Design and Prototyping of Optical Systems for Engineering Applications
Experiment 3

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Meeting Agenda

- Experiment 2 Results, Questions, Comments
- Cleaning Optics
- Experiment 3: Spectroscopy

Experiment 2

- Your Comments
- Magnification
- Making a Real Image
- Stray Light Issues

Cleaning Optics

- Read as part of Prelab

  https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=9025 on cleaning optics.
- Try to keep optics clean; Cleaning may cause some damage.
- In particular, cleaning can easily damage coatings.
- Uncoated glass is forgiving if hard materials (*eg.* sand) are avoided.
- We will experiment with spares from my junk drawer.
- Never try to clean a grating, camera, *etc.*
- Be careful of cemented optics; you may dissolve the cement.
- When in doubt, ask vendor.
- Sometimes vendor can re–coat optics.

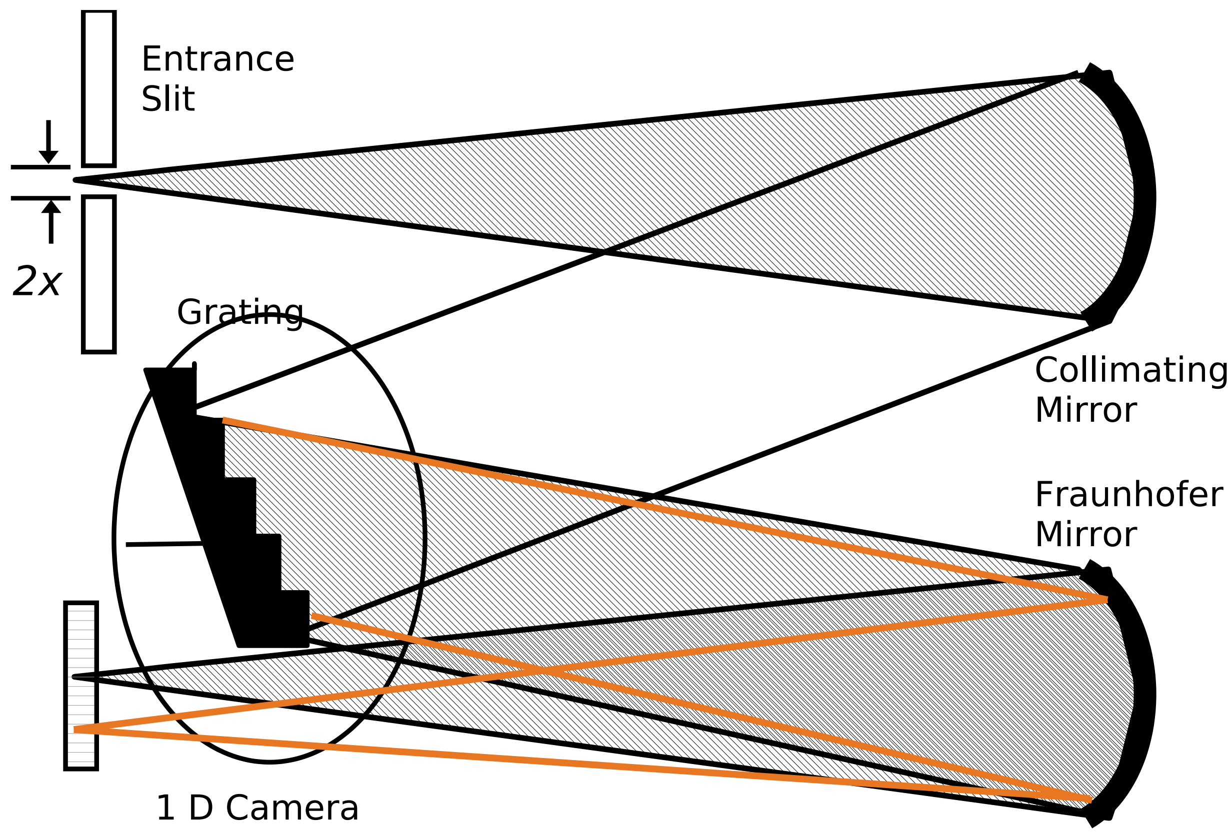
Spectroscopy

- Part 1: Spectrometry
  - Download Software: Thorlabs CCS200 Spectrometer
  - Transmission Measurement (ofe2-15-17 to 22)
  - Diffuse Reflectance Measurement
  - Rough Calibration of Spectrometer
  - Light Source Measurement
- Part 2: Fluorescence Imaging

