Section Notes 4: Feb. 14

- Quick sidenote on waveguides.
- Aberrations:

(First Questions?)

First some defs & physical pictures.

- Types of aberrations:

i) Chromatic

ii) Monochromatic
- Defined by Zernike polynomials
- Typical (prevalent aberrations)
  - Defocus
  - Astigmatism
  - Spherical
  - Coma

iii) Some examples
- effects on Gaussian
- images
- real images (pictures)

Sidenote on problem 4

we get some eff eq of $\frac{du_2}{dz} = iJ\,\Delta u_1(z)$

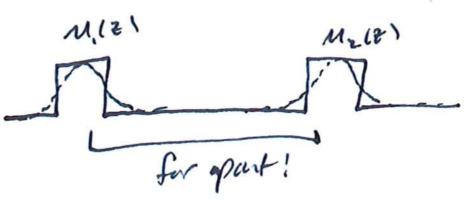
where does this come from??

(section on waveguide coupling in "Photonics" p. 264 incl.)

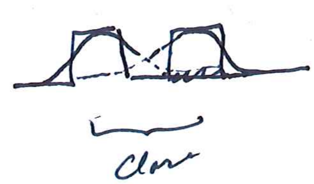
Consider first the simple wave guide

This has a mode satisfying M.E.

Then consider two wave guides ~~close~~ far apart



Bring close together ⇒



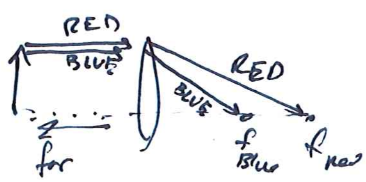
now the form of $u_1(x)$ or $u_2(x)$ no longer satisfies M.E. in a stationary way.

So, what are aberrations?

Remember our imaging condition was that all rays leaving from one point are exactly imaged to another point!
Not always the case in the real world.

Easiest example are chromatic aberrations:

Chromatic



We know that generically $f \sim (\omega)$ so the focal length will shift with the frequency of the light (currently on your h.w.)

Monochromatic Shifts

The things we typically worry about in the lab (and sometimes think of naturally).
There is a rigorous way to discuss this which I will hint at later.

One think to keep in mind is that the "rays" we discussed from last week are not the whole story ~~One way of~~ In class we talked about Gaussian beams and how light can have some phase curvature:

$$A(\vec{r}) = \frac{A_0}{z}\underbrace{e^{\left(-ik\left(\frac{x^2+y^2}{2z}\right)\right)}}$$

this is a way of drawing a "phase front" of the beam, or a plane of constant phase that depends on the functional form of $\sim \phi = k\left(\frac{x^2+y^2}{2z}\right)$

Monochromatic aberrations cont.

There can be other phase factors on this beam that differ from this simple focusing term and in fact when computed ~~for~~ by optical engineers they simply take the rays at different points (r, k) before a lens and propagate them forward and take care to measure the path length / ~~of~~ phase.

The ways of usefully defining these planes of constant phase as a function of (x, y, z) are called the Zernike polynomials.

So aberrations are associated with some surface curvature.

$$\Rightarrow \tilde{A}(\vec{r}) = A(\vec{r})\, e^{i\phi_z} = A(\vec{r})\, e^{i\sum_n B_n Z_n(\rho, \phi)}$$

where ρ is a radius on some circular aperture (also could be diameter of my lens)

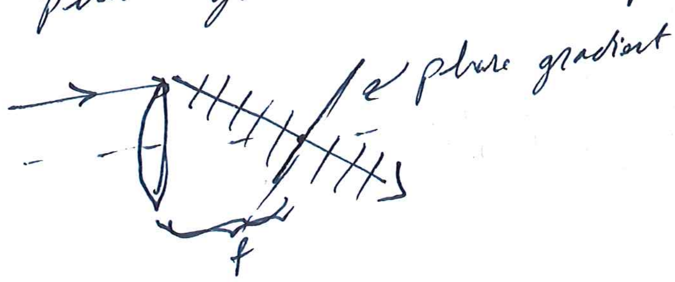
$\ni$ ϕ is azimuthal angle.

Zernike polynomials

- associated w/ common aberration
- orthogonal basis.

