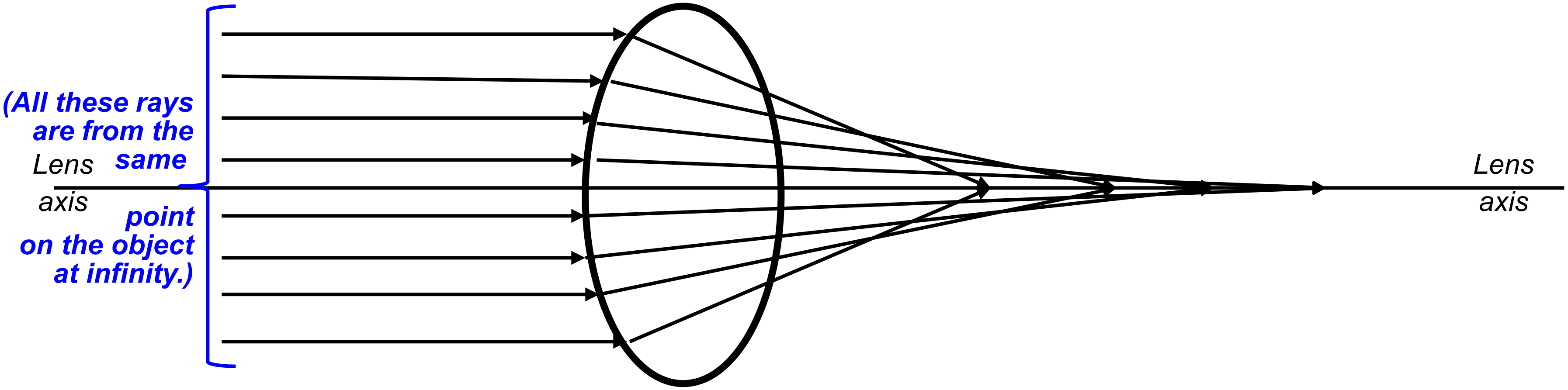
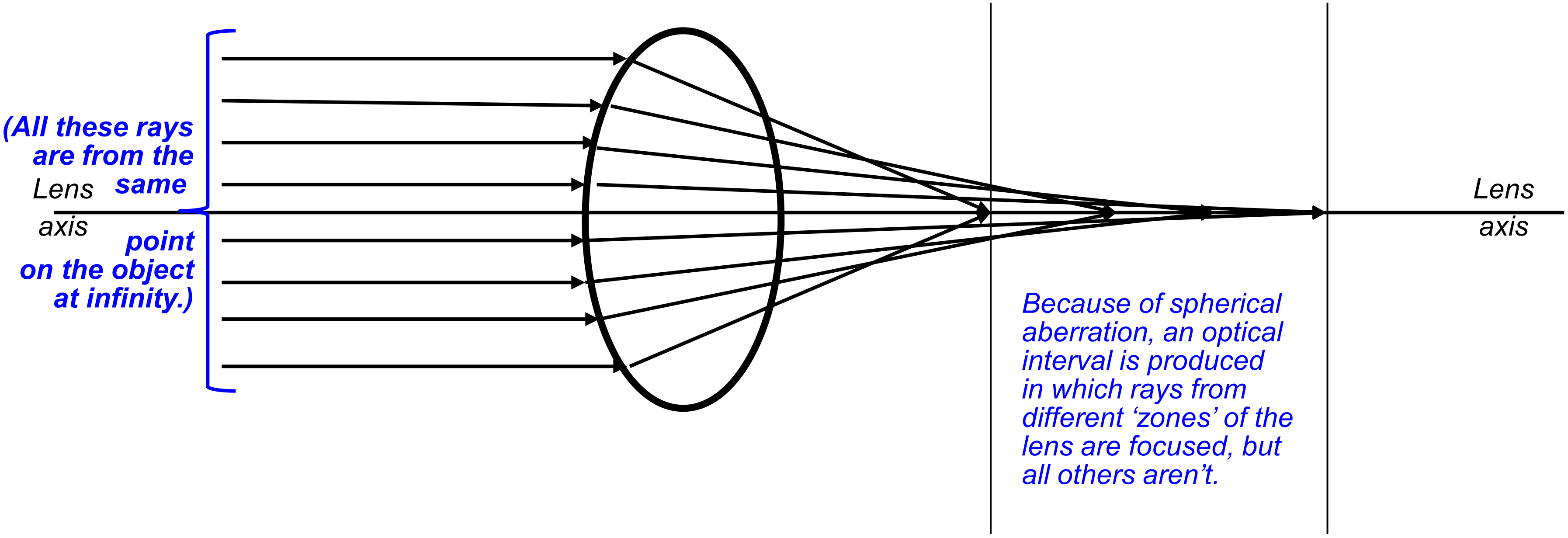
On the other hand, when progressively peripheral rays are refracted less *and less sharply, the lens is said to possess* **negative** *spherical aberration.*

Aberrations: *Spherical*



(All these rays are from the same point on the object at infinity.)

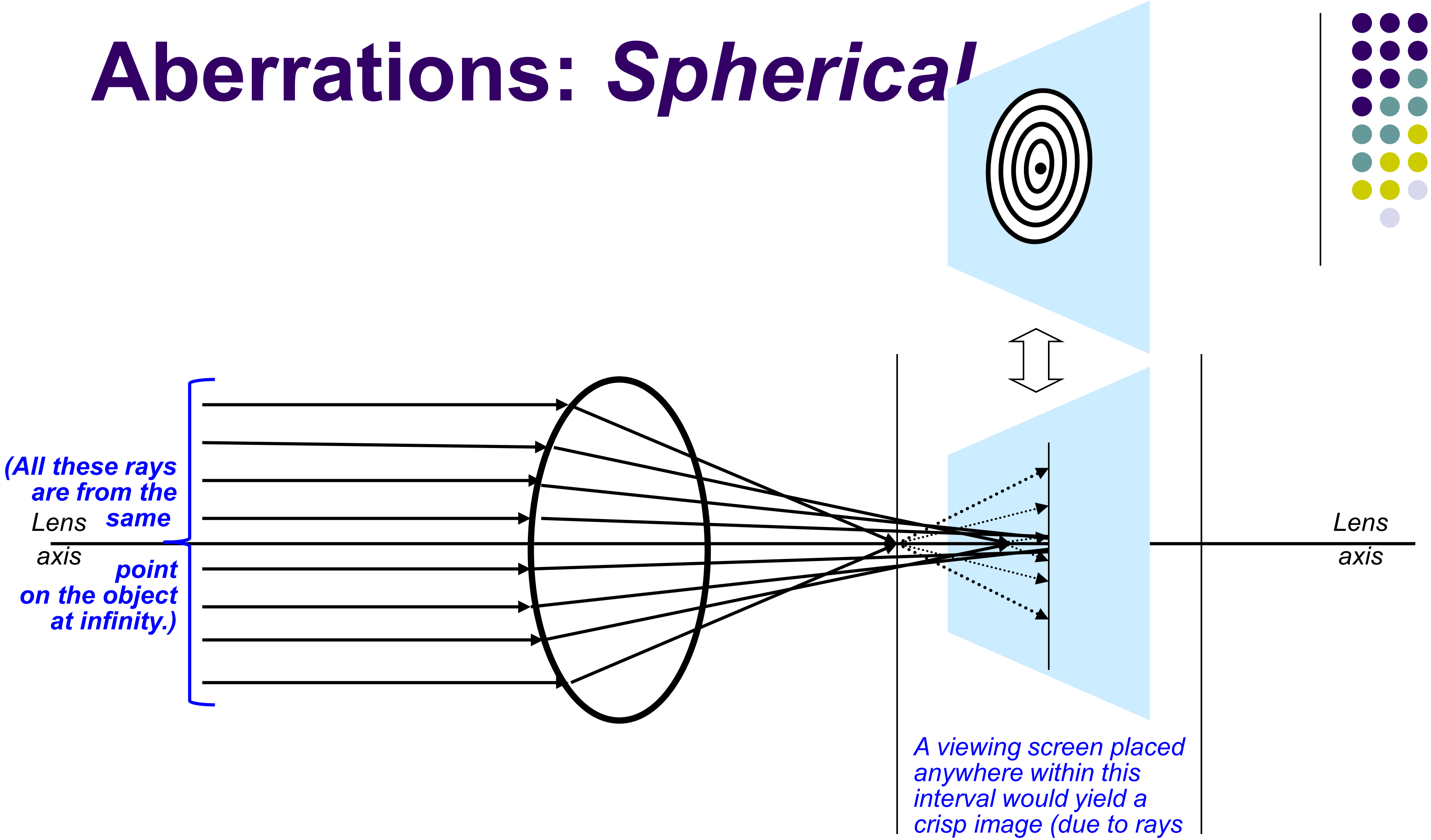
Aberrations: *Spherical*



(All these rays are from the same point on the object at infinity.)

Because of spherical aberration, an optical interval is produced in which rays from different 'zones' of the lens are focused, but all others aren't.

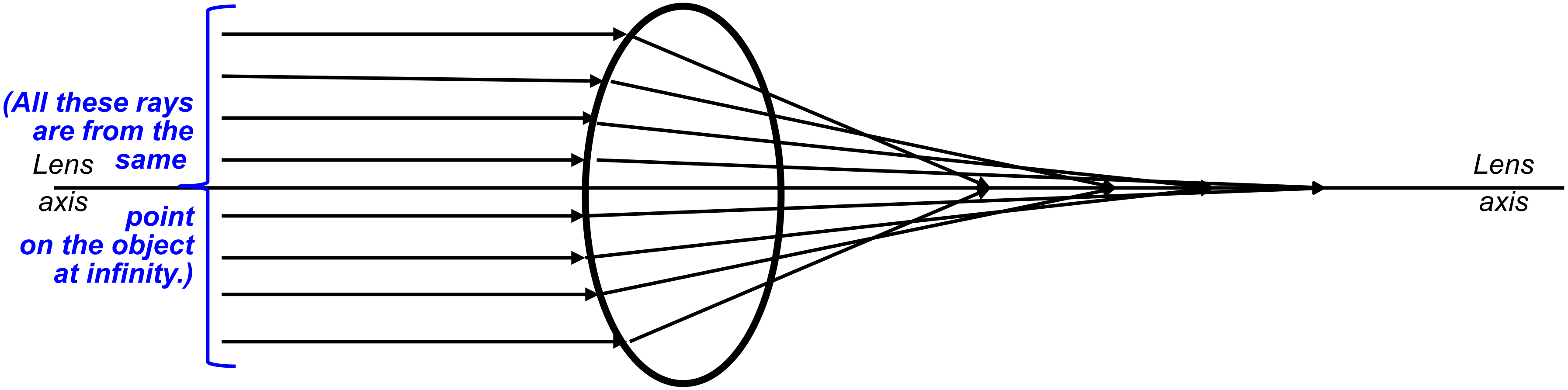
Aberrations: *Spherical*



(All these rays are from the same point on the object at infinity.)

A viewing screen placed anywhere within this interval would yield a crisp image (due to rays passing through one zone of the lens), with surrounding 'halos' representing rays from the other zones (and therefore out-of-focus at this point in the interval)

