Reading: Volume 1, chapters 26 and 27, of Feynman Lectures (see link on class website). Giancoli chapters 32 and 33.

- Last time: can use Fermat’s principle to get Snell’s law of refraction: \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \). Lifeguard analogy example: path of minimum time determined by \( v_{s\text{and}}^{-1} \sin \theta_1 = v_{\text{water}}^{-1} \sin \theta_2 \).

- Another way to get Snell’s law: light carries momentum proportional to \( \vec{k} \) (can be seen either classically, from momentum conservation, or quantum mechanically). Let the interface between \( n_1 \) and \( n_2 \) be \( y = 0 \), and the incoming light has \( \vec{k}_1 = k_1(\sin \theta_1, -\cos \theta_1, 0) \) and the refracted light have \( \vec{k}_2 = k_2(\sin \theta_2, -\cos \theta_2, 0) \). As we discussed last time, \( \lambda = \lambda_{\text{vac}}/n \), so \( k_1 = k_{\text{vac}} n_1 \) and \( k_2 = k_{\text{vac}} n_2 \). Snell’s law is then equivalent to \( k_{1,x} = k_{2,x} \), i.e. the \( x \)-component of momentum is conserved. This makes sense, since momentum conservation is related to translation symmetry (you’ll learn more about that in upper division physics, and the interface at \( y = 0 \) preserves \( x \)-translation symmetry.

- Total internal reflection. Basis of fiber optics, global communication network.

- Chromatic dispersion: smaller \( \lambda \) has bigger \( n \), so different colors of white light get refracted at different angles. Why we see rainbows in Nature, or using prisms.

- Spherical refracting surface. Let object be distance \( d_0 \) from interface between index \( n_1 \) and \( n_2 \), where the interface has radius \( R \). The image location \( d_i \) is determined, as before, from the condition that all rays take the same time (understand from Fermat), with \( ct = n_1 L_1 + n_2 L_2 \). Use same argument as in mirror to find \( L_1 \) and \( L_2 \)

\[
L_1 \approx d_o + \delta + y^2/2d_0, \quad L_2 \approx d_0 - \delta + y^2/2d_i, \quad \delta \approx y^2/2R,
\]

The condition that \( t \) is independent of \( y \) then determines

\[
\frac{n_1}{d_o} + \frac{n_2}{d_i} = \frac{n_2 - n_1}{R}.
\]