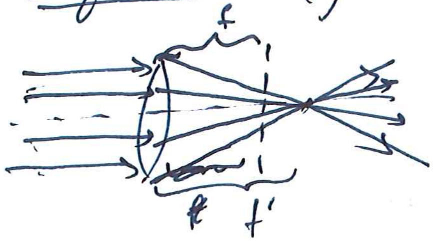
First few are a bit obvious.

- Piston, literally overall phase offset.
- tilt / tip
  phase gradient across plane.



Most common for human eyes

Defocus (just in the wrong place)



focuses in the wrong place!

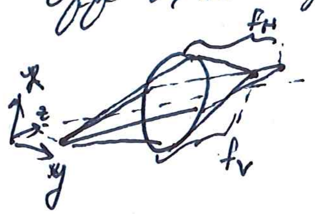
looks like $\sim e^{i 2\pi \rho^2}$

Two common this places comes up?
- Eyeballs!?
- Cameras! "Think of depth of field" focus

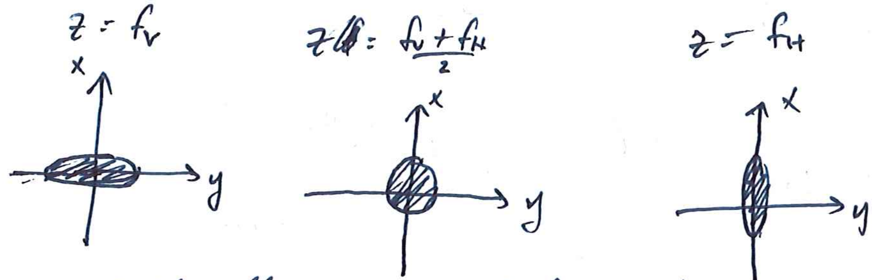
Okay, start of real Aberrations! what is a common aberration for human eyes? (after defocus)

Astigmatism! ~~[illegible]~~

Off axis rays focus in different places!



as a function of z we'd see



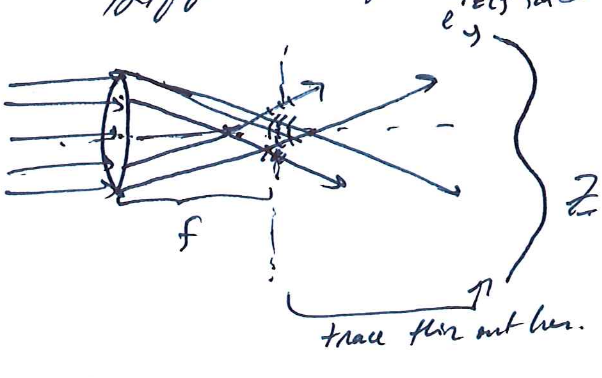
Side note: Zernike polynomials $\sim e^{i 2\pi \rho^2 \sin(2\phi)}$

So why don't people see little ellipses all the time when they have astigmatic eyes??

Because your eye can refocus and tries to "minimize" the error. So sometimes it isn't that your eyes can't focus over the correct range, but have competing focal lengths sometimes.

Spherical

Different heights along the lens focus at different points in z



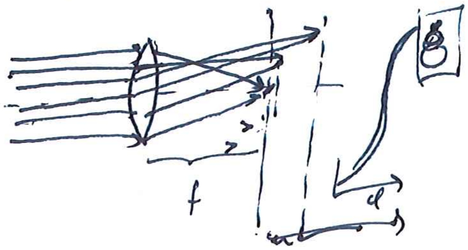
So different heights focus at different points!

Zernike poly:

$Z_{spherical} \sim e^{i 2\pi (6\rho^4 - 6\rho^2 + 1)}$ ...

Coma

Different angles have different foci



gives rise to the "comet tail"

This one isn't so clear for

Zernike $\rightsquigarrow$ $e^{i2\pi(3\rho^3 - 2\rho)}$ and

This is common for telescopes a w/ parabolic mirrors. While on-axis is corrected from spherical aberrations, off-axis rays will not go to the same point. This causes stars to appear as a comet tail.

Show our tool too for aberrations!

I) PSF
- Tilt (Tip)
- Defocus
- Astigmatism.
- Spherical
- Coma.

II) Live Meitner
- Defocus.
- Spherical
- Coma
- Astigmatism
- Tilt.

III) Real world examples.
- Field Curvature
- Snell's Window
- Depth of Focus
- Coma / Telescopes