Learning Objectives 3

- Spectroscopy: Transmission, Reflection, Diffuse and Specular
- Colors and Wavelengths
- Compact Spectrometer Operation
  - Principles, Resolution
  - Calibration: White and Dark Measurements
  - Absolute Calibration Issues
- Fluorescence Imaging

Spectrometer



Pixel Number is a function of Wavelength

Test Object: Interference Filter

- Examples: Band–Pass, Band–Stop, Long–Pass, Short–Pass, Cold Mirror, Hot Mirror

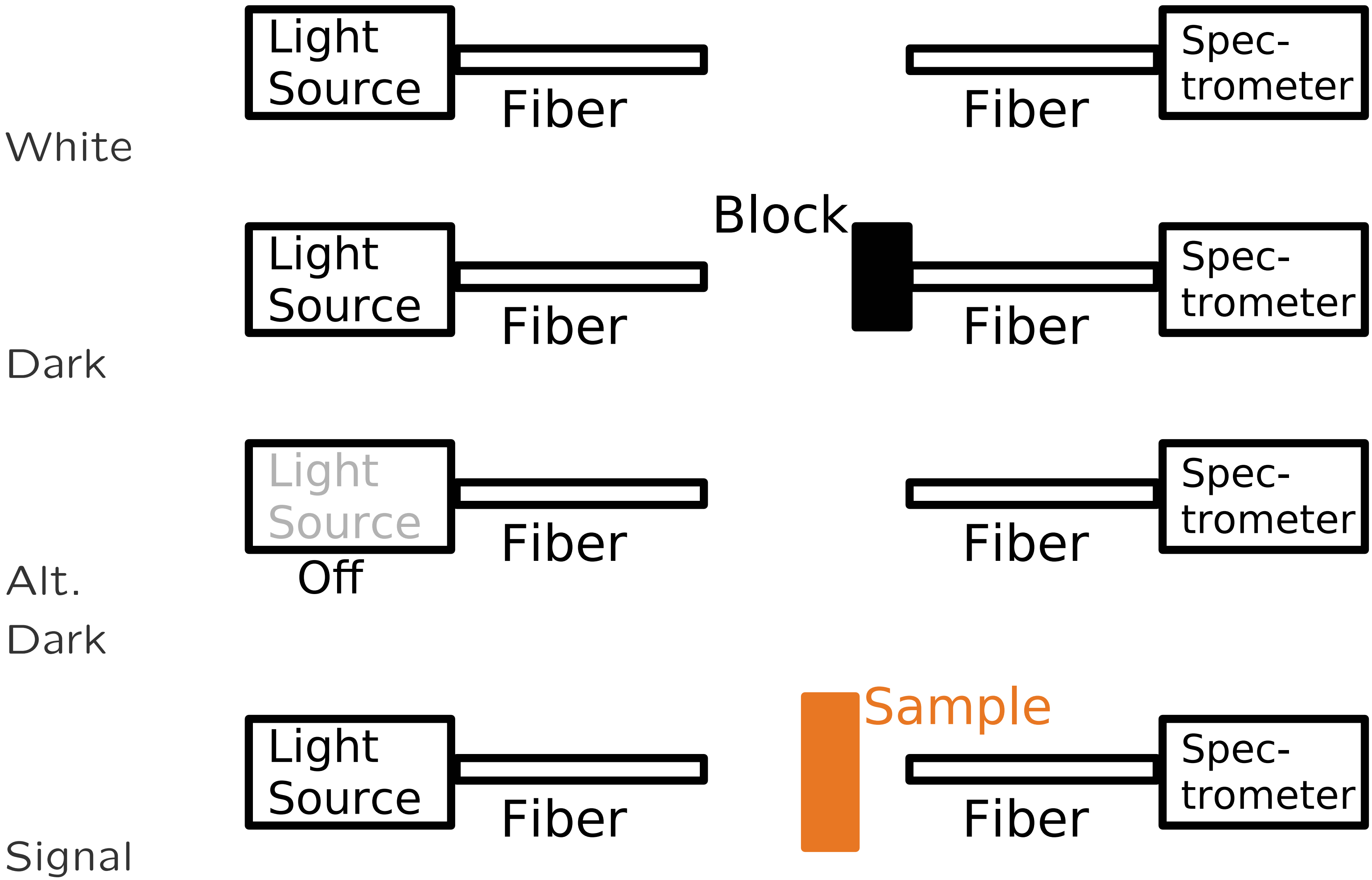
- May Depend on Angle and Polarization

- Compare Colored Glass or Plastic

- Conservation Law in Steady State

$$T + R + A + S = 1$$

Transmission Measurement

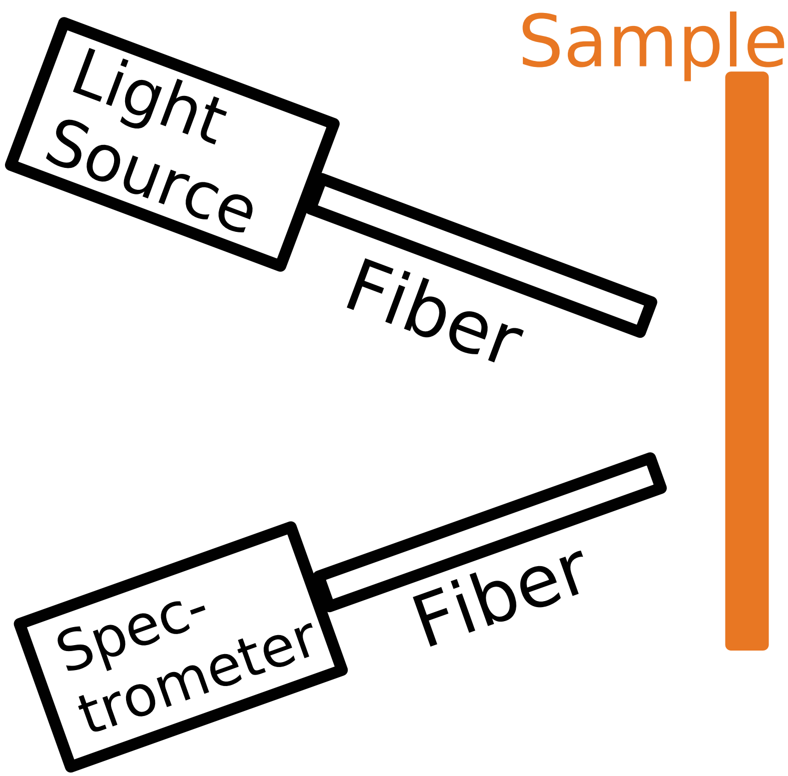


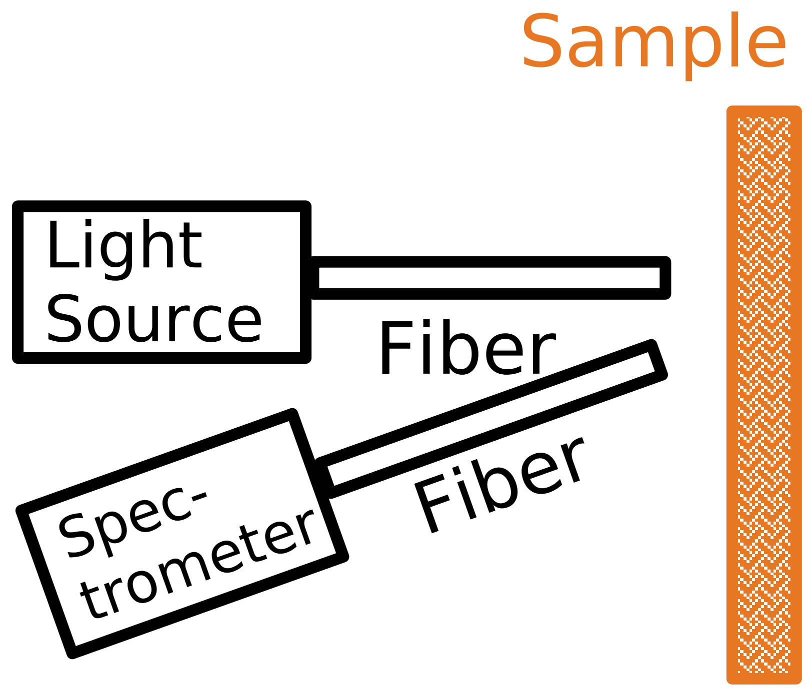
Spectral Transmission

- White Light Source; $W_\lambda(\lambda)$
  - Typical Units, W/m^2/sr/nm
  - Calibrated Sources Exist
