15. Production of Polarized Light

Last Lecture
• Polarized Light
• Jones Vectors for Polarized Light
• Jones Matrices for Polarizers, Phase Retarders, Rotators

This Lecture
• Dichroic Materials
• Polarization by Scattering
• Polarization by Reflection from Dielectric Surfaces
• Birefringent Materials
• Double Refraction
• The Pockel’s Cell
Dichroism: Polarization by selective absorption

- Wire grid polarizer absorbs light with the polarization along the length of the wires because this polarization generates a current along the length of the wires. Resistance in the wires causes energy dissipation, and the phase of the EM wave radiated by the electrons is 180° out of phase with incoming field.

Figure 8.12 A wire-grid polarizer.

Hecht, Optics, Chapter 8
Figure 8.36 Scattering of polarized light by a molecule.
Polarization by Scattering

- Rayleigh scattering for unpolarized light will be strongly polarized when the scattering direction is a 90°.

Hecht, Optics, Chapter 8

Figure 8.37 Scattering of unpolarized light by a molecule.
Polarization by Reflection from a Dielectric Surface

- For unpolarized light incident at a certain angle (Brewster’s angle: $\theta_p$), the reflected beam will be pure TE but weak and the transmitted beam will be a mixture of TE and TM light.

This situation can be improved dramatically by using a pile-of-plates polarizer.
Polarization by Reflection from a Dielectric Surface: Pile-of-Plates Polarizer

- The pile-of-plates polarizer makes use of multiple reflections at Brewster’s angle to produce well-polarized transmitted light
Polarization by Reflection from a Dielectric Surface

• What we have just learned about the polarization of scattered light can be used to understand the absence of reflected light for a TM wave incident at Brewster’s angle.

At Brewster’s angle,

\[ n_i \sin \theta_i = n_t \sin \theta_t \]

\[ \theta_t = 90° - \theta_i \]

\[ n_i \sin \theta_i = n_i \sin(90° - \theta_i) \]

\[ = n_i \cos \theta_i \]

\[ \theta_i = \theta_p = \tan^{-1} \left( \frac{n_t}{n_i} \right) \]

\[ \theta_i + \theta_t = 90° \]
Polarizers Using Birefringent Materials

(a) Wollaston prism

(b) Rochon prism

(c) Sernarmont prism

Figure 15-16 Polarizing prisms.
Polarizers Using Birefringent Materials

\[ n_\parallel = 1.4864 \]
\[ n_\perp = 1.6584 \]
\[ \theta_{c\parallel} = 42.28^\circ \]
\[ \theta_{c\perp} = 37.08^\circ \]

for \( \lambda = 589.3 \text{ nm} \)

The Glan-air or Glan-Foucault polarizer, usually fabricated from calcite or in more recent years from alpha-beta barium borate (\( \alpha \)-BBO).

Hecht, Optics, Chapter 8
Double Refraction in Birefringent Materials

The wavelets associated with the e-wave travel at different speeds in directions parallel and perpendicular to the optical axis. For the o-wave, the electric field vector is always perpendicular to the optical axis and the wavelets propagate spherically.

Hecht, Optics, Chapter 8

Figure 8.23  An incident plane wave polarized perpendicular to the principal section.

Figure 8.24  An incident plane wave polarized parallel to the principal section.
Double Refraction in Birefringent Materials

Figure 15-13  (a) Creation of an elliptical Huygens’ wavelet by the extraordinary ray. The material in this case is uniaxial negative, like calcite. (b) Nonalignment of ray direction $\mathbf{S}$ and propagation vector $\mathbf{k}$ for the extraordinary ray in birefringent material.
Birefringence

Oblong molecules: “liquid crystals”

Dipoles of the molecules orient along an externally applied electric field. Change the field → change the birefringence → change the polarization of transmitted light → pass through polarization analyzer to change the intensity → Digital displays, LCD monitors, etc.

Stress-induced birefringence:

Applying a mechanical stress to a material will often produce an asymmetry → birefringence. This is commonly used to measure stress.
Electric-Field-Induced Birefringence: 
The Pockel's Cell

Hecht, Optics, Chapter 8

\[ \Delta \varphi = 2 \pi n_0^3 r_{63} V / \lambda_0 \]

\[ \Delta \varphi = \pi \frac{V}{V_{\lambda/2}} \]

\[ V_{\lambda/2} = \frac{\lambda_0}{2n_0^3 r_{63}} V \]

**Table 8.4** Electro-optic constants (room temperature, \( \lambda_0 = 546.1 \text{ nm} \)).

<table>
<thead>
<tr>
<th>Material</th>
<th>( r_{65} ) (units of ( 10^{-12} \text{ m/V} ))</th>
<th>( n_0 ) (approx.)</th>
<th>( V_{\lambda/2} ) (in kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADP (NH₄H₂PO₄)</td>
<td>8.5</td>
<td>1.52</td>
<td>9.2</td>
</tr>
<tr>
<td>KDP (KH₂PO₄)</td>
<td>10.6</td>
<td>1.51</td>
<td>7.6</td>
</tr>
<tr>
<td>KDA (KH₂AsO₄)</td>
<td>