Aberrations: *Spherical*



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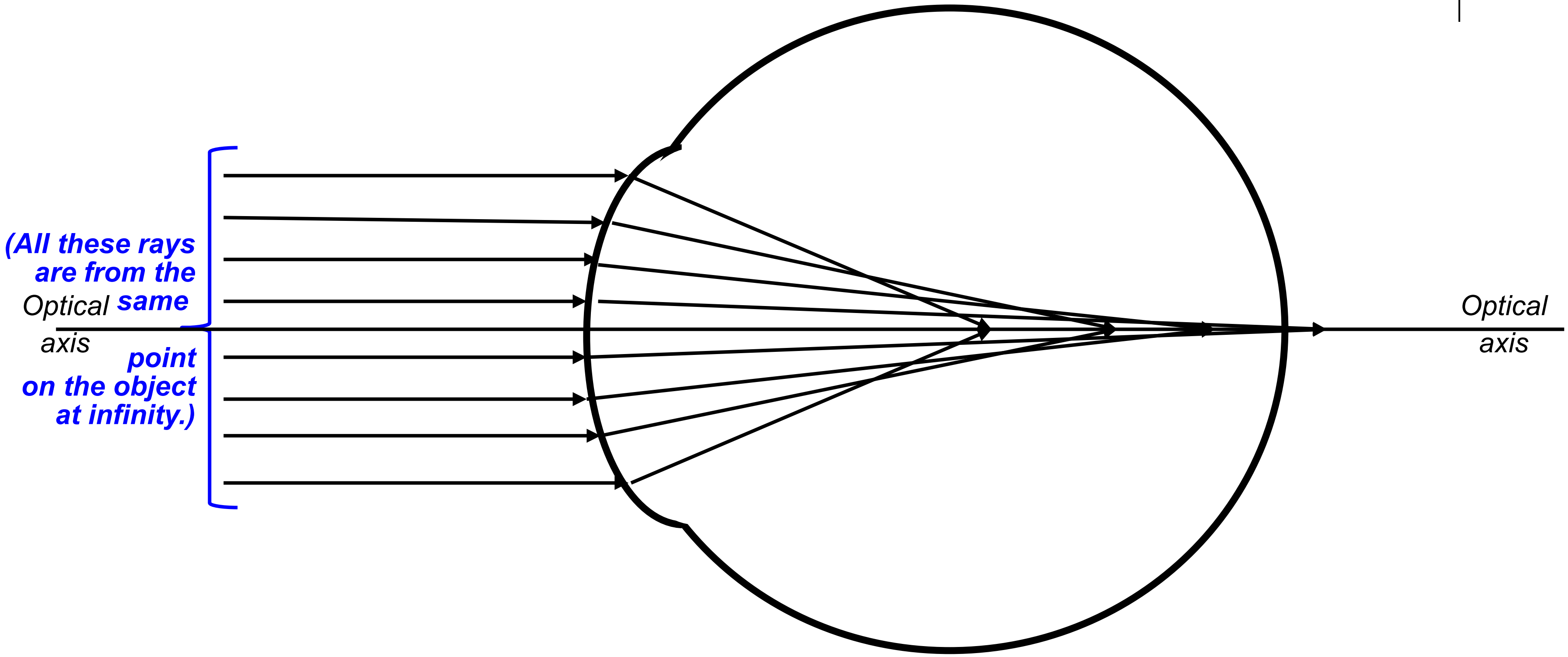
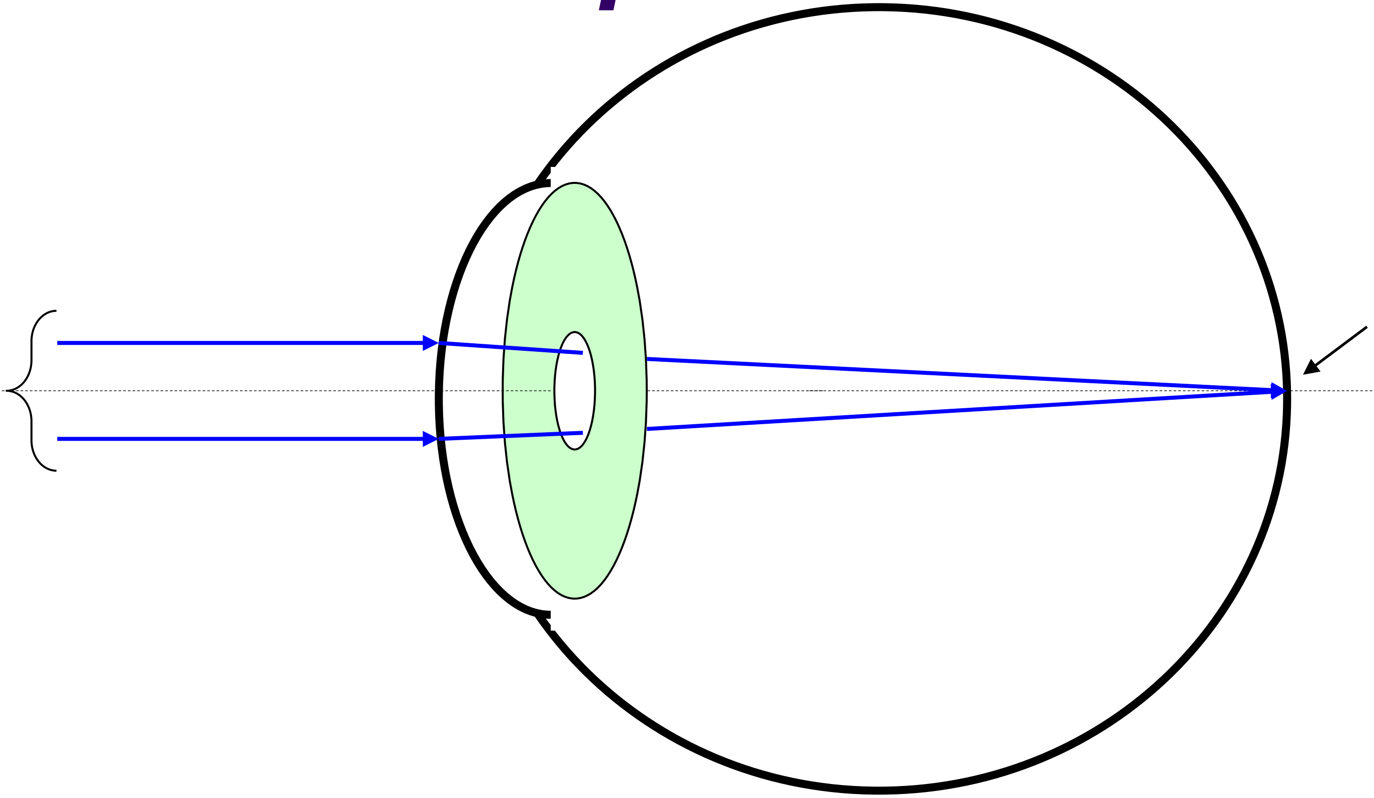
And because it is an optical instrument…

Aberrations: *Spherical*



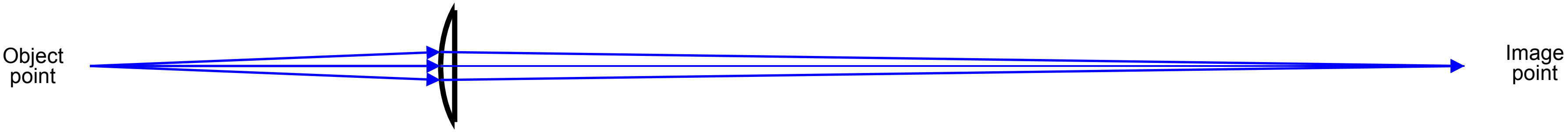
And because it is an optical instrument…the eye is subject to the same phenomenon.

Aberrations: *Spherical*



(Remember, all these rays are from the same point on the object at infinity.)

When the pupil is small, light reaching the retina consists largely of paraxial rays; ie, rays passing through the central portion of the cornea.



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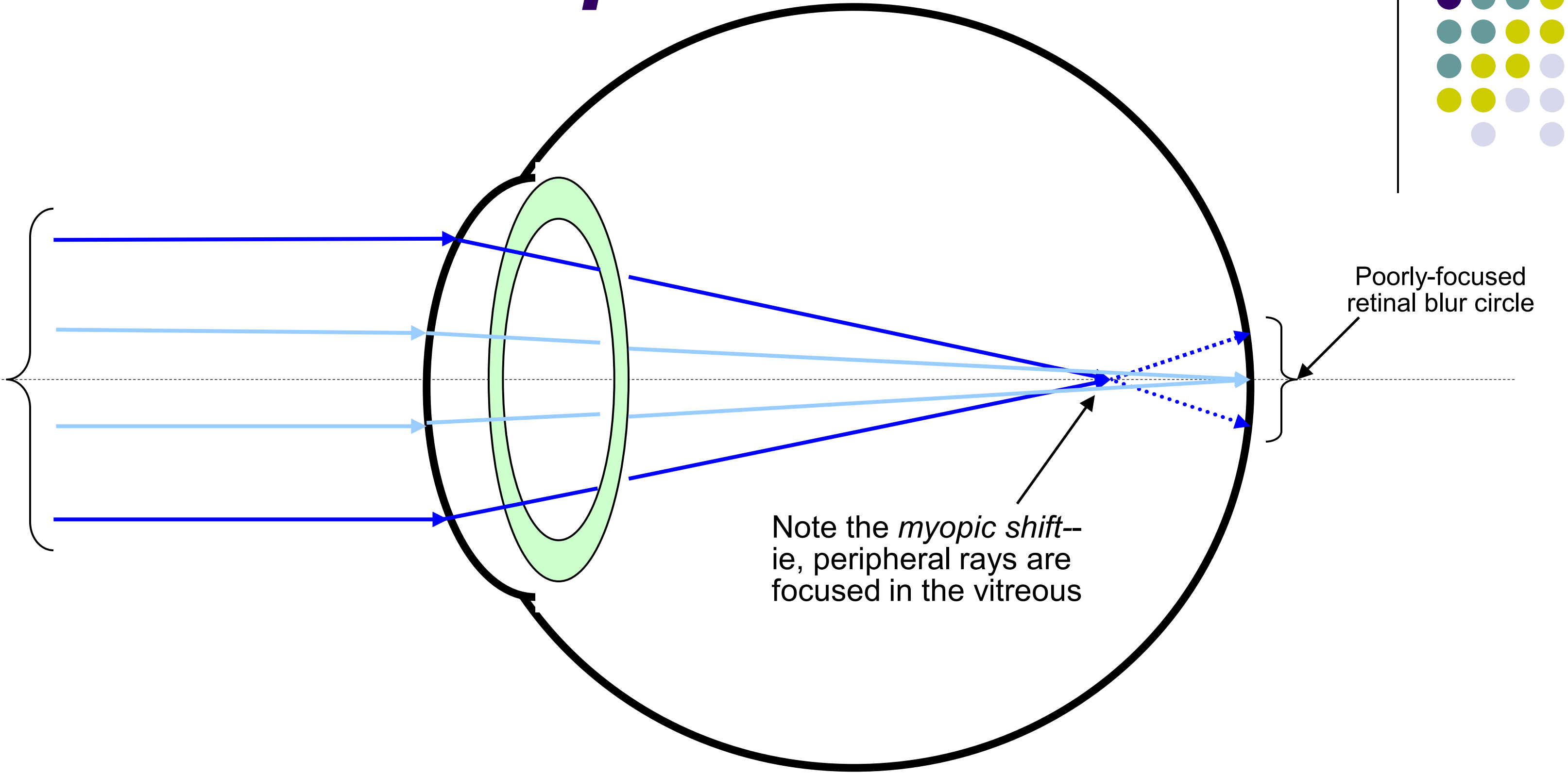
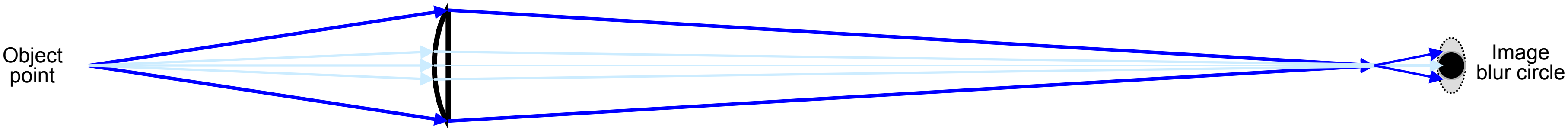


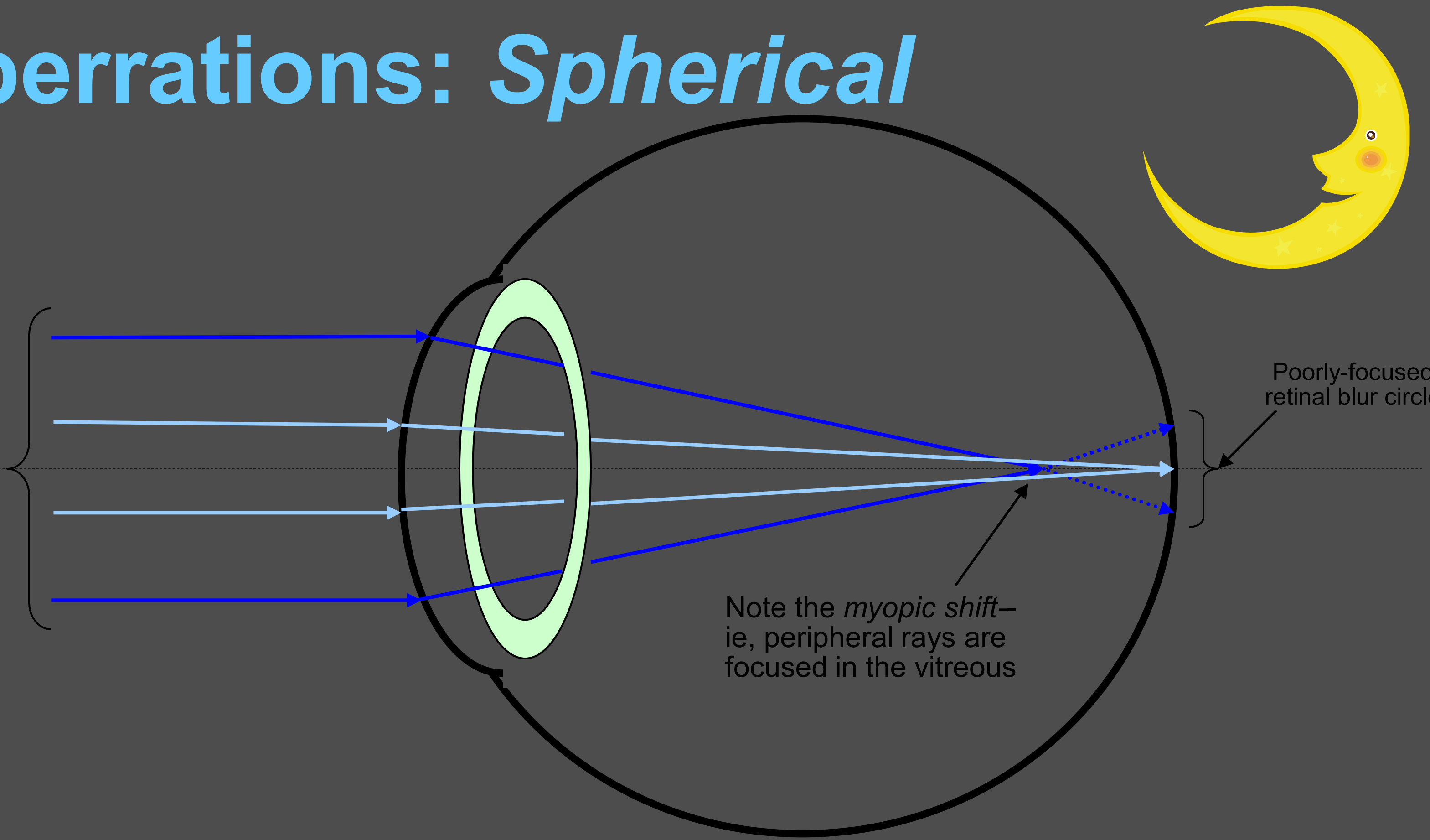
Poorly-focused retinal blur circle

Note the *myopic shift*-- ie, peripheral rays are focused in the vitreous

When the pupil is small, light reaching the retina consists largely of paraxial rays; ie, rays passing through the central portion of the cornea. However, when the pupil is large, rays passing through the peripheral cornea come into play, and spherical aberration causes these rays to be focused more anteriorly, resulting in a myopic component to the final image.



