Physics 202, Lecture 23

Today’s Topics

- Lights and Laws of Geometric Optics
  - Nature of Lights
  - Reflection and Refraction
  - Law of Reflection
  - Law of Refraction
  - Index of Refraction, Snell’s Law
  - Total Internal Reflection
  - Dispersion and Prisms
Antennas

- Antennas are essentially arrangement of conductors for transmitting and receiving radio waves.
- Parameters: gain, impedance, frequency, orientation, polarization, etc.

**Diagram:**
- **λ/4 half-wave antenna**
- **maximum strength**
- **Beverage**
- **rhombic**
- **vantenna**
- **Yagi**
- **helical**
- **loop**
- **mocristrip**
- **log-periodic**
**Spectrum of EM Waves**

- **Speed of light:**
  - $v=c$ in vacuum
  - $v<c$ in medium

- **Wavelength:** depends on medium
- **Frequency:** unchanged in medium

**Color of lights: frequencies of waves**
- $\lambda=400\text{nm}$
- $1\text{ nm} = 10^{-9}\text{ m}$
- $\lambda=700\text{nm}$

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Frequency (GHz)</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>10$^6$</td>
<td>~2000</td>
</tr>
<tr>
<td>Radio waves</td>
<td>10$^7$</td>
<td>~3000</td>
</tr>
<tr>
<td>TV, FM</td>
<td>10$^8$</td>
<td>~6000</td>
</tr>
<tr>
<td>Microwaves</td>
<td>10$^9$</td>
<td>~10000</td>
</tr>
<tr>
<td>Infrared</td>
<td>10$^{10}$</td>
<td>~100000</td>
</tr>
<tr>
<td>Ultraviolet</td>
<td>10$^{11}$</td>
<td>~200000</td>
</tr>
<tr>
<td>Visible light</td>
<td>10$^{12}$</td>
<td>~400000</td>
</tr>
<tr>
<td>X-rays</td>
<td>10$^{13}$</td>
<td>~700000</td>
</tr>
<tr>
<td>Gamma rays</td>
<td>10$^{14}$</td>
<td>~1000000</td>
</tr>
</tbody>
</table>
Light And Optics

- Nature of Lights
  - Lights as rays
  - Lights as EM waves: $f, \lambda, \phi, v, A$, interference ...
  - Lights as group of photons (Quantum Theory)

- Optics: Physics of lights
  - Geometric Optics: Treat light as rays. (Ch. 31,32)
    - Ray approximation.
  - Wave Optics: Wave properties become important Interferences, diffraction…(Ch. 33.)
Ray Approximation (1)

- When the wavelength of the light is much smaller than the size of the optical objects it encounters, it can be treated as (colored) rays.

Ray approximation is valid when \( \lambda \ll d \)

Ray approximation is not valid near the gap when \( \lambda \sim d \). OK elsewhere.
Ray Approximation (2)

- Basic features of ray approximation
  - Light rays travel in straight lines in a uniform medium
  - Light rays change direction at the boundary of media → Reflection and Refraction
  - Light rays travel at speed of light in the medium
  - Trace of rays are reversible
  - Frequency (color) remains the same along the path.
  - Wavelength changes as light enters a different medium
  - When two set of light rays meet, they pass through each other, interference is not considered.
  - Phases are usually not a concern.
Light Rays at the Boundary

- At a boundary, three things may happen:
  - Rays are reflected. (Reflection)
  - Rays are refracted. (Refraction)
  - Rays are absorbed. (Absorption)

\[ I_{\text{in}} = I_{\text{reflection}} + I_{\text{refraction}} \ (\text{+ } I_{\text{absorption}}) \]

Note: Frequency is unchanged in reflection and refraction.
Reflection

- Law of reflection: On a smooth boundary, the angle of reflection equals the angle of incidence ($\theta_1 = \theta_1'$).
Law of refraction:

\[
\frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{v_1} = \frac{v_2}{c}
\]

if \(v_1 = c\) (in vacuum)

Note: \(\theta_1 > \theta_2\) if \(v_1 > v_2\)
From Air to Glass and From Glass to Air

\[ \frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{c} \]

\[ \theta_2 < \theta_1 \]

\[ \frac{\sin \theta_2}{\sin \theta_1} = \frac{v_2}{c} \]

\[ \theta_2 > \theta_1 \]
Index of Refraction

- Index of refraction $n \equiv \frac{c}{v}$
  - vacuum $\rightarrow n=1$
  - low $v \rightarrow$ high $n$
  - all media have $n>1$
  - $\lambda_1 n_1 = \lambda_2 n_2$

- Snell’s law of refraction

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

Frequency is unchanged when light enters into a different medium.
# Index of Refraction For Various Material

## Table 35.1

<table>
<thead>
<tr>
<th>Substance</th>
<th>Index of Refraction</th>
<th>Substance</th>
<th>Index of Refraction</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solids at 20° C</strong></td>
<td></td>
<td><strong>Liquids at 20° C</strong></td>
<td></td>
</tr>
<tr>
<td>Cubic zirconia</td>
<td>2.20</td>
<td>Benzene</td>
<td>1.501</td>
</tr>
<tr>
<td>Diamond (C)</td>
<td>2.419</td>
<td>Carbon disulfide</td>
<td>1.628</td>
</tr>
<tr>
<td>Fluorite (CaF$_2$)</td>
<td>1.434</td>
<td>Carbon tetrachloride</td>
<td>1.461</td>
</tr>
<tr>
<td>Fused quartz (SiO$_2$)</td>
<td>1.458</td>
<td>Ethyl alcohol</td>
<td>1.361</td>
</tr>
<tr>
<td>Gallium phosphide</td>
<td>3.50</td>
<td>Glycerin</td>
<td>1.473</td>
</tr>
<tr>
<td>Glass, crown</td>
<td>1.52</td>
<td>Water</td>
<td>1.333</td>
</tr>
<tr>
<td>Glass, flint</td>
<td>1.66</td>
<td><strong>Gases at 0° C, 1 atm</strong></td>
<td></td>
</tr>
<tr>
<td>Ice (H$_2$O)</td>
<td>1.309</td>
<td>Air</td>
<td>1.000 293</td>
</tr>
<tr>
<td>Polystyrene</td>
<td>1.49</td>
<td>Carbon dioxide</td>
<td>1.000 45</td>
</tr>
<tr>
<td>Sodium chloride (NaCl)</td>
<td>1.544</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* All values are for light having a wavelength of 589 nm in vacuum.

© 2004 Thomson - Brooks/Cole
When light enters into a medium of lower index of refraction ($n_1 > n_2$) at incident angle $\theta$ larger than the critical angle $\theta_c$ ($\sin \theta_c = n_2/n_1$), no refraction will occur.

$\rightarrow$ Total internal reflection for $\theta > \theta_c$

Example: Water to Air $\sin \theta_c = 1/n_{\text{water}} \rightarrow \theta_c = 48.8^\circ$.

Total Internal Reflection
Dispersion

- For a given material, the index of refraction \((n = c/v)\) is a function of frequency (color) of the light.
  - It is called dispersion,
  - Diffraction angle depends on color
- Examples:

Prism  
Rainbow  

<table>
<thead>
<tr>
<th>Material</th>
<th>Refraction Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown glass</td>
<td>1.54</td>
</tr>
<tr>
<td>Acrylic</td>
<td>1.52</td>
</tr>
<tr>
<td>Fused quartz</td>
<td>1.50</td>
</tr>
</tbody>
</table>

\(\lambda, \text{ nm}\)