Physics 228  Spring 2018  
Analytical Physics IIB  
Optics and Modern Physics  

Course Website:  
www.physics.rutgers.edu/ugrad/228

What do you need:  

• iClicker for lecture participation  
• Textbook: Young & Freedman University Physics  
  14th ed., Vols. 2&3  
• Mastering Physics access code for online homework  
• Mastering Physics course ID: montalvo97075  
Pencils, calculator, brains, ...
Lecture 1 (Y&F Chapter 33)

Let’s explore optics!

- The nature of light
- Reflection
- Refraction: Snell's law

We start with some “magic” - we will make some things disappear!
Beaker in Liquid Demo

Where did the beaker go? Iclicker!

a) The liquid dissolved it.
b) The liquid hid it - you can't see through the liquid.
c) You cannot see glass in any liquid.
d) Light goes through the liquid and the beaker the same way.
e) It's a trick - Professor “palmed” the beaker when pouring the liquid.

Oil and glass have similar index of refraction.
What is light?

“Something” moves in straight lines (mostly), maybe bounces from mirrors and other objects, and allows us to see objects.

Is the “something” a particle or a wave?

For centuries this was a mystery. In some ways light resembles particles, but in other ways light resembles waves.
In the 1600s, Newton concluded light was particles.

- Optical interference effects had been observed, but were not understood.

- Prisms separate light into colors, like different energy particles.

Light = Particles?

Interferene of waves from two point sources
Light = Waves?

But in the 1800s...

- Optical interference was explained in terms of wave superposition
- Maxwell's equations give rise to traveling wave solutions: oscillating charges produce electromagnetic waves!

Diffraction pattern at the edge of a shadow of a razor blade.

Interference from ridges on CD separates colors

Interference in soap bubble separates colors
In 1905, Einstein explained the photoelectric effect - only photons of high enough frequency will eject an electron from a surface - with particles of light, now called “photons”.

This is an early success of quantum mechanics.

We now know that both light and matter have behaviors that correspond to particles and waves.
How to Generate Light

Hot objects emit light.

Oscillating charges or currents generate electromagnetic waves: microwaves, cell phone signals, radar. This is nothing but “light” at extremely low frequencies.

Lasers and light emitting diodes (LEDs) use a quantum mechanical effect: electrons moving between energy levels emit photons.
Waves

Water waves:

Sound waves:

Longitudinal

Transverse
Waves Basics

Period: $T$
Frequency: $f = \frac{1}{T}$

Propagation speed: $v$

Speed of light in vacuum: $c = 299,792,458$ m/s

In transparent media: $v = \frac{c}{n}$ (n is refractive index)

Wavelength: $\lambda$

Speed: $v = \frac{\text{distance}}{\text{time}} = \frac{\lambda}{T} = \lambda f$

Speed in vacuum: $c = \frac{\lambda_0}{T}$

thus: $\lambda = \frac{\lambda_0}{n}$

Engrave these equations into your brain (not on formula sheet)!
How Does Light Propagate in a Uniform Medium?

In straight lines, outward from a source.

What happens when the medium changes?

Reflection, refraction.

If surfaces are “smooth”, there is specular reflection: \( \theta_{\text{reflected}} = \theta_{\text{incident}} \).

But if surfaces are rough, there is diffuse reflection, also called scattering: The light bounces off in all directions.

(The angles are defined relative to the surface normal)
Refraction

**SNELL'S LAW**

\[ n_1 \sin \theta_1 = n_2 \sin \theta_2 \]

\[ \frac{\sin \theta_1}{\sin \theta_2} = n \]

The medium with larger index has the smaller angle - the ray is closer to the normal.
Derivation of Snell's Law

\[ \frac{n_1}{n_2} = \frac{\lambda_2}{\lambda_1} = \frac{d \sin(\theta_2)}{d \sin(\theta_1)} \]

\[ n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \]
Law of reflection

Apply Snell’s law to the incident and reflected waves:

\[ n_1 \sin(\theta_1) = n_2 \sin(\theta_2) \]

In reflection \( n_1 = n_2 \), thus \( \theta_1 = \theta_2 \).
Due to refraction, objects get distorted, or are not where they appear to be...
Due to refraction, objects get distorted, or are not where they appear to be...
Light passes from air (n = 1) into glass (n = 1.5). Which of the following is true?

a) $\lambda_{\text{air}} > \lambda_{\text{glass}}$, $f_{\text{air}} < f_{\text{glass}}$

b) $\lambda_{\text{air}} > \lambda_{\text{glass}}$, $f_{\text{air}} > f_{\text{glass}}$

**c) $\lambda_{\text{air}} > \lambda_{\text{glass}}$, $f_{\text{air}} = f_{\text{glass}}$**

d) $\lambda_{\text{air}} < \lambda_{\text{glass}}$, $f_{\text{air}} > f_{\text{glass}}$

e) $\lambda_{\text{air}} < \lambda_{\text{glass}}$, $f_{\text{air}} < f_{\text{glass}}$