Aberrations: *Spherical*



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Poorly-focused retinal blur circle

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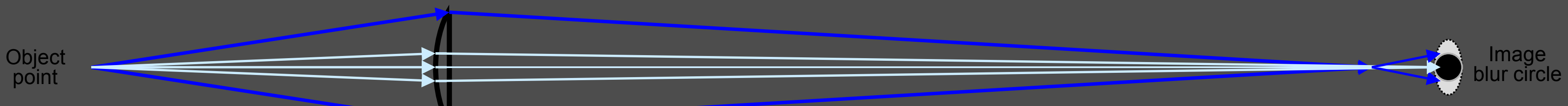
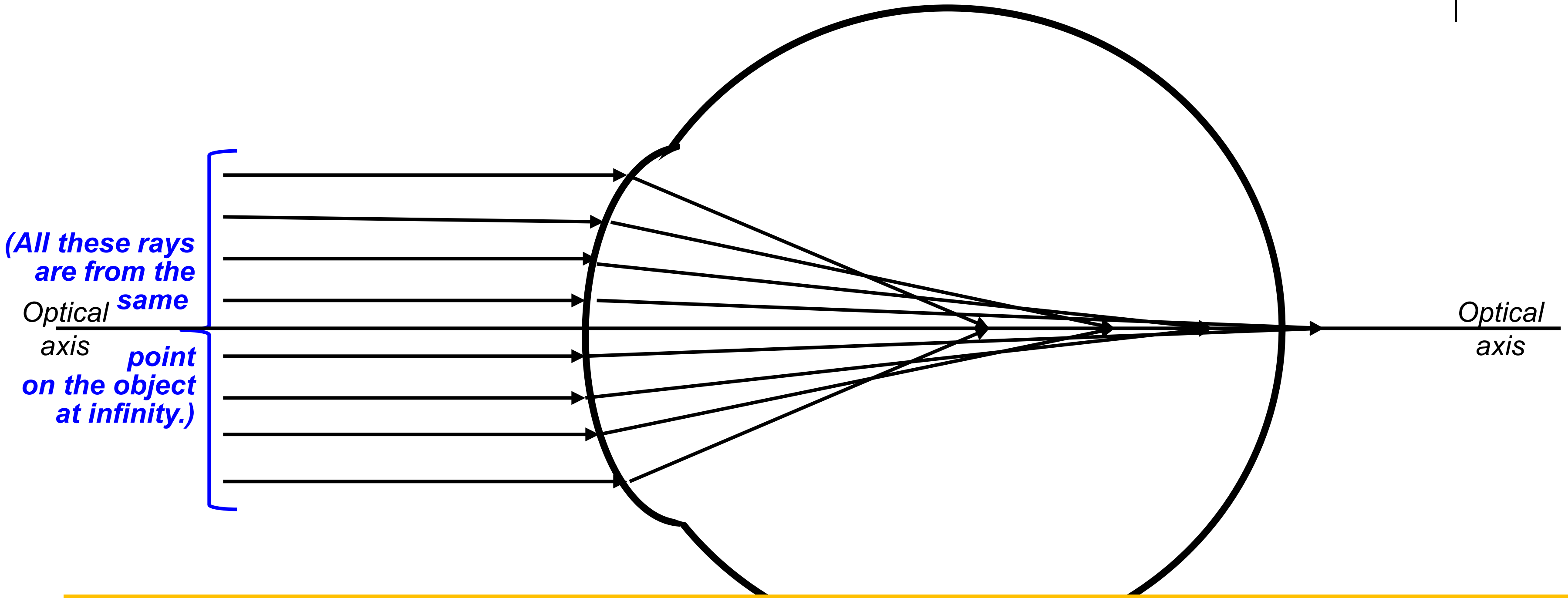
When the pupil is small, light reaching the retina consists largely of paraxial rays; ie, rays passing through the central portion of the cornea. However, when the pupil is large, rays passing through the peripheral cornea come into play, and spherical aberration causes these rays to be focused more anteriorly, resulting in a myopic component to the final image. **Spherical aberration is a factor in the phenomenon called *night myopia*, in which pts complain of blurred vision brought on by dusk- and night-time illumination levels.**

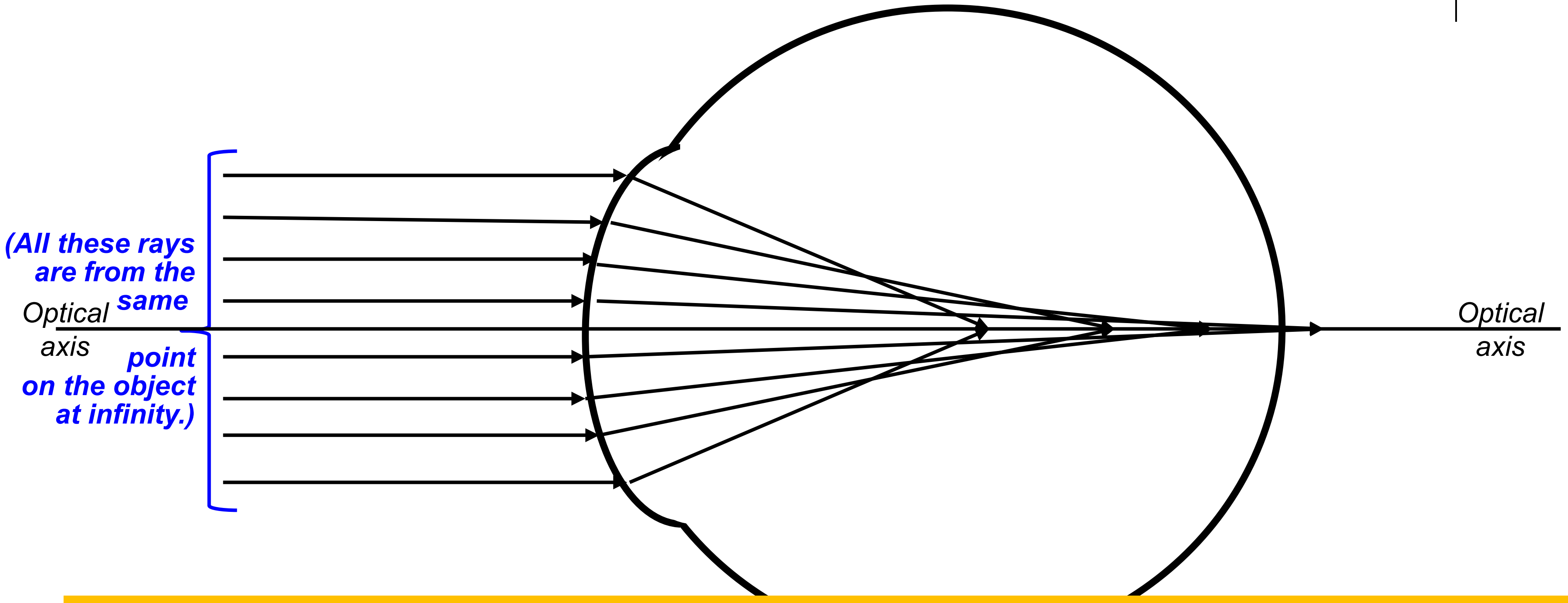


Aberrations: *Spherical*



How much spherical aberration does the average human cornea possess?

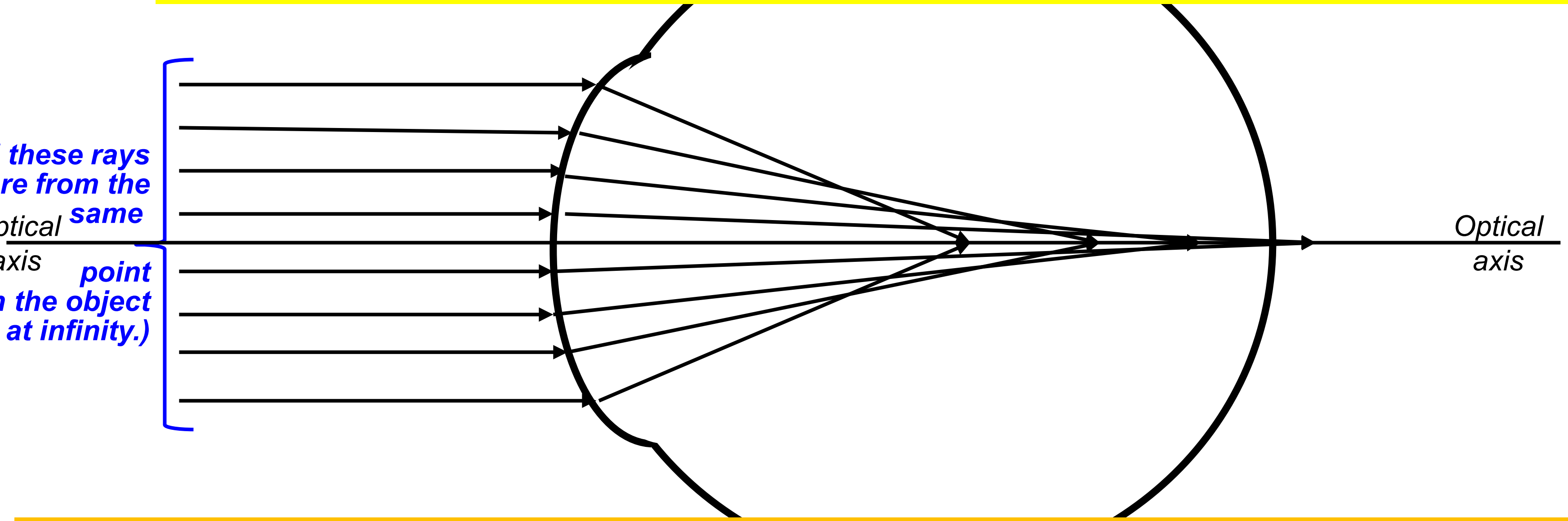
Aberrations: *Spherical*



How much spherical aberration does the average human cornea possess?
About +0.27 μm

Ab

Why is the unit of spherical aberration microns*--a unit of distance? What distance is being referred to?*



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How much spherical aberration does the average human cornea possess?

About +0.27 μm

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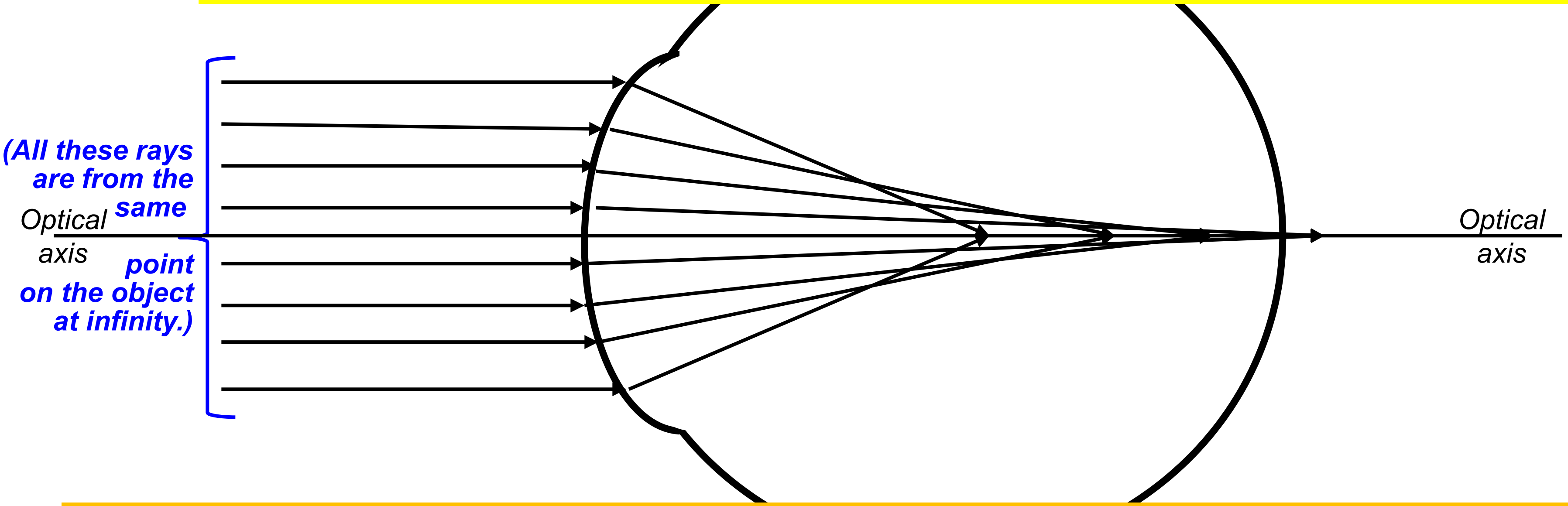
Why is the unit of spherical aberration microns--*a unit of distance? What distance is being referred to?*
It refers to the distance between the location where central rays form a focal point and where the peripheral rays form a focal point



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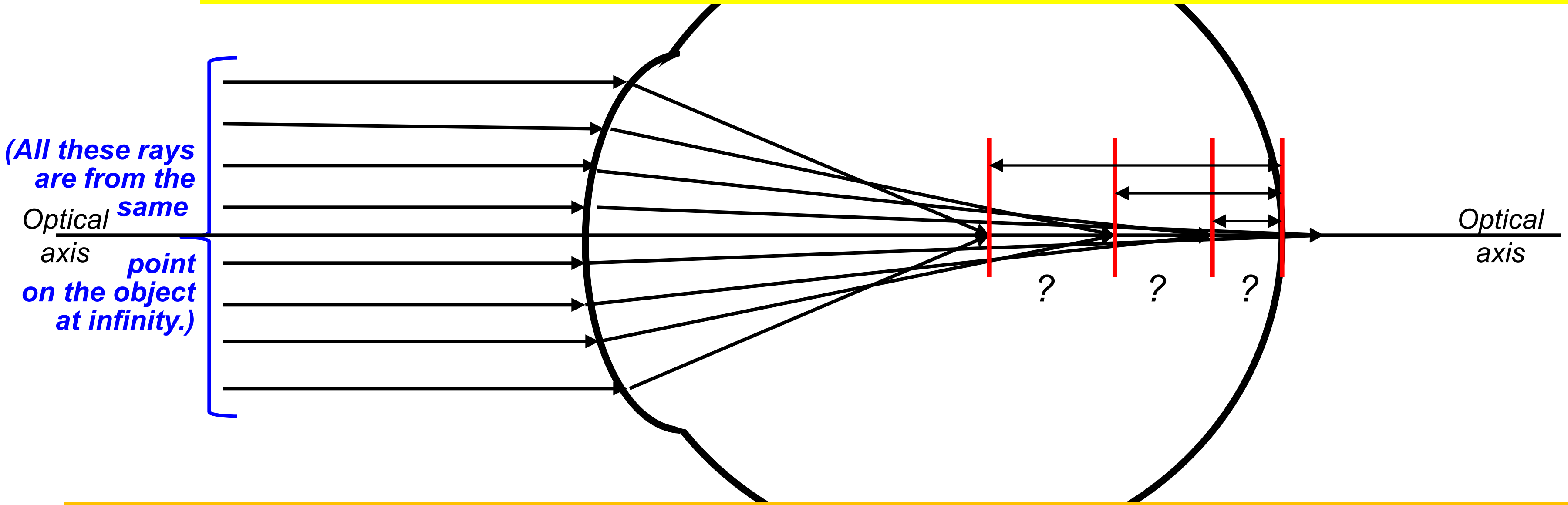
But as can be seen in the figure, the location of the focal point for rays passing through the corneal periphery is a function of 'how peripheral' those rays are. Given this, how can one measure spherical aberration?



