Presentation

- Dec. 4
  - Transistors
  - Planetary Magnetic Fields

- Dec. 6
  - Laser

- Dec. 11
  - Wireless
  - Superconductivity

- Dec. 13
  - Particle Detectors
  - Electromagnetism in Medicine and/or Chem
Electromagnetic Plane wave

Direction of \(\{\text{Propagation, Energy flow}\} \) given by \(\vec{E} \times \vec{B}\)

Energy flow
\[
\vec{S} = \frac{\vec{E} \times \vec{B}}{\mu_0}
\]

\( |\vec{S}| \) = Intensity = Energy flux = Watts/m\(^2\)

Area density of Power ~ Brightness
\[ |E| = c |B| \]

\[ \langle S \rangle = \frac{E_0^2}{2\mu_0 c} = \frac{c B_0^2}{2\mu_0} = \frac{E_0 B_0}{2\mu_0} \]

Momentum of EM wave

\[ P = \frac{\nu}{c} \]

Radiation Pressure of EM wave

on "black" surface = \(\frac{S}{c}\)

\(\langle \text{Pressure} \rangle = \frac{\langle S \rangle}{c}\)

on perfectly reflecting surface = \(\frac{2S}{c}\)

\(\langle \text{Press} \rangle = \frac{2\langle S \rangle}{c}\)
Polarization of Electromagnetic Waves

- $\vec{E}$ oriented along $x$ axis
- Wave is polarized along $x$-axis

Polarization $\rightarrow$ Dir. of $\vec{E}$ vector
General Soln = $\sum (E_x, E_y)$

Go to basis where we draw just $E$ for each of the possible orthogonal solns

$E_x = E_0 x \sin(kx - \omega t)$

$E_y = E_0 y \sin(kx - \omega t + \phi)$

Amplitudes & phases may differ to give different types of polarization
\[ I_{new} \approx E_0^2 \cos^2 \theta \approx I_{init} \cos^2 \theta \]
\[ I = 0 \]

\[ \theta = 90^\circ \]

\[ \theta = 45^\circ \]

\[ I = \left( \frac{1}{2} I \right) \cos^2 45^\circ \]

\[ I = \left[ \left( \frac{1}{2} I \right) \cos^2 45^\circ \right] \cos^2 45^\circ \]

*Not zero!*
\[ I_0 \quad \frac{1}{2} I_0 \quad I = \frac{1}{2} I_0 \cos^2 30 \]

EM waves + laws of optics

Light in a material

\[ C = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \quad \rightarrow \quad V = \frac{1}{\sqrt{\varepsilon \mu}} \quad v < c \]
\( \frac{C}{V} \equiv n \equiv \text{index of refraction} \) 

 vacuum

\( \lambda V = c \quad \lambda V = \nu \)

\( \lambda V = \frac{c}{n} \)

\( \lambda n = \frac{c}{\nu} = \lambda_0 \)

in Material

\( \lambda \)

in Vacuum

\( V \)
Vacuum
$n = 1$

glass
$n = 1.5$

$n_1, \theta_1 \rightarrow n_2 \rightarrow 10 n_2$

$n_2 > n_1$
Snell's law: \( n_1 \sin \theta_I = n_2 \sin \theta_R \)

Refraction

Law of Reflection: \( \theta_I = \theta_{Refl} \)
Dispersion

\[ n \text{ depends on } \lambda (\nu) \]

Typically, \( n(\text{red}) < n(\text{blue}) \)

\[ c = \lambda \nu \]
white light

Rainbow of color

because red < blue
red bent less

operation of a thin convex lens
Converging lens (convex)

Diverging lens (concave)

Common aberration

Chromatic dispersion
If $\theta_2 > \theta_c$, Total internal reflection.

$n_1 \sin \theta_1 = n_2 \sin \theta_2$

$n_1 \sin \theta_c = n_2 \sin 90$

$\theta_c = \text{critical Angle}$
Polarization by Reflection

Scattering (electric Dipole)

Polarization by Scattering
Thin lenses and optical instruments

http://cvs.anu.edu.au
http://www.ebiomedia.com
(a) Converging lenses

(c) Ray 3 passes straight through the center of the lens (assumed very thin).
(b) Diverging lenses
Power of lens measured in diopters

\[ P = \frac{1}{f} \]

where \( f \) is focal length in meters

Power is positive for converging lenses and negative for diverging lenses
Magnification:
\[ m = \frac{h_i}{h_o} = -\frac{d_i}{d_o} \]

Lens equation:
\[ \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f} \]
Convention from Giancoli p. 841:

- Focal length is + for converging lens and - for diverging lens
- Object distance is + if on the side of the lens from which the light is coming (usual, unless in multi-lens system)
- Image distance is + if on the opposite side of the lens from where the light is coming, if on same side, image distance is –
- Image distance is + for real images and – for virtual images
- Height of image is + if image is upright and – if image is inverted. Height of object is always taken to be +.
Aberrations

Spherical aberration

Chromatic aberration
The electromagnetic spectrum
from "The Joy of Visual Perception: A Web Book"
http://www.yorku.ca/cyc/
Types of eyes in the animal kingdom

A. Ocellus

B. Pinhole Eye

C. Compound Eye

D. Lens and Retina (Vertebrate)
Aeschna dragonfly
28,000 facets
A bee’s eye view
Fig. 2.9. Resolution of the eyes of various animals measured physiologically and deduced from anatomical criteria compared to body height: (1) man; (2) peregrine falcon; (3) hen; (4) cat; (5) pigeon; (6) chaffinch; (7) rat; (8) bat (Myotis); (9) frog; (10) lizard; (11) minnow; (12) dragonfly (Aeshna); (13) bee (Apis); (14) Chlorophanus; (15) housefly (Musca); (16) hover fly (Syrriia), frontal region FO; (17) jumping spider (Methaphidippus), anteromedian eye AM, postero-lateral eye PL; (18) fruit fly, Drosophila. (From Kirschfeld 1976.)
Anableps - minnow