WAVES Notes — 10/10/01, Week 6 at the Fleet

Classifications -- What kinds of waves do you know about?

Standing

-Shake a string at the right frequency.
-Resonant cavities such as:
1) pipes for sound (check out the Sikus on the Floor)
2) lasers for light
3) Bose-Einstein Condensates for matter!

Traveling

-Transverse (EM, pulse on a string)
-Longitudinal (slinky, sound)
-Combo (my favorite, ocean waves)

How are EM waves excited?

Recall the generator effect — a changing magnetic field produces a current in a wire. Well, what if there is no wire? There are still electric fields due to a changing magnetic field. So how do you get a changing magnetic field, other than by moving a magnet around? A charge with constant velocity is like a tiny current which creates a magnetic field. So to get a changing magnetic field, change the velocity of the charge — i.e., a charge which is accelerated generates a changing magnetic field! This changing magnetic field then creates a changing electric field, and the process continues. Maxwell s equations describe this beauty mathematically.

So by accelerating a charge, you can create a self-propagating electromagnetic wave. It s self-propagating due to the generator/motor effects, only this time in free space.

Structure of EM radiation

The E and B fields oscillate in planes which are perpendicular to each other. This is happening all around you as we are bathed in EM radiation (visible and otherwise).

Geometrical Optics

Applies to large (much larger than the wavelength) and smooth apertures/surfaces. Introduce rays and wavefronts, or wavecrests.

Law of reflection $\theta = \theta$

Law of refraction (Snell s Law) $n_1 \sin\theta_1 = n_2 \sin\theta_2$

What is n? This describes the effective change in the velocity of light as light enters a medium, or substance; n = c/v, c = speed of light in vacuum.
Check out pictures of ocean waves approaching the shore. Why are the wavecrests always nearly parallel to the beach, even if the storm source is not directly offshore?
How do your glasses work?

Fermat s Principle — Given a source and a destination, light rays choose a path which minimizes the time of travel compared with any other paths. Wow! How does the light know?!

Use the analogy of a drowning swimmer at the beach. What is the fastest path a lifeguard should take if he must cross a street, then the beach, then the water? The lifeguard (or you) may not get it right, but a light ray will every time.
Recall in class the derivation of Snell s Law using Fermat s Principle. Find the minimum of a function (in this case time as a function of x) by taking its derivative and setting it equal to zero.

DEMO — Use the Reflection/Refraction Tank to find the index of refraction, n, for water.

Wave Optics
Applies to small (on the order of a wavelength) apertures, and sharp corners.
These phenomena include interference and diffraction.

DEMO — Interference Plates. Very fun.

Constructive Interference (two waves constructively interfere if they have a phase difference of 0, 2 Pi, 4 Pi, etc.; in other words, if they have an optical path difference equal to an integer number of wavelengths.)
Destructive Interference (two waves destructively interfere if they have a phase difference of Pi, 3Pi, 5Pi, etc.; in other words, if they have an optical path difference equal to a half integer number of wavelengths.)

Young s Double Slit Experiment — Key to interference pattern is different optical path lengths from the two slits; this creates a phase difference between two waves. This is THE classic wave experiment. If you want to see if something is a wave, construct a double slit experiment. This has actually been done for electrons, demonstrating that matter has a wavelike character!

Thin Film Interference — Why are soap bubbles and oil slicks colorful?
Derive condition for maximum signal: $2an = (m+1/2)\lambda$, m = 0, 1, 2, . , where a is the thickness of the film, and n is the index of refraction. Key concepts are optical path length difference, and the Pi phase change which occurs when a wave reflects from a denser (higher n) material. Think about a pulse on a string reflecting from a fixed end — the wave gets phase shifted. This phase shift is the cause of the 1/2 in the formula.

DEMO — Newton s Rings. Super Cool.

Diffraction — Light incident on a small hole (about as small as λ) will spread out beyond the hole, resulting in constructive and destructive fringes. Light bends if incident on a sharp corner too.

Diffraction grating — multiple narrow, closely spaced ($\sim< \lambda$ slits or grooves which act as directional filter. Similar to the double slit experiment, the condition for maximum signal is $d\sin\theta = m\lambda$, where d is the spacing between grooves. For your homework, use $d = \lambda$.

DEMO — CD and lines of colors.