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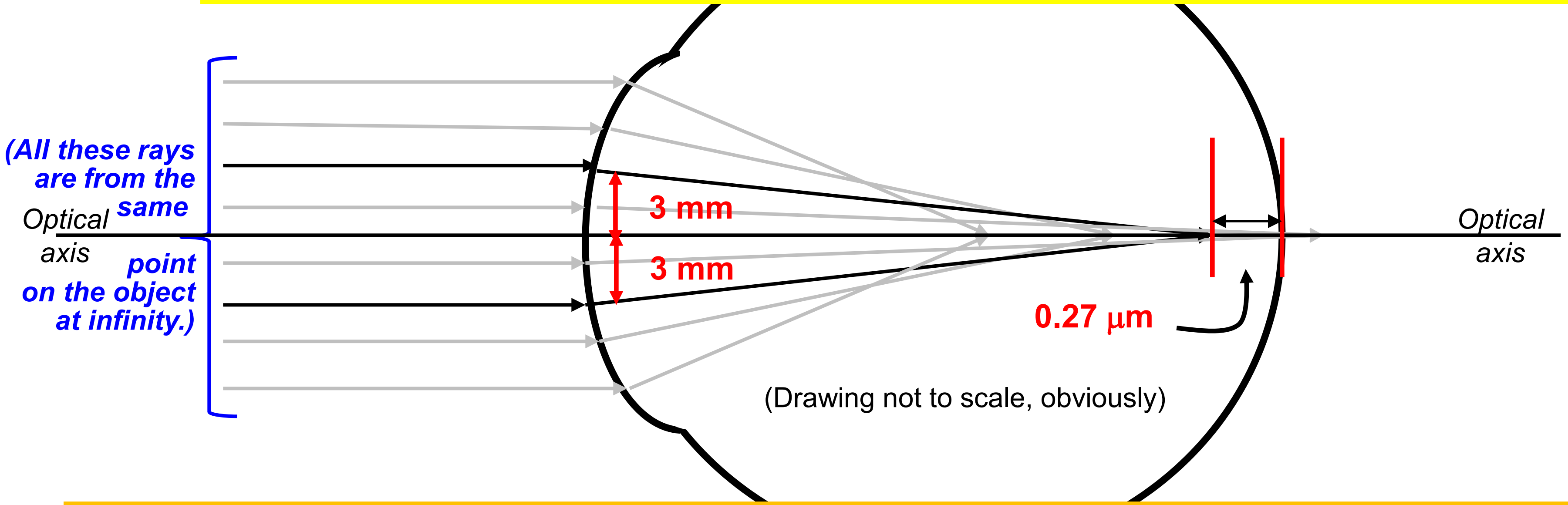
By convention, rays passing through the cornea 6 mm from the optical axis are used



(Drawing not to scale, obviously)

How much spherical aberration does the average human cornea possess?
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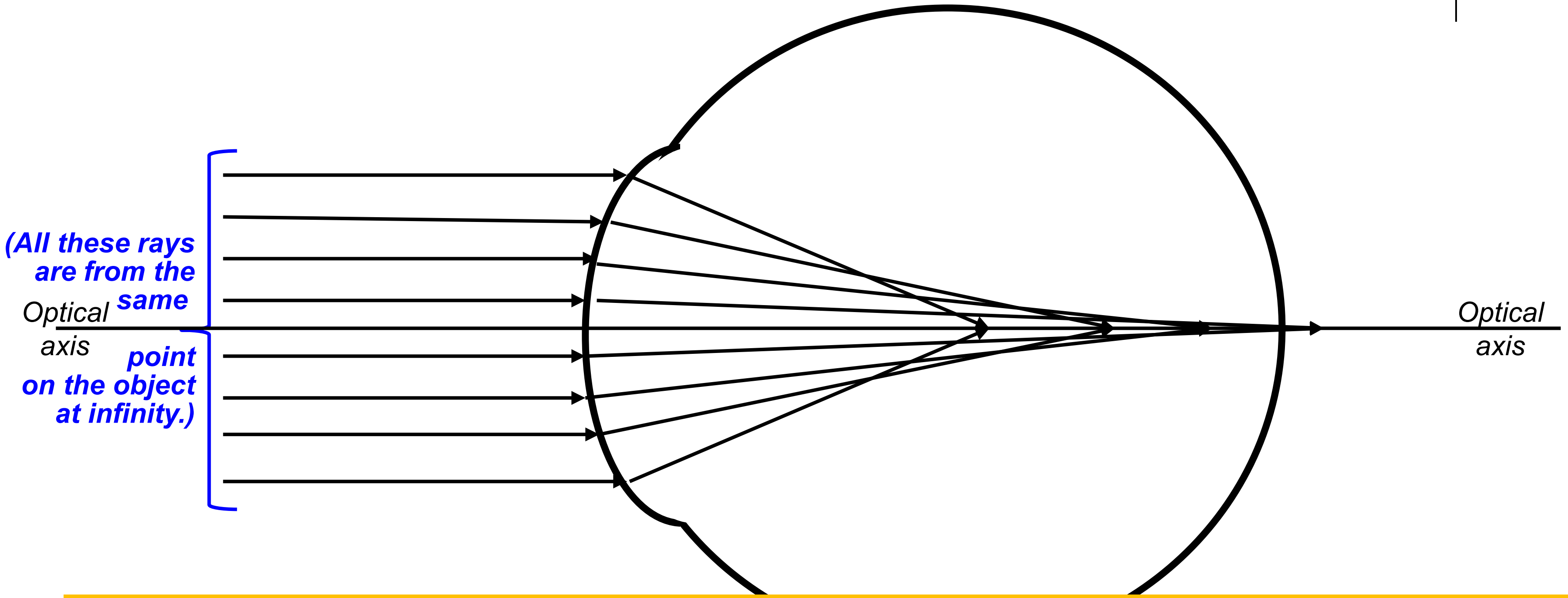
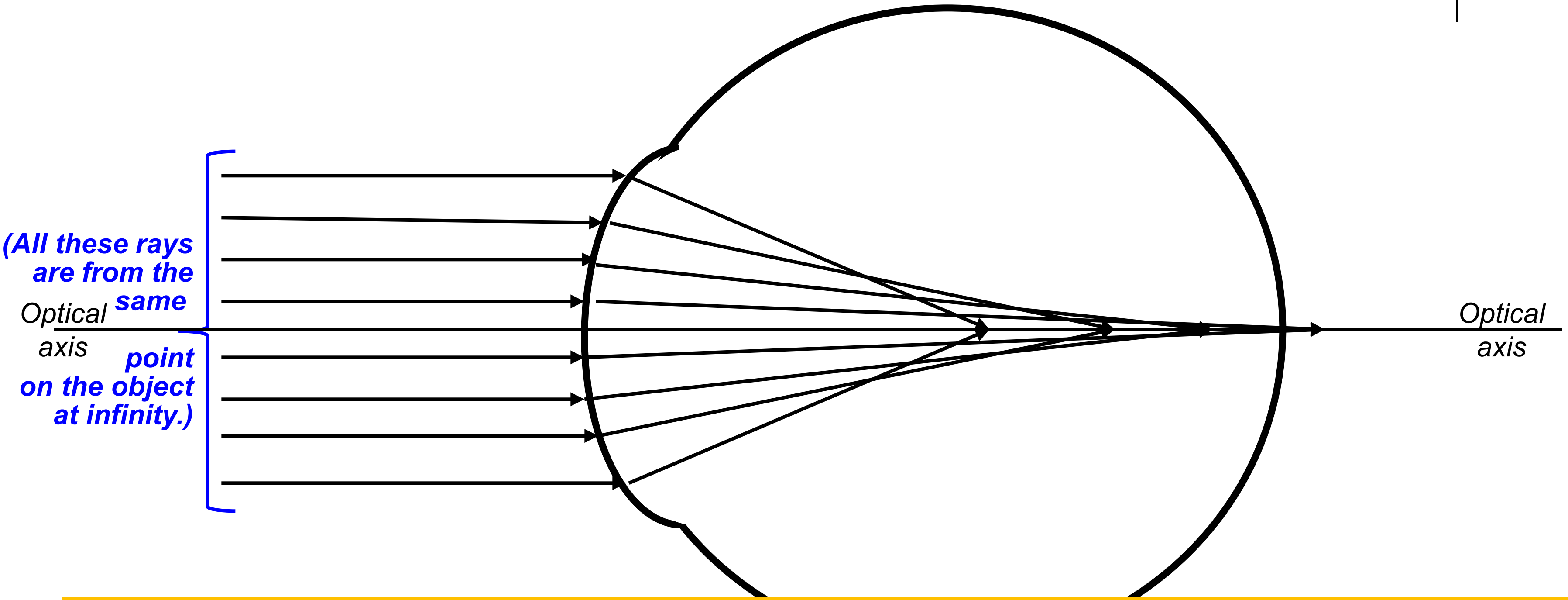
Aberrations: *Spherical*



How much spherical aberration does the average human cornea possess?
About +0.27 µm

*So this means the cornea possesses **positive** spherical aberration. But the cornea’s Q factor is negative. What gives?*

Aberrations: *Spherical*



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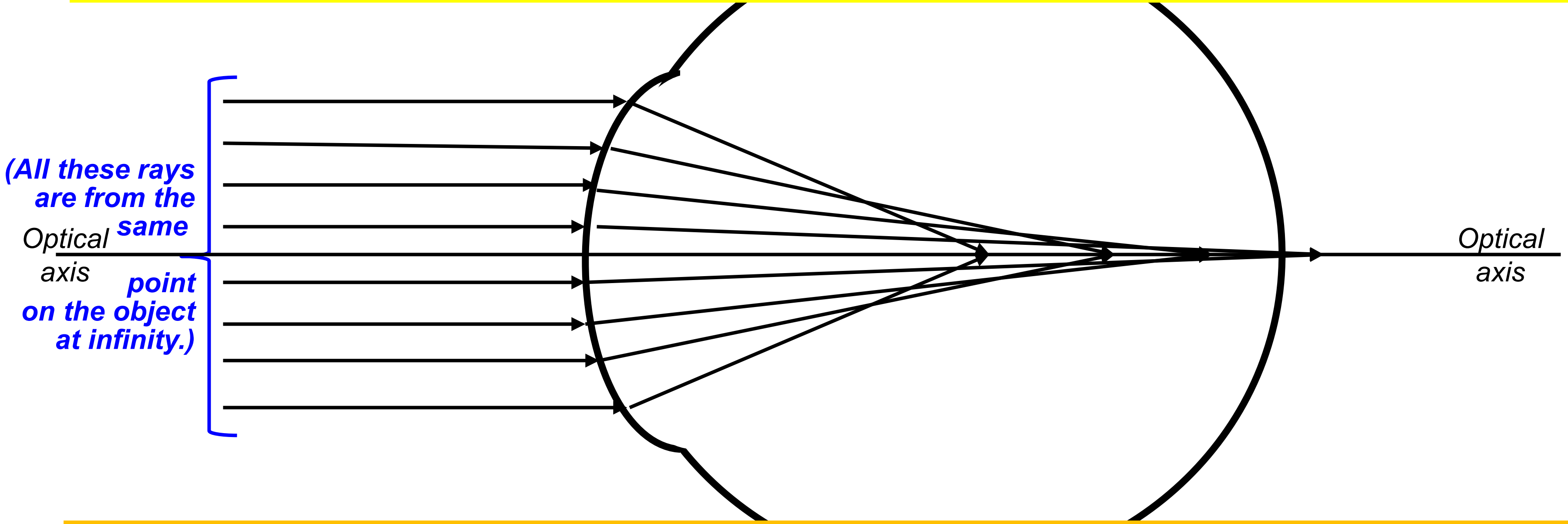
The Q factor measures the *relative* asphericity of the cornea. A negative Q factor simply means the corneal periphery has less power than the central cornea; it does not mean the cornea as a whole doesn't have spherical aberration!

Recall that the cornea's Q factor is -0.26. What would it be if the cornea had no spherical aberration?



