Sound

Sound wave: Departure of the pressure from the equilibrium pressure: $\Delta P = -B\,\partial D/\partial x$. All other general properties of the wave holds for sound wave ($v = \lambda f$, interference, etc).

Beats: Arise from $\sin(\omega_1 t + \phi_1) + \sin(\omega_2 t + \phi_2) = 2\sin(\omega_a t + \phi_a)\cos(\omega_d t + \phi_d)$, where $\omega_a = (\omega_1 + \omega_2)/2$, $\omega_d = (\omega_1 - \omega_2)/2$, $\phi_a = (\phi_1 + \phi_2)/2$, $\phi_d = (\phi_1 - \phi_2)/2$. If $\omega_1 \approx \omega_2$, then this superposed wave has an "envelope" function, $\cos(\omega_d t + \phi_d)$, which varies slowly in time. This causes the sound intensity oscillate slowly in time with angular frequency $= 2|\omega_d| = |\omega_1 - \omega_2|$. This is the beat angular frequency.

Decibel: logarithmic intensity scale (dB), $\beta \equiv 10\log_{10}\frac{I}{I_0}$, where $I_0 = 10^{-12}$ W/m^2.

Standing waves: For a guitar string of length l, or for an open tube, we get $n\lambda_n = 2l$. For a half open tube, $(2n-1)\lambda_n = 4l$, where $n = 1, 2, 3, \ldots$. At an open end of tube, pressure ΔP has a node. At a closed end of tube, displacement D has a node.

Doppler effect: $f' = \frac{v \pm v_o}{v \pm v_s} f$, where v_o is the speed of the observer of sound, and v_s is the speed of the source. Sign chosen based on physics.

Ray model of light

Law of reflection: $\theta_r = \theta_i$ (specular reflection), for a smooth surface. Origin of all mirror equations.

Index of refraction: $n \geq 1$. $v = c/n$. $\lambda_m = \lambda_v/n$. λ_m is the wave length inside the medium with refractive index n. λ_v is the wavelength in vacuum. λ_v is what is usually used to refer to different part of light spectrum. If n depends on wave length, then we got a **dispersion** (rainbow, prism, optical communication).

Law of refraction: $n_1 \sin\theta_1 = n_2 \sin\theta_2$ (Snell's law) – the basis of total internal reflection, apparent height (reduced by n if observed from air), dispersed light from prism (red bends the least), rainbow scattering, and all lens equations.

The frequency of light (or more generally any wave) does not change upon reflection or refraction (or diffraction, as we will learn later).

Total internal reflection: if $\theta_1 \geq \theta_c = \sin^{-1}\frac{n_2}{n_1}$.

Spherical/plane mirrors $f = r/2$, where r is the radius of curvature. Sign convention: $r < 0$ for convex mirror, and $r > 0$ for concave mirror.

Lensmaker's equation $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$, where R_1 and R_2 are the radii of curvature for the two sides of the lens. Sign convention: $R_1, R_2 > 0$ for convex surface, < 0 for concave surface. Focal point is left-right symmetric.

Dipoter: The unit (D) for the power of a lens: $P \equiv 1/f$ (in SI unit, including sign!).

Master equation for a mirror or a lens: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$. Sign conventions: d and

f are positive if on the "right side" (= real) and negative if on the "wrong side" (= virtual). Or, $d_o > 0$ (< 0) if the input beam diverges (converges) on the optical element, and $d_i, f > 0$ (< 0) if the image beam is convergent (divergent) from the element. The zero point for d and f values is the position of the optical element!

Multiple optical elements: Treat one at at time! The image of one element becomes the object of the next element. Real or virtual character can change when applying this "chain rule." Lecture note 13,14 is a must-read!

Ray tracing: Horizontal ray converges to, or diverges from, the focal point. Ray passing through, or emanating from, the focal point becomes horizontal. Ray going through the zero of the optical element either bounces back symmetrically (mirror) or follows an unbent straight line (lens).

Lateral magnification: $m \equiv h_i/h_o$. For a single optical element, this is equal to $-d_i/d_o$. Also, only for a single optical element, a real image is inverted, while a virtual image is upright.

Angular magnification, Magnifying power: $M \equiv \theta'/\theta$, where θ' is the angle of the beam at the zero position of the last optical element of an optical device, and θ is the angle of the beam at the zero position of the eye lens when the object is viewed with bare eye. Measure of resolving power. $M = N/f$ for a simple magnifying lens with relaxed eye. $N \equiv 25$ cm (normal near point). $M = 1 + N/f$ with strained eye to see an object at N. For a simple refracting telescope, $M = -f_o/f_e$, where f_o is the focal length of the objective, and f_e is the focal length of the eyepiece.

Wave nature of light

Young's double slit experiment: Much like a two speaker interference experiment. $d \sin\theta = m\lambda$, where $m = 0, \pm1, \pm2, ...$ for constructive interference, and $d \sin\theta = (m + 1/2)\lambda$ for destructive interference.

Thin film interference: Keep in mind that a π phase shift is equivalent to an *effective* $\lambda_n/2$ path length difference, where λ_n is the wave length inside thin film. Consider two light paths. (1) Direct reflection off the top of thin film. (2) Transmission to the inside of thin film, reflection off the far inner wall of thin film, and then transmission back to the original medium. These physical paths are different by $2d$, where d is the thickness of the thin film, assuming normal incidence. This is *not* the total path length difference to consider! Must subtract $\lambda_n/2$ from it to get the total path length difference, if only one of the two reflections in (1) and (2) has a π phase shift. No such subtraction necessary, if both or none of the two reflections involve a π phase shift. If the resultant *total* path length difference (physical minus effective) is $m\lambda_n$, then the reflection is constructive (so strong reflection). If the resultant total path length difference is $(m + \frac{1}{2})\lambda_n$, then the reflection is destructive. $m = 0, \pm1, \pm2, ...$ (but make sure $d \geq 0$).