- Signal $S_\lambda(\lambda)$
- Transmission

$$T(\lambda) = \frac{S_\lambda(\lambda) - D(\lambda)}{W_\lambda(\lambda) - D(\lambda)}$$

Reflection





Specular Reflection:
Match Angles
Use Mirror for “White”

Diffuse Reflection:
Possibly Angle–Dependent
Use Diffuse White Standard

Spectral Reflection

- Similar to Transmission, but Harder
- Allows Calculation of Absorption and Scatter

$$T + R + A + S = 1$$

- Note: Put reflective side toward source

Always prefer high R instead of high T if possible.
These are Good General Rules for Beamsplitters

Diffuse Spectral Reflection

- Calibration: Spectralon from my Lab (assume 100%) $W_\lambda(\lambda)$
- Signal: $S_\lambda(\lambda)$
- Reflectance

$$R(\lambda) = \frac{S_\lambda(\lambda) - D(\lambda)}{W_\lambda(\lambda) - D(\lambda)}$$

- Specular Reflection Spectrum is often Gray
- Interference filters are one exception

Light Source

- Point the Spectrometer Fiber Directly at the Source.

- Need for Calibration: $\eta(\lambda)$ varies (often a lot) because of material properties, interference, *etc*.

$$N_{electrons} = \frac{P_\lambda(\lambda)t\ \delta\lambda}{hc/\lambda}\eta(\lambda)$$

- Rough Calibration with Tungsten Lamp, $P_\lambda(\lambda)$. Thorlabs OSL2, without fiber (Why?)

$$F_{cal}(\lambda) = \frac{P_{w\lambda}(\lambda)}{W_\lambda(\lambda) - D(\lambda)}$$

- Unknown Source

$$P_{s\lambda}(\lambda) = \frac{S_\lambda(\lambda) - D(\lambda)}{W_\lambda(\lambda) - D(\lambda)}P_{w\lambda}(\lambda) = F_{cal}(\lambda)\left[S_\lambda(\lambda) - D(\lambda)\right]$$

Spectral Measurement

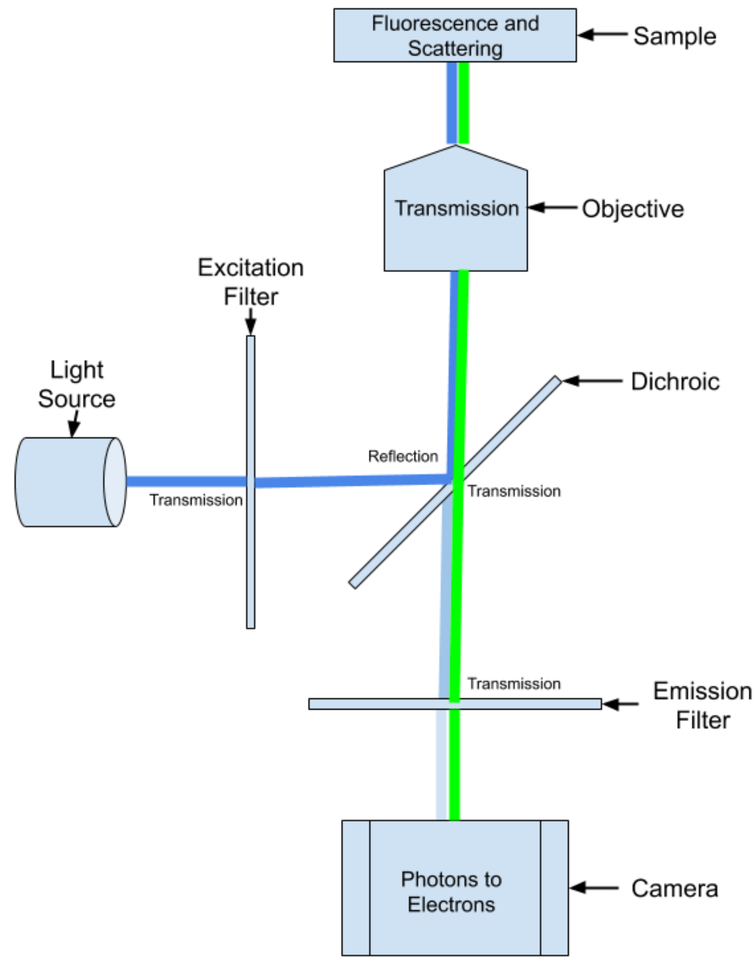
- Ceiling Lights
- White LED if you have one (in your phone?)
- 370nm LED (See next slide for caution)
- Computer Screen (White, Red, Green, Blue)

