Chapter 19: Optical Instruments

Section 19.1: The Camera

Lenses and Apertures

- Light enters the camera through the aperture
- Converging lens focuses a real image on a focal plane
- Adjusting the aperture can adjust focus

Old-Timey Film Cameras

- Photographic film is on the focal plane
- Photo film is a substrate coated with gelatin embedded with light-sensitive chemical (silver halide)
- Expose the film, and then develop it (another series of photo-sensitive chemicals)

Modern-Day Digital Cameras

- CCD = charge-coupled device
- Pixels = energy sensors, records the intensity of the incoming light
- Color comes from RGB filters
- Greater pixel density, greater resolution of the image

Section 19.2: The Human Eye

Eye Am A Camera

- Same basic mechanism: aperture, lens, screen
- Pupil: Adjustable aperture that reacts automatically to light levels
- Crystalline Lens: Converging lens automatically changes focal length
- Retina: Screen covered with pixel-like sensors (rods & cones) that react to color and intensity

Focusing and Accommodation

- Relaxed eye $f \approx 17\text{–}20\text{mm}$ (everybody's a little different)
- Think about the lens equation: $\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$
- You change s all the time! Look across the room (far); now look at your screen (close)
- Object distance changes, but image distance s' = lens to retina = constant
- And yet your eyes work…how is that possible?!?!
- The lens in your eye changes shape to change its focal length

Near Point/Far Point (Let's Assume You Don't Need Corrective Lenses)

- Near point = closest thing you can focus on with your relaxed eye (about 25cm or so)
- Far point = farthest thing you can focus on (this should be about infinity!)

Presbyopia: Probably Not Your Problem (Yet)

- As you get older, your lens loses some flexibility and the supporting muscles weaken
- You will start to lose the ability to focus on close objects
- This is why your mom has a pair of reading glasses in every room of the house

Myopia: Near-Sightedness

- If you wear corrective lenses, you are probably near-sighted
- Distant objects are blurry, objects must be brought close to focus
- Typically results when your eyeball is slightly elongated and image focuses in front of the retina

Hyperopia: Far-Sightedness

- This is much less common, but sometimes occurs in very small children
- Near objects are blurry, farther objects are clear
- Typically results when your eyeball is slightly squashed and image focuses behind the retina

Corrective Lenses

- Lens power $P=\frac{1}{f}$ (units = $1/\text{m} = \text{D}$ = diopters)
- Use a diverging (negative) corrective lens to 'push' the image back onto the retina
- Use a converging (positive) corrective lens to 'pull' the image forward onto the retina

Astigmatism: Aspherical Cornea

- Your cornea should be spherical
- Astigmatism = barrel-shaped cornea (more curvature one way than the other)
- Most people have some degree of astigmatism (most corneas aren't perfectly spherical)

Section 19.3: The Magnifier

Angular Size and Apparent Size

- How far affects how tall an object appears (duh, right?)
- A small object up close looks as large as a large object far away (duh, right?)
- Angular size θ is basically (actual height)/(actual distance)

Angular Magnification

- We already know that M = ratio of heights or ratio of distances: $M = -\frac{s\prime}{s} = \frac{h\prime}{h}$
- Angularly: $M = -\frac{\theta\prime}{\theta}$

Designing a Magnifying Glass

- Start by viewing an object with no magnifier: $\theta_o = \frac{h}{s_o} = \frac{h}{25\text{cm}}$, this is about as close as you can typically get
- Add a magnifying glass: $\theta = \frac{h}{s} = \frac{h}{f}$ (because you typically place object just inside focal point for max magnification)
- $M = -\frac{\theta}{\theta_o} = \frac{25\text{cm}}{f}$

Section 19.4: The Microscope

Compound Magnifier

- Microscopes magnify twice by using two lenses
- Converging objective lens forms first image: real, inverted, magnified
- Converging eyepiece forms an image of the image: virtual, upright, magnified

How Much Magnification?

- Objective: place the object at s just a little bit larger than f_o
- Creates a real image with $M_o = -\frac{s'}{s} = -\frac{L}{f_o}$
- Eyepiece: objective image is located just inside f_e: $s_e = f$
- Eyepiece is a magnifier: $M_e = \frac{25\text{cm}}{f}$
- Total magnification: $M = Mo \times Me = -(\frac{L}{f_o})(\frac{25\text{cm}}{f})$

Section 19.5: The Telescope

Refracting Telescope

- Invented (sort of) by Galileo in about 1609
- Uses two converging lenses, but different than a microscope
- Objects are effectively at infinity compared the focal length of objective lens

How Much Magnification?

- This isn't exactly the right question to ask
- The goal is to maximize the field of view
- Use angular magnification

Reflecting Telescope

- Invented by Newton in about 1668
- Uses a primary (objective) mirror and a secondary (eyepiece) lens
- Primary mirror is concave (converging!)
- Eyepiece is converging (just like other instruments)

Many Advantages of Reflectors

- Lenses are hard: Difficult to make large lenses of high enough quality
- Mirrors are easy: You only have to make one side perfect and shiny
- Mirrors diminish chromatic and spherical aberrations

Section 19.6: Color and Dispersion

Color is Wavelength

- Or, color is frequency; either way
- Long wavelength = red
- Mid-range wavelength = green
- Short wavelength = blue (violet)
- Just like every ear is unique and perceives sound slightly differently, same with eyes

White Light Is Every Color

- Newton was the first to suggest that white light was the presence of all colors (as opposed to the absence of color)
- You have probably seen how white light can be separated into colors (rainbows!)

Dispersion

- How does a prism separate light? Refraction!
- Different frequencies of light have slightly different indices of refraction
- High frequency light (short λ blue-violet) has a higher n, slower speed, bent more
- Lower frequency (longer λ red) has lower n, faster speed, bent less

Rainbows: Refraction, Total Internal Reflection, Refraction

- Formed by the refraction process we already understand
- Every time the light refracts through a medium, the dispersion is increased
- The trick is getting the geometry of the problem exactly right

The Color You See

- Why is a blue shirt blue? White light strikes, blue light reflects
- The color you see is the reflected light; the other colors get absorbed
- White shirt: reflects all colors, absorbs none
- Black shirt: absorbs all colors, reflects none

Section 19.7: Resolution of Optical Instruments

Lens Aberrations

- Spherical aberration: light does not focus exactly at the focal point, you get a schmear of light instead of a pinpoint
- It's the rays near the edge that are the problem; fix this with an aperture to block off the edge rays
- Chromatic aberration: dispersion! Red light will always have a slightly longer focal length than the blue
- Use a second lens to reverse the aberration (careful; you don't want to undo what the first lens is meant to do)

Diffraction-Limited Resolution

- Even if you fix the aberrations, you still have a problem
- Circular aperture diffraction (I know, we skipped this in Chapter 17)
- Long story short: resolution is limited by the size of the aperture
- This is why you want enormous telescopes

Applies to Your Eyes, Too

- Your pupil is an aperture
- Your eye balances out the pros and cons: large pupil means better angular resolution, but worse aberration
- Conveniently, the cones on your retina are perfectly spaced to maximize resolution; thanks, evolution!

And Microscopes…

- A resolving power RP about 0.5λ means that you can discern details that are half the wavelength you are using
- Trying to magnify more doesn't work!