Reflection
   Principle of Least time
   Plane mirror—virtual images
   Concave mirror
       Ray tracing, focal point

Refraction
   Principle of Least Time
   Snell’s law \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \)
   Examples: swimming pool, plate glass
   Total Internal Reflection
   Refraction at curved surface, focal point

Lenses
   Thin Lens properties: focal length, diameter
   Ray tracing—“easy” or principal rays
       Parallel to axis, through lens center, through focal point.
   The lens equation \( 1/p + 1/q = 1/f \)
   Size and location of images; real and virtual
   Brightness of images—effect of lens diameter, image area
   Multiple lenses:
       Effect of the eye lens
       Magnifier
       Telescope
       Microscope

Dispersion (n depends on wavelength)
   Prisms
   Rainbows

Photon Model of Light. \( E = hf = hc/\lambda \).
   The total energy is the energy per photon times number of photons.
   Photons also carry momentum, \( E = pc \).

Particles have a wave nature. momentum is related to wavelength. \( p=h/\lambda \).
   For non-relativistic particles \( E = p^2/2m \) or \( p = \sqrt{2mE} \)
   Calculate wavelength of 50 eV electron.
Energy momentum relationship from relativity.
\[ E^2 = p^2c^2 + m^2c^4 \]

Two special cases: if mass is zero (photon) then \( E=pc \).
For “slow” particles (speed \( \ll c \)) Do Taylor series expansion:
Find \( E = mc^2 + p^2/2m \) where the first term is the rest energy
and the second term is non-relativistic KE.

Diffraction and interference for particles.
Using the particle wavelength the diffraction and interference phenomena resemble
those for light--- however if we count particles then in the description of the
diffraction (or interference pattern) what was \textbf{Intensity} for
the case of light becomes \textbf{probability} for detecting a particle.

Diffraction leads to the Uncertainty relationship between position and momentum.
\[ \Delta y \Delta p_y \sim \hbar \]  where \( \Delta y \) is the slit width and \( \Delta p_y \) is spread of sideways momentum
(related to angular spread of diffraction pattern)

Evidence for the photon model for light. The Photoelectric effect.
\[ E_{\text{photon}} = \text{work function} + KE_{\text{max}} \]

Polarization of light in the Photon model.

The Feynman thought-experiment-- Can we observe particle and wave aspects
simultaneously?