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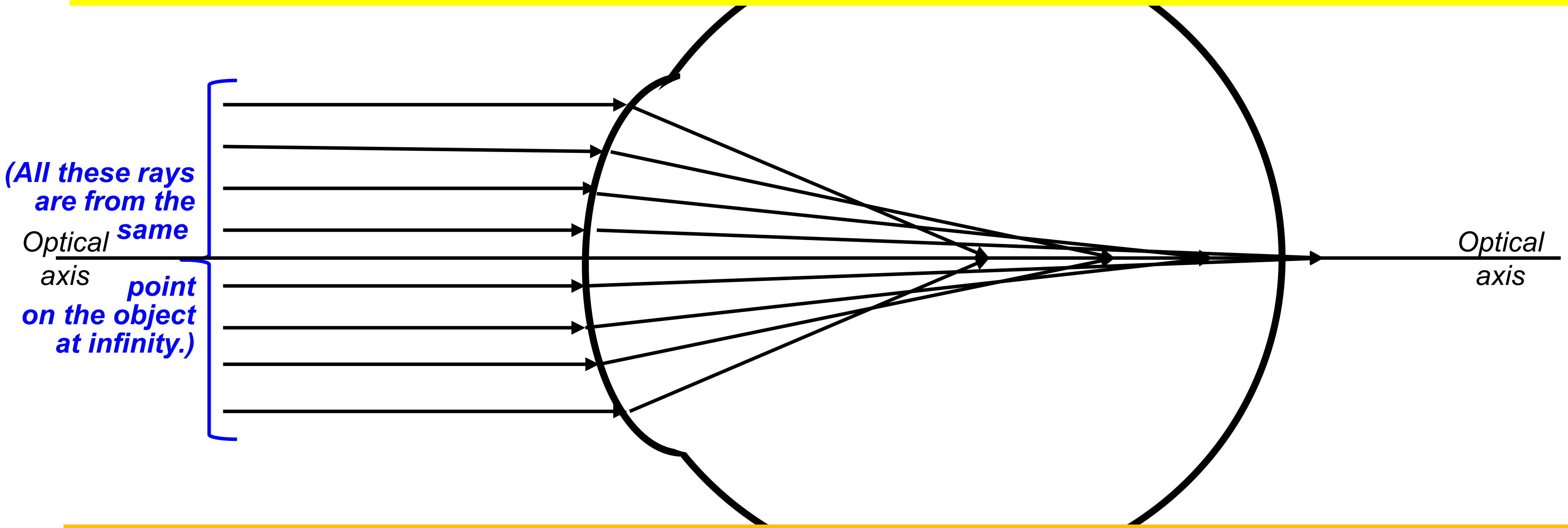
Recall that the cornea's Q factor is -0.26. What would it be if the cornea had no spherical aberration?
About -0.52



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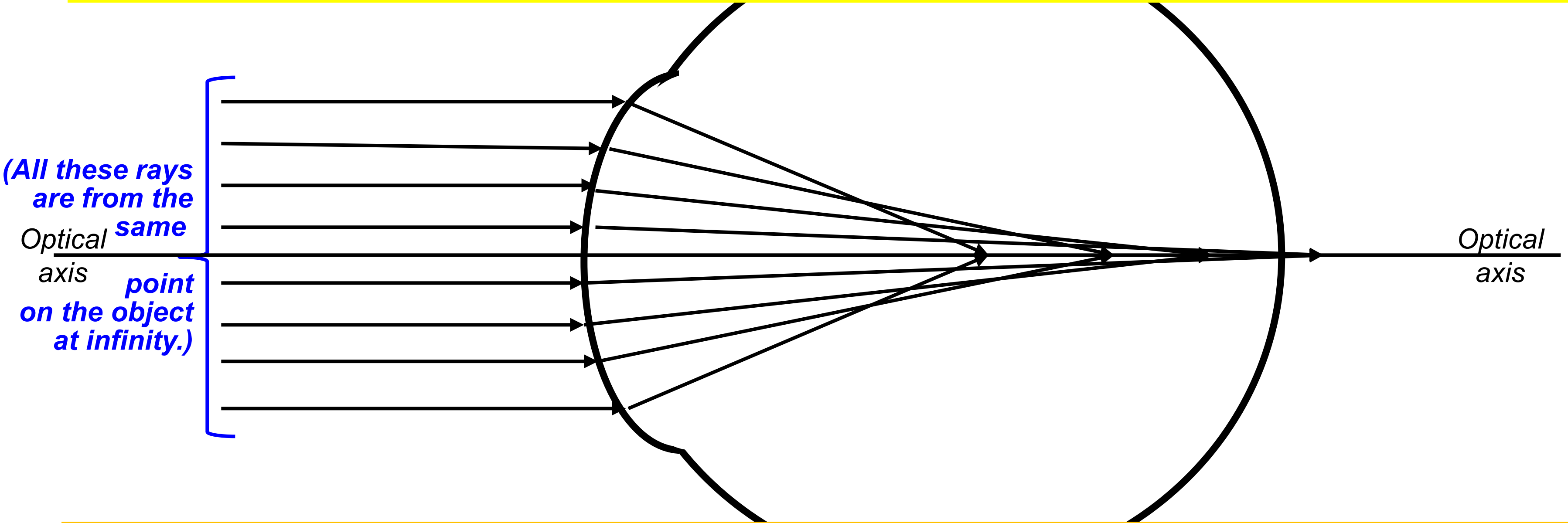
About -0.52

Why didn't we evolve corneas with a Q factor of -0.52?



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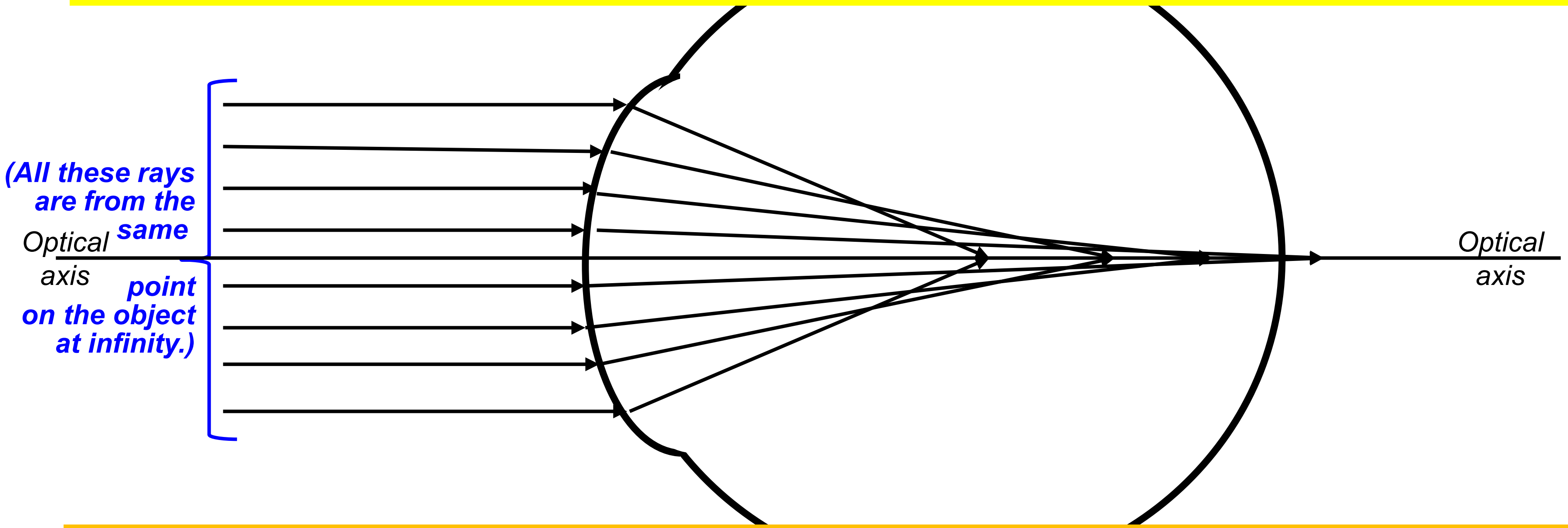
About -0.52

Why didn't we evolve corneas with a Q factor of -0.52?
Well, no one can say for sure of course. But what **can** be said with certainty is that a Q factor of -0.52 would require a radically different angle between the cornea and the sclera--an angle that could not be achieved given the biomechanics and size of the normal human globe.



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About -0.52

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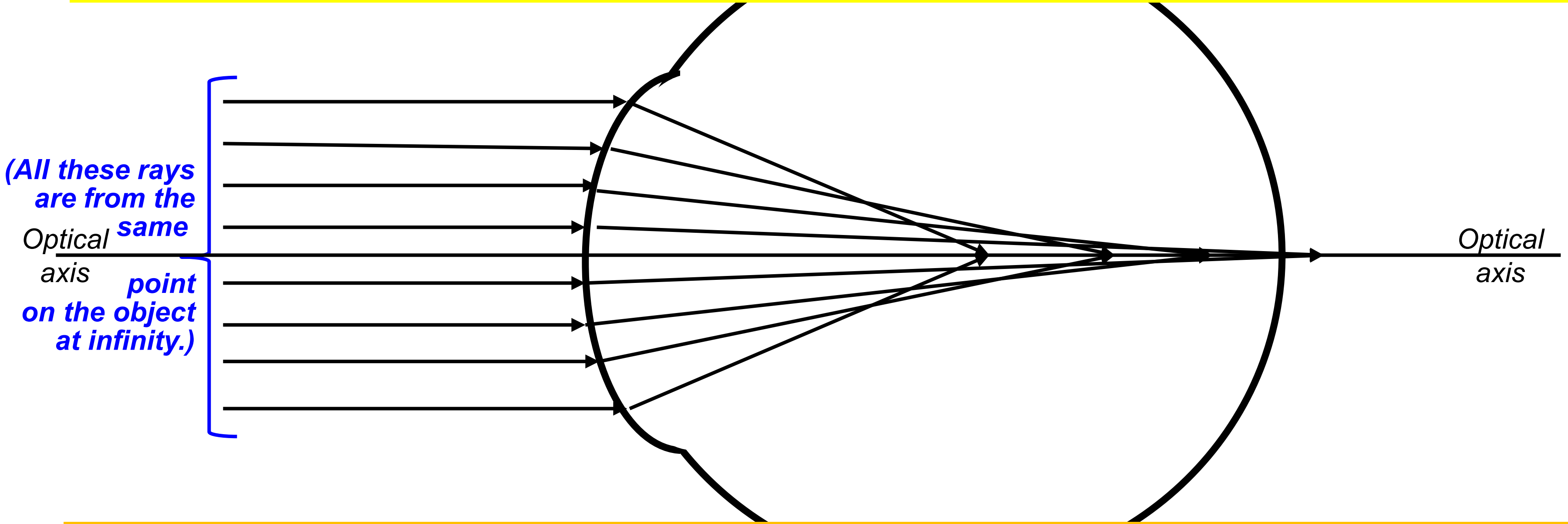

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About -0.52

Why didn't we evolve ~~corneas~~ eyes with a Q factor of -0.52? We did!
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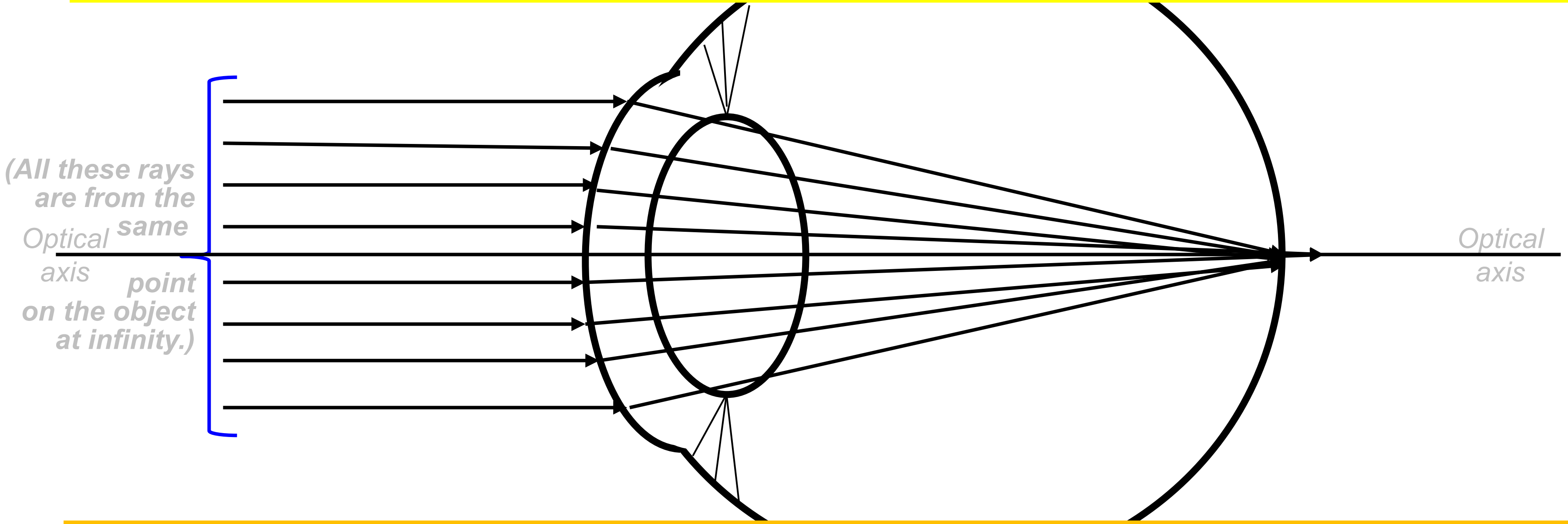

How much spherical aberration does the average human cornea possess?
About +0.27 µm

*So this means the cornea possesses **positive** spherical aberration. But the cornea's Q factor is negative. What gives?*
The Q factor measures the *relative* asphericity of the cornea. A negative Q factor simply means the corneal periphery has less power than the central cornea; it does not mean the cornea as a whole doesn't have spherical aberration!

Recall that the cornea's Q factor is -0.26. What would it be if the cornea had no spherical aberration?
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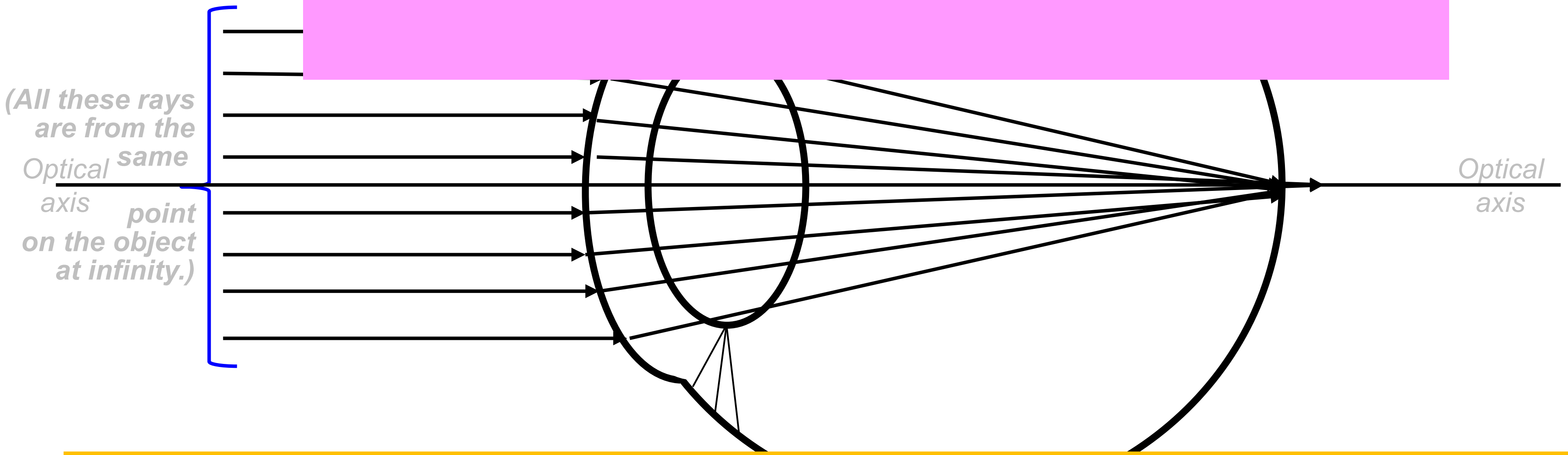