UV Light–Emitting Diode

- Use the correct LED Mount (See note on Right Cabinet)
- Always Be Careful of UV Light
  - Eye Hazard at Close Distance (*e.g.* 1mW/cm^2)
  - More Hazards for Mercury Lamps (not used here)
    - Greater Eye Hazard
    - Skin Hazard
    - Explosion Hazard
    - Mercury Exposure if Broken

Fluorescence

- Appropriate Light Source
  - Radiance
  - Wavelength
- Dichroic Beamsplitter
  - Reflect Short
  - Transmit Long
- Excitation Filter
  - Select Line?
  - Reject Unwanted λ
- Emission Filter
  - Block Excitation
  - Block Other Fluorescence
- Camera



Anuj Gajjar, Northeastern Univ.

Prelab 3

Download software and light–source data

Think about absorbing gelatin filters and interference filters. How do you expect the transmission spectra to differ?

Interference filters often have a very wide dynamic range to block unwanted wavelengths.Find a way to measure transmission spectra over a wide range of magnitudes

What difference do you expect between specular and diffuse reflection from an object?

Look up the spectra of hemoglobin and oxyhemoglobin. What impact do these materials have on skin color?

Prepare an image that has red, green, blue, and white quadrants.

Think about safe use of the ultraviolet LED.

Read https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=9025 on cleaning lenses

Experiment 3

Set up the white light source and spectrometer for convenient use.

Practice cleaning optics on components from the "junk drawer"

Measure transmission spectra of some filters, your glasses, my glasses (blue blockers), lenses, two Polaroid sheets parallel and crossed, *etc*.

Measure specular reflectance on some of the components and compute the extinction $(A + S)$. This may be interesting for the interference filters and blue blockers among others.

Measure the diffuse reflectance spectra of some materials; Plastic, clothing, your finger, *etc*. See if you can see a specular reflection and measure it.

Collect a spectrum of the white light source (without the fiber. Why?)

Measure the spectra of the room lights, white LED, UV LED, laser, and the colors on your computer screen *etc*. [1pc] Observe flourescence of white paper, various markers, skin, maybe minerals, *etc*.

Reflections 3

How well do your spectral measurements agree with your visual observations?

What type of lights do you think are used to light the room? Why do you think this?

Were you able to see the hemoglobin spectrum in skin?

What problems would you expect in measuring the (specular) reflection spectrum of a dichroic filter? How well did you do?

Why might it be a bad idea to use paper as a calibration standard for diffuse reflectance?

In measuring the spectrum of a light source discuss the issues of knowing or being able to perform an absolute *vs.* relative calibration with a reference source.

Broadband Power Transmission

- Broadband source through a broadband filter

$$P_{in} = \int P_\lambda(\lambda)\, d\lambda$$

$$P_{out} = \int T(\lambda)\, P_\lambda(\lambda)\, d\lambda$$

- Broadband Transmission depends on both spectra

$$T = \frac{\int T(\lambda)\, P_\lambda(\lambda)\, d\lambda}{\int P_\lambda(\lambda)\, d\lambda}$$

- Power Meters
  - Photon Detectors: Response depends on λ
  - Thermal Detectors: More uniform across λ