1/7/15 Ken Intriligator's Phys 4D Lecture outline

⋆ Reading: Volume 2, chapter 20 of Feynman Lectures (see link on class website). See also Volume 1, chapter 36 if you're interested in the just for fun stuff about color vision.

• Last time: Maxwell's equations in empty space show that $\vec{E}$ and $\vec{B}$ satisfy the wave equation, with $v = c$:

$$\left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\vec{E} = 0, \qquad \left(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)\vec{B} = 0, \tag{1}$$

The Maxwell equations involving the curl relate $\vec{E}$ and $\vec{B}$ to each other – if you know one, you can solve for the other. The upshot, as you will verify in a HW assignment, is that electromagnetic waves have a direction of propagation, given by wavenumber vector $\vec{k}$ with $|\vec{k}| = 2\pi/\lambda$ the wavenumber, and $\vec{k}\cdot\vec{E} = \vec{k}\cdot\vec{B} = 0$ and $\vec{S} \equiv \vec{E}\times\vec{B}/\mu_0 \sim \vec{k}$.

• As we mentioned in the first lecture, accelerating charges creates a kink in the electric field lines, and that is the source of light. The details of how to determine what electric / magnetic field is created by charge acceleration is a little involved. It involves the time derivatives of the electric dipole moment, and other charge multipole moments. We will **not** discuss these details in physics 4D. You will learn the details about this later, in physics 100b or 100c.

• Our eyes as electromagnetic wave detectors: brightness ↔ intensity is the time averaged value of $\vec{E}^2 \sim \vec{B}^2 \sim |\vec{S}|$; color ↔ wavelength λ or frequency $\omega = ck = c2\pi/\lambda$. Aside: we only notice colors by way of three color detectors, which is why we see color addition (e.g. projectors can use only 3 colors to make up everything we can see. There is also no such color as e.g. brown in the rainbow spectrum, we just see that as a particular average of true colors), or color subtraction when mixing paints. We don't directly see the direction of $\vec{E}$ or $\vec{B}$, i.e. the polarization. But polarized glasses can help cut down on the glare. We will discuss that in an upcoming week.

• Our eyes can see only a sliver of the spectrum of light, from $\lambda = 380nm$ (violet) to $\lambda = 750nm$ (red). About 40% of our sun's light is in this range. What is your favorite wavelength? Mine is around $600nm$.

• Reflection and refraction of light. In geometric optics, we draw light rays and follow where they go. We will first discuss mirrors. Angle of incidence = angle of reflection.

• Focusing light waves: condition is that all rays have the same length. For plane waves, this determines that the reflector shape should be parabolic (the shape of radar or satellite dishes). If we want to focus from one point to another point, the condition that all paths have the same length determines the shape to be an ellipse, with the emitter and detector at the two foci.

• In practice, it's easier to make a spherical mirror than a parabolic or elliptic mirror. The spherical mirror gives a good approximation for small deviations from the center axis. Put an object at distance d_0 from the mirror, and find the location of the image at d_i. The condition that all rays have the same length give

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{2}{R} \equiv \frac{1}{f}, \qquad m \equiv \frac{h_i}{h_o} = -\frac{d_i}{d_0}.$$

Show why from the geometry (using $R - x \approx y^2/2x$ for triangle with $y \ll x$). For concave mirror, $R > 0$; above also applies for convex mirror, with $R < 0$.