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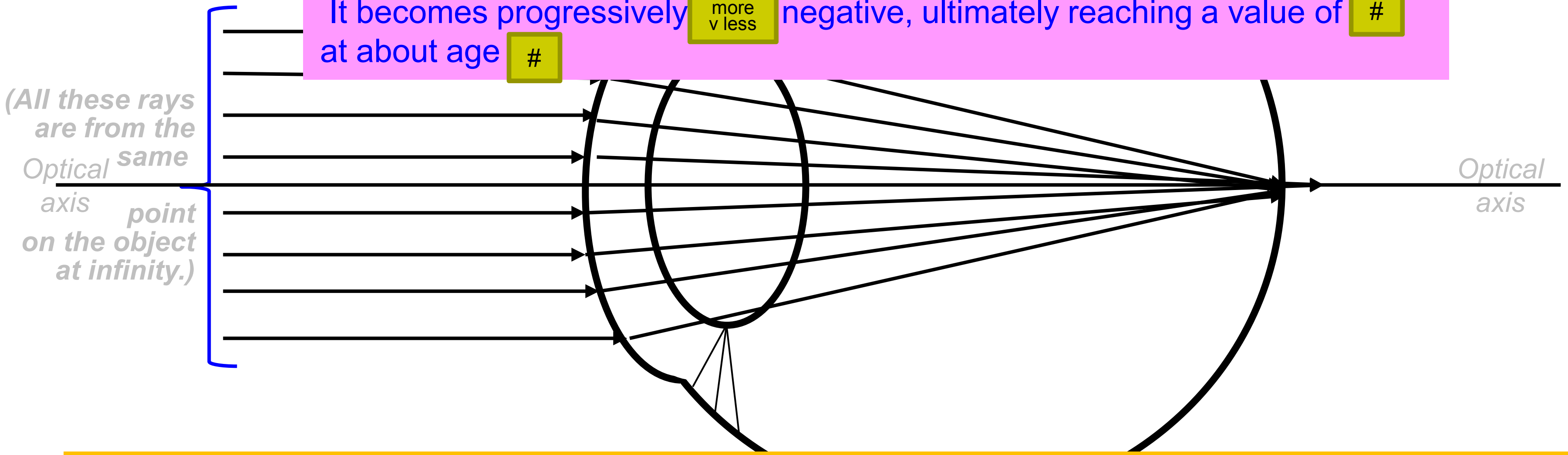

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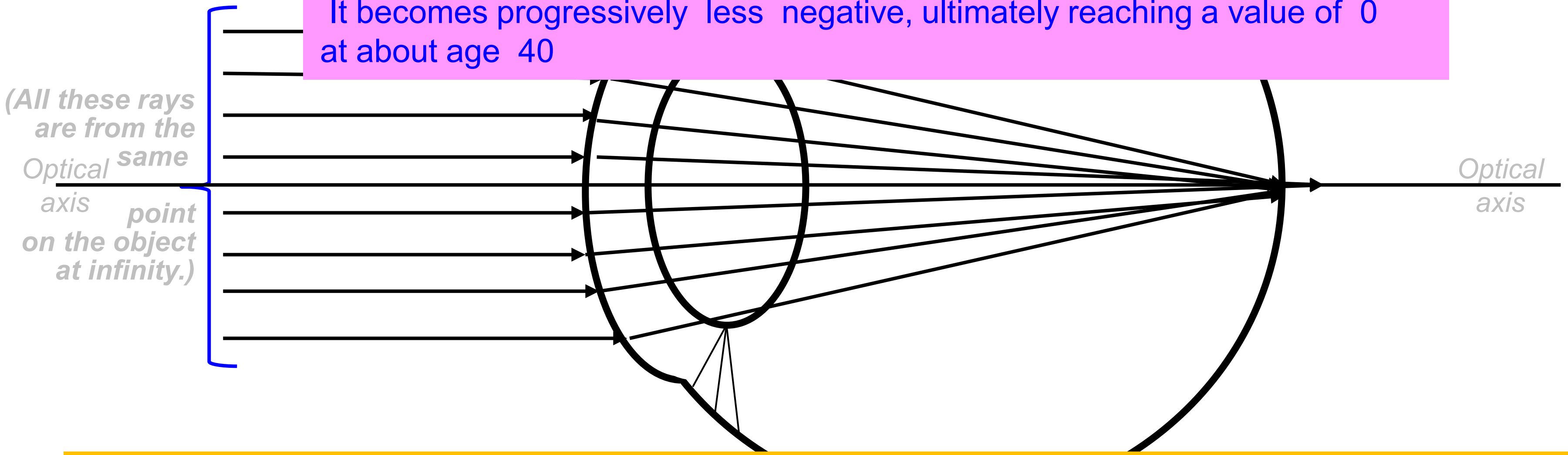
It becomes progressively less negative, ultimately reaching a value of 0 at about age 40



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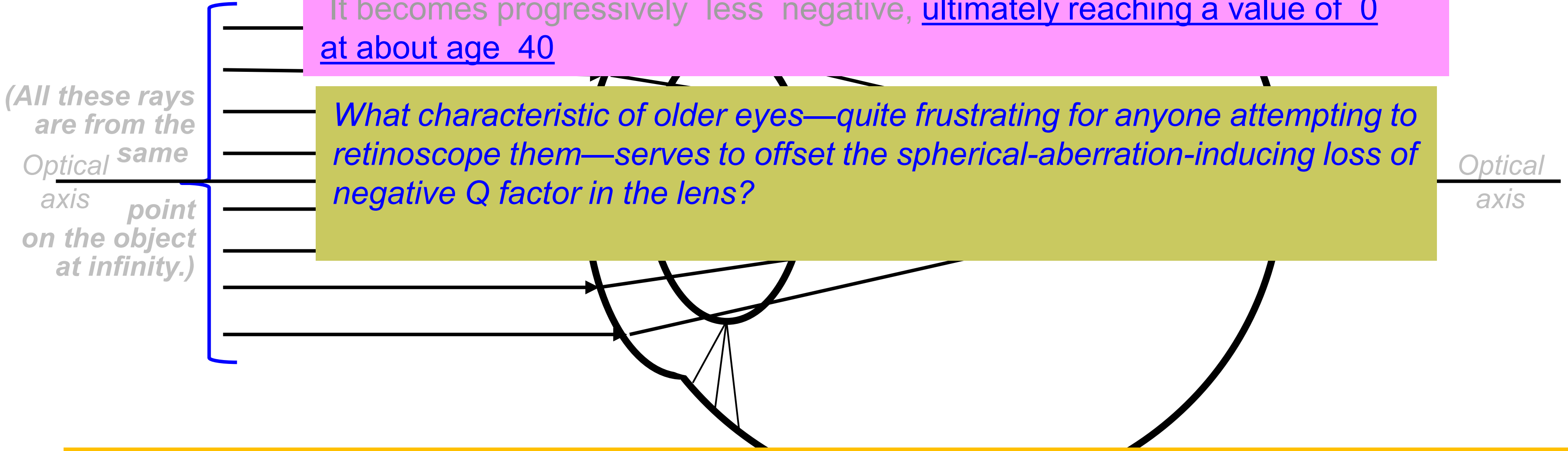

What characteristic of older eyes—quite frustrating for anyone attempting to retinoscope them—serves to offset the spherical-aberration-inducing loss of negative Q factor in the lens?

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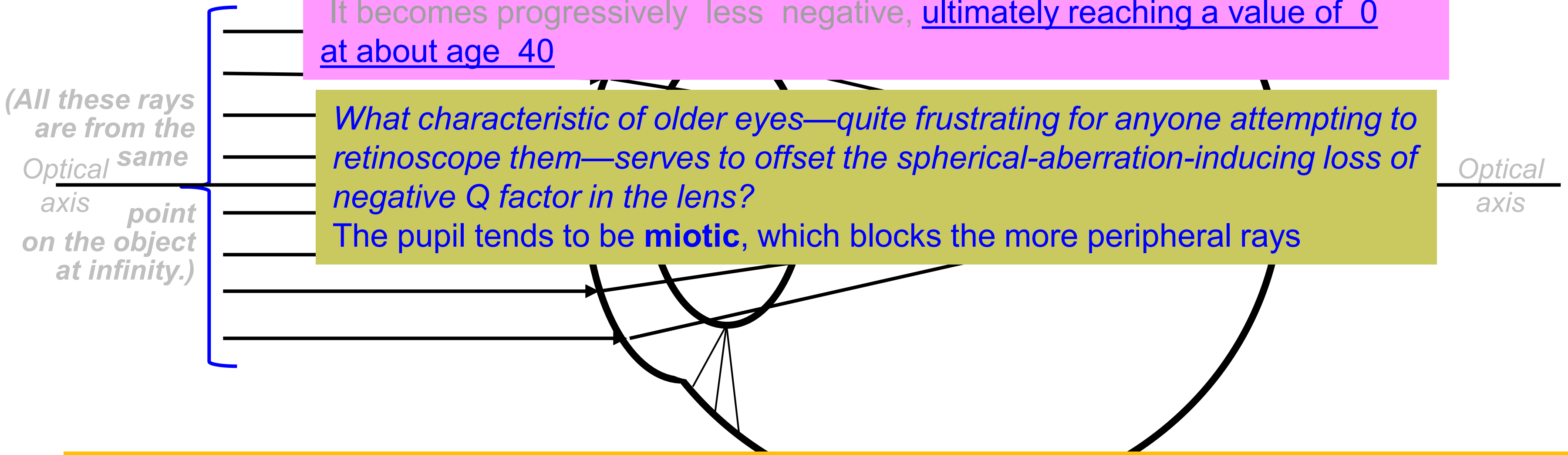

What characteristic of older eyes—quite frustrating for anyone attempting to retinoscope them—serves to offset the spherical-aberration-inducing loss of negative Q factor in the lens?
The pupil tends to be **miotic**, which blocks the more peripheral rays

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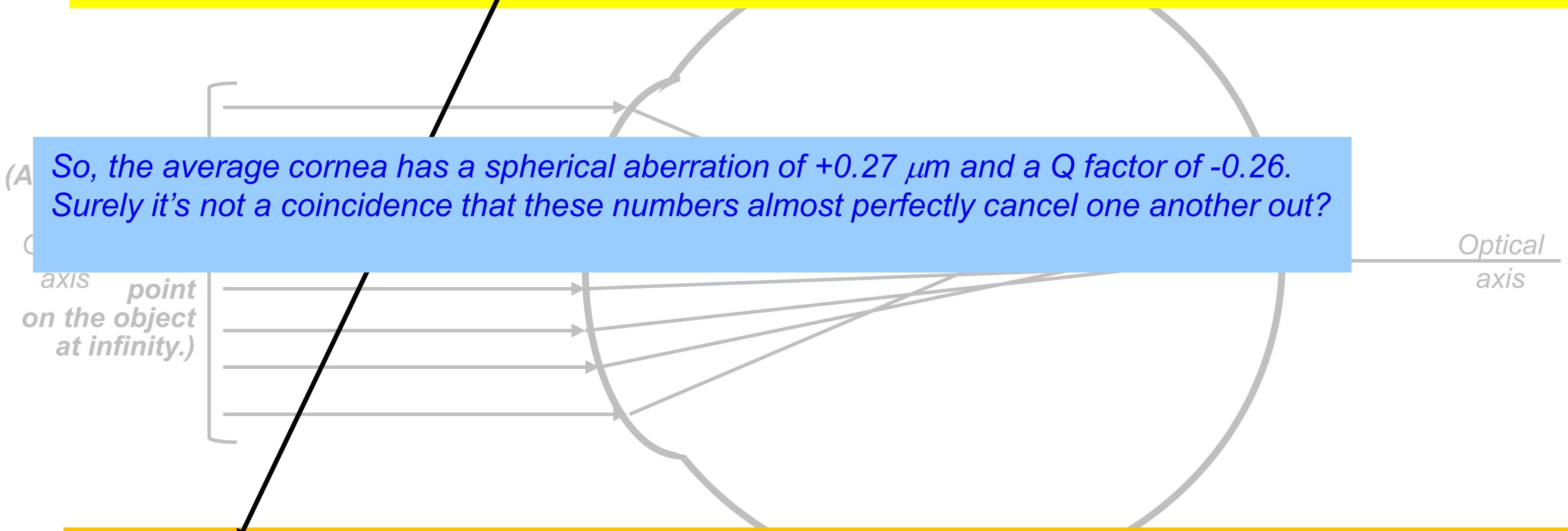
Recall that the cornea's Q factor is ***-0.26****. What would it be if the cornea had no spherical aberration?*
About -0.52

Why didn't we evolve corneas with a Q factor of -0.52?
Well, no one can say for sure of course. But what **can** be said with certainty is that a Q factor of -0.52 would require a radically different angle between the cornea and the sclera--an angle that could not be achieved given the biomechanics and size of the normal human globe. Thus, a Q factor of -0.52 would require a very radical 're-design' of the globe--and thus of the orbits, and the cranium, and etc.



So, the average cornea has a spherical aberration of +0.27 μm and a Q factor of -0.26. Surely it's not a coincidence that these numbers almost perfectly cancel one another out?

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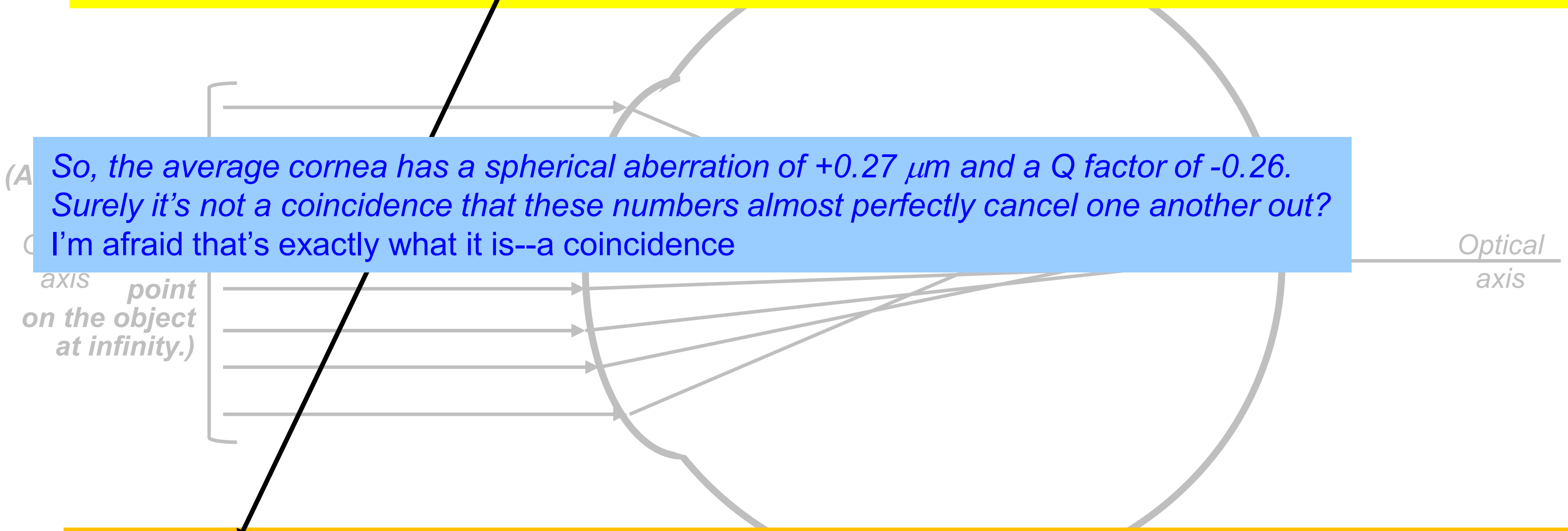

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Surely it's not a coincidence that these numbers almost perfectly cancel one another out?
I'm afraid that's exactly what it is--a coincidence

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Aberrations: *Zernike Polynomials*

- A mathematical system for describing and systematizing optical aberrations

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In other words: *Any wavefront, no matter how complex its shape, can be ‘broken down’ into a set of Zernike shapes.*

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  - The set of shapes starts off very simple/basic, becoming progressively more complex as the series proceeds

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    - The progression is described by the *order* of a given shape
      - Order start at zero, and goes up from there

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order	***New Lingo***	***Shape***
2nd	Defocus *Positive* defocus *Negative* defocus	
2nd	Cylinder	
4th	Spherical aberration	
3rd	Coma	
3rd	Trefoil	
	(Others, less clinically relevant)	

Intentionally out of order! While coma and trefoil are of lower-order than spherical aberration, SA is clinically more significant.

Aberrations: *Zernike Polynomials*

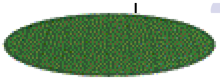
Zernike Polynomial Order	***New Lingo***	***Shape***
0th	***?***	
1st	***?***	
	Defocus *Positive* defocus *Negative* defocus	
2nd	Cylinder	
4th	Spherical aberration	
3rd	Coma	
3rd	Trefoil	
	(Others, less clinically relevant)	

Wait--you said ZPs start at zero and go up from there. What are the 0th and 1st-order aberrations?

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order — ***New Lingo*** — ***Shape***

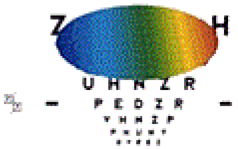
0th ⟷ 'Piston'



PISTON

1st ⟷ 'Prism'

VERTICAL PRISM



HORIZONTAL PRISM

(aka *tip* and *tilt*)

Wait--you said ZPs start at zero and go up from there. What are the 0th and 1st-order aberrations?
'Piston' and 'prism'

→ Defocus

Positive defocus

Negative defocus

2nd ⟷ Cylinder

4th ⟷ Spherical aberration

3rd ⟷ Coma

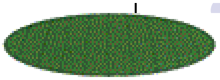
3rd ⟷ Trefoil

(Others, less clinically relevant)

Aberrations: *Zernike Polynomials*

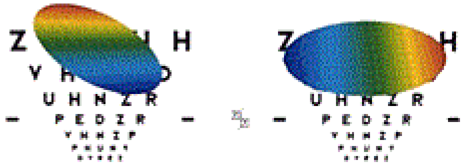
Zernike Polynomial Order **New Lingo** ***Shape***

0^{th} ↔ 'Piston'



PISTON

1^{st} ↔ 'Prism'



VERTICAL PRISM HORIZONTAL PRISM

(aka *tip* and *tilt*)

Wait--you said ZPs start at zero and go up from there. What are the 0^{th} and 1^{st}-order aberrations?
'Piston' and 'prism'

→ Defocus

Positive defocus

Negative defocus

2^{nd} ↔ Cylinder

Why haven't we talked about piston and prism?

4^{th} ↔ S aberration

3^{rd} ↔ Coma

3^{rd} ↔ Trefoil

(Others, less clinically relevant)

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order		***New Lingo***	***Shape***
0^{th}	↔	'Piston'	
1^{st}	↔	'Prism'	
	→	Defocus *Positive* defocus *Negative* defocus	
2^{nd}	↔	Cylinder	
4^{th}	↔	S aberration	
3^{rd}	↔	Coma	
3^{rd}	↔	Trefoil	

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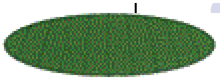

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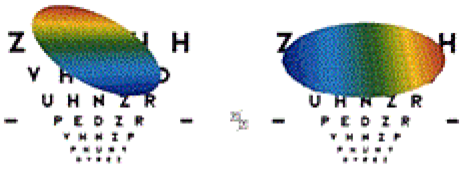

VERTICAL PRISM

HORIZONTAL PRISM

(aka *tip* and *tilt*)

Why haven't we talked about piston and prism?
Because while they are technically aberrations in the ZP system, they do not degrade the quality of the visual image and are thus **clinically irrelevant**

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order	**New Lingo**
0th	'Piston'
1st	'Prism'
2nd	Defocus
Myopia =	*Positive* defocus
Hyperopia =	*Negative* defocus
2nd	Cylinder
4th	Spherical aberration
3rd	Coma
3rd	Trefoil

(Others, less clinically relevant)

Shape

DEFOCUS
(positive)
'Bowl'

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order	***New Lingo***	***Shape***
0th	'Piston'	
1st	'Prism'	
2nd	Defocus	
Myopia =	*Positive* defocus	
Hyperopia =	*Negative* defocus	
2nd	Cylinder	 ASTIGMATISM 'Saddle'
4th	Spherical aberration	
3rd	Coma	
3rd	Trefoil	
	(Others, less clinically relevant)	

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order **New Lingo** ***Shape***

0th ↔ ‘Piston’

1st ↔ ‘Prism’

2nd ↔ Defocus

Myopia ← = → *Positive* defocus

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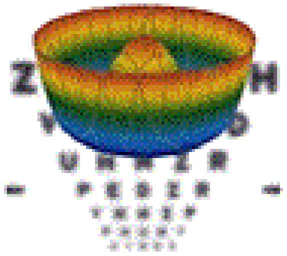
2nd ↔ Cylinder

4th ↔ Spherical aberration

3rd ↔ Coma

3rd ↔ Trefoil

(Others, less clinically relevant)



SPHERICAL ABERRATION

‘Bundt cake pan’

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order **New Lingo** ***Shape***

0th ↔ 'Piston'

1st ↔ 'Prism'

2nd ↔ Defocus

Myopia ↔ = ↔ *Positive* defocus

Hyperopia ↔ = ↔ *Negative* defocus

2nd ↔ Cylinder

4th ↔ Spherical aberration

3rd ↔ Coma

3rd ↔ Trefoil

(Others, less clinically relevant)

'Recliner'

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order	**New Lingo**	***Shape***
0th	'Piston'	
1st	'Prism'	
2nd	Defocus	
Myopia =	*Positive* defocus	
Hyperopia =	*Negative* defocus	
4th	Spherical aberration	
3rd	Coma	 'Recliner'
3rd	Trefoil	
	(Others, less clinically relevant)	

In layman's terms, what is the problem with the incoming light that leads to the higher-order aberration of coma?

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order **New Lingo** ***Shape***

0th ↔ 'Piston'

1st ↔ 'Prism'

2nd ↔ Defocus

Myopia ↔ = ↔ *Positive* defocus

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In layman's terms, what is the problem with the incoming light that leads to the higher-order aberration of coma?
Coma occurs when **the source of the rays is located off the optical axis**. Because of its location, light from this source reaches one side of the pupil before the other.

4th ↔ Spherical aberration

3rd ↔ Coma

3rd ↔ Trefoil

(Others, less clinically relevant)

'Recliner'

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order	***New Lingo***	***Shape***
0th ↔	'Piston'	
1st ↔	'Prism'	
2nd ↔	Defocus	
Myopia ↔ =	*Positive* defocus	
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4th ↔	Spherical aberration	
3rd ↔	Coma	
3rd ↔	Trefoil	
	(Others, less clinically relevant)	

In layman's terms, what is the problem with the incoming light that leads to the higher-order aberration of coma?
Coma occurs when **the source of the rays is located off the optical axis**. Because of its location, light from this source reaches one side of the pupil before the other. The result is that rays entering the 'near' side and the 'far' side of the pupil are focused not at as a single point, but rather as a point with a 'smear' attached (not unlike a comet's tail, which is why the words share a root).

'Recliner'

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order	***New Lingo***	***Shape***
0th ↔	'Piston'	
1st ↔	'Prism'	
2nd ↔	Defocus	
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2nd ↔	Cylinder	
4th ↔	Spherical aberration	
3rd ↔	Coma	
3rd ↔	Trefoil	

'Three peaks'

(Others, less clinically relevant)

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order **New Lingo** ***Shape***

0th ↔ 'Piston'

1st ↔ 'Prism'

2nd ↔ Defocus

Myopia ↔ = ↔ *Positive* defocus

Hyperopia ↔ = ↔ *Negative* defocus

2nd ↔ Cylinder

In layman's terms, what is the problem with the incoming light that leads to trefoil?

3rd ↔ Coma

3rd ↔ Trefoil

(Others, less clinically relevant)

'Three peaks'

Aberrations: *Zernike Polynomials*

Zernike Polynomial Order	***New Lingo***	***Shape***
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1st	'Prism'	
2nd	Defocus	
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	(Others, less clinically relevant)	

In layman's terms, what is the problem with the incoming light that leads to trefoil*?*
Happily, the *BCSC* books do not spend much time on trefoil, so you don't need to know much more about it than:
1) it is a clinically significant (albeit modestly so) higher-order aberration; and
2) its shape, ie, be able to recognize its wavefront analysis profile (more on this later).

'Three peaks'

Aberrations: *Zernike Polynomials*

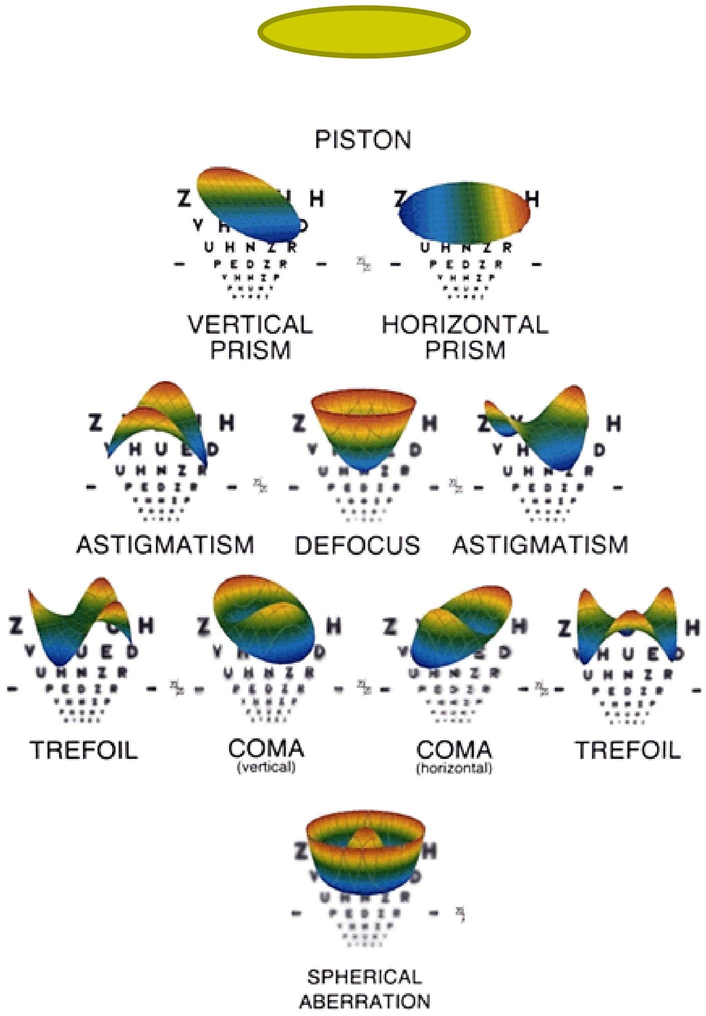
0th

1st

2nd

3rd

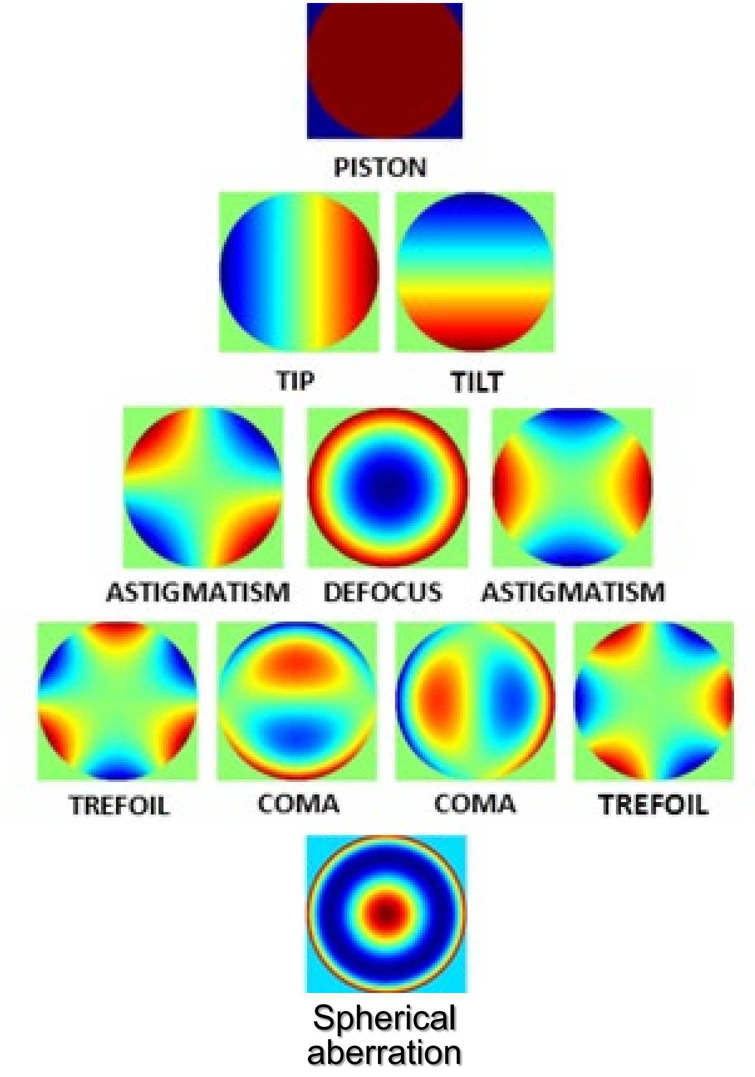
4th



In addition to the 3-D representation of each shape…

3-D representation

Aberrations: *Zernike Polynomials*



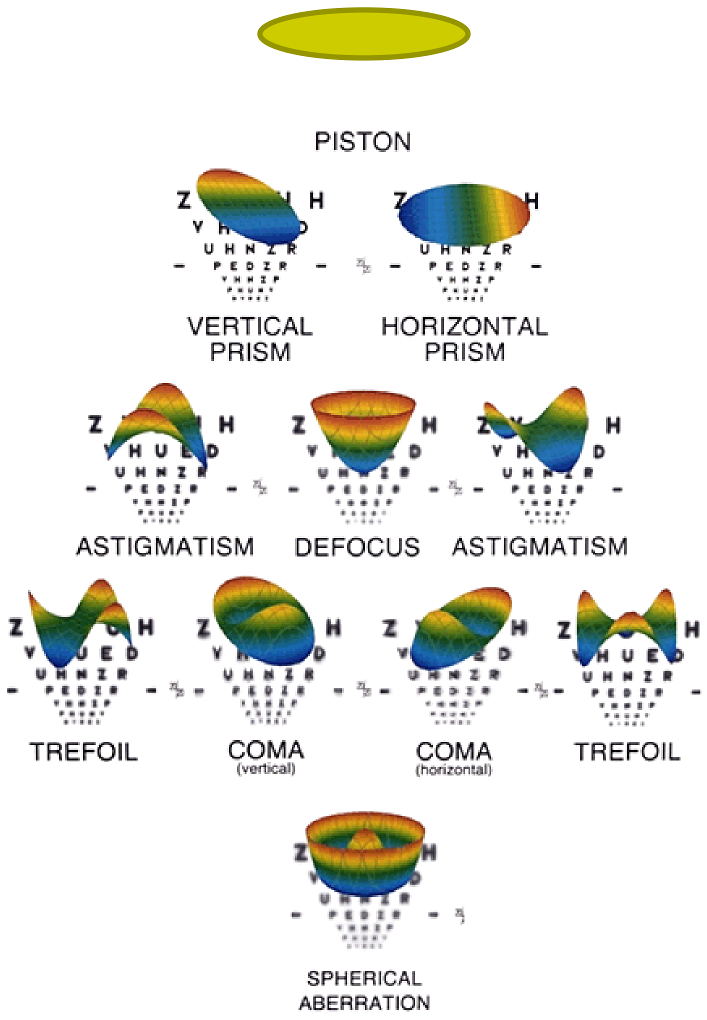
0th

1st

2nd

3rd

4th

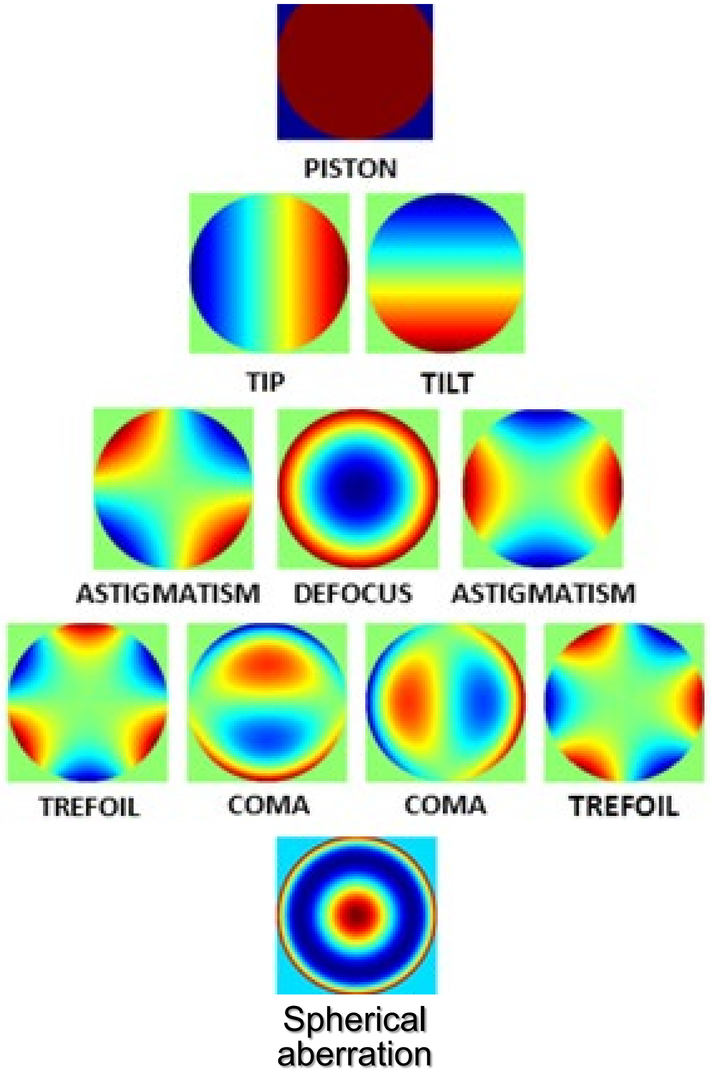


2-D representation

In addition to the 3-D representation of each shape… You need to be able to recognize its 2-D image as well!

3-D representation

Aberrations: *Zernike Polynomials*



2-D representation

0th

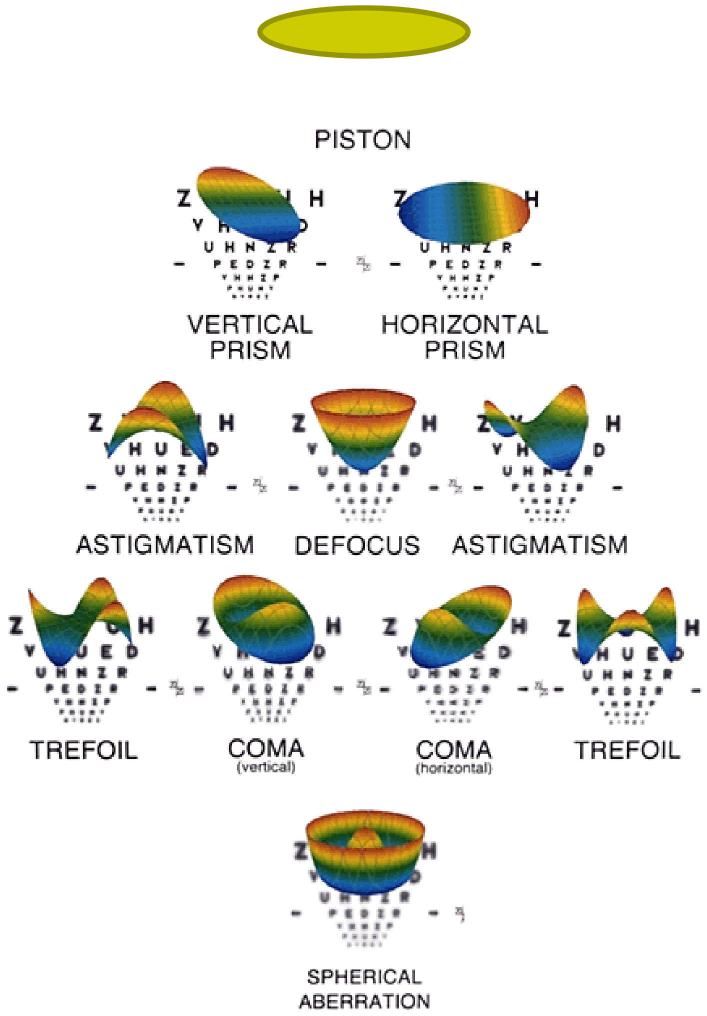
1st

2nd

3rd

4th

And in addition to the 2- and 3-D representation of each shape…



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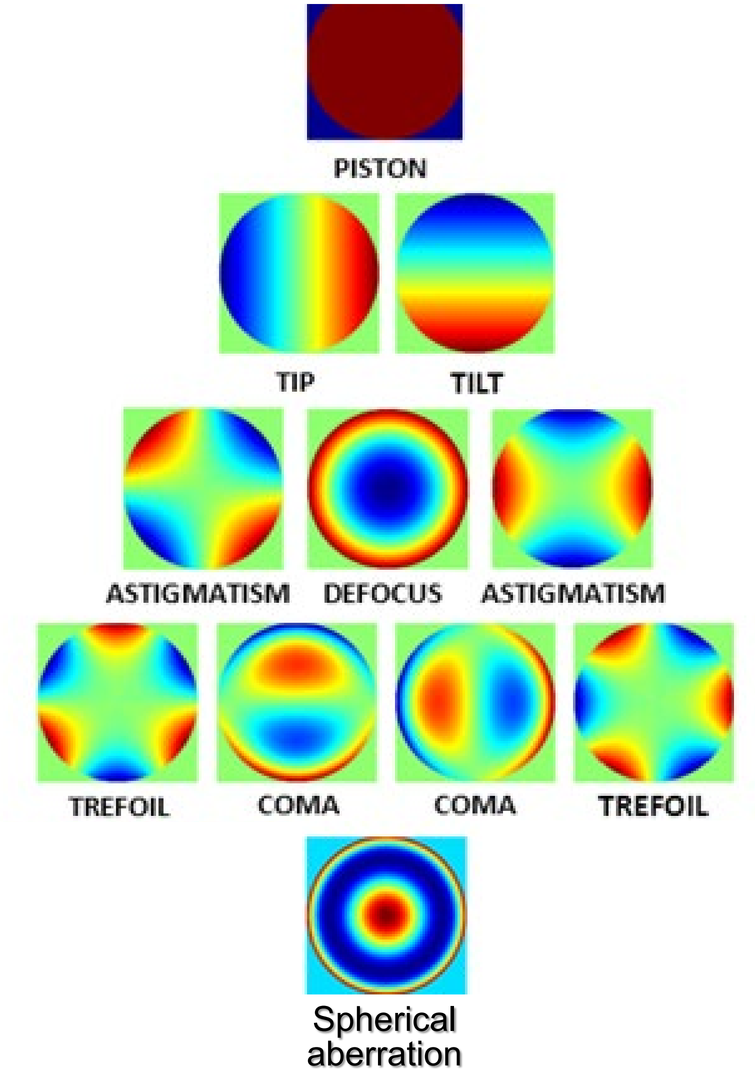
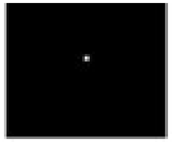
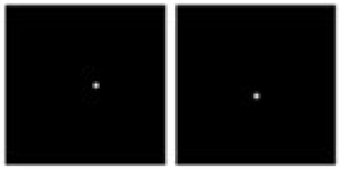


0th

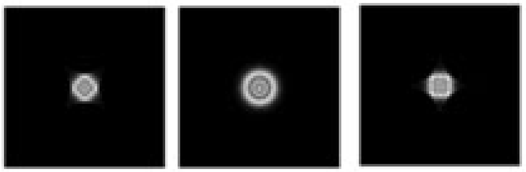


(As mentioned previously, note that *piston*, *tip* and *tilt* do **not** degrade the quality of the image)

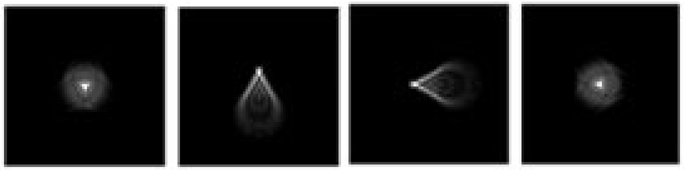
1st



2nd

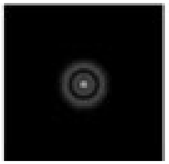


3rd



(Note that *coma* looks like a comet)

4th



2-D representation

And in addition to the 2- and 3-D representation of each shape…
<u>You need to be able to recognize its optical impact on an image-point</u>

Optical effect of each

Aberrations

- two-words *keratorefractive surgery* did away with the second problem

Essentially, *irregular astigmatism* was a wastebasket term for aberrations that:

1) ~~could not be measured in the clinic; and~~
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Aberrations

- *Wavefront-guided keratorefractive surgery* did away with the second problem

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  - Allows surgeons to correct/minimize the higher-order aberrations identified via wavefront analysis

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- *Wavefront-guided keratorefractive surgery* did away with the second problem
  - Allows surgeons to correct/minimize the higher-order aberrations identified via wavefront analysis
  - That said, precisely *which* higher-order aberrations should be corrected (and to what degree) is an unsettled issue at this time

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*How does a wavefront-**guided** ablative procedure differ from a wavefront-**optimized** ablative procedure?*

unsettled issue at this time

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How does a wavefront-optimized ablative procedure differ from a so-called conventional ablative *procedure?*
In a conventional procedure, the ablation is determined solely by a standard phoropter-based refraction obtained by the surgeon during pre-op. That is, the phoropter-based refraction is used to program the correction of sphere and cyl. In a wavefront-optimized ablation, the wavefront analysis is used to program the correction of sphere and cyl.

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In addition to wavefront-guided, wavefront-optimized and conventional approaches to ablation, there is one more. What is it?

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So, there are *four basic techniques* for performing keratoablative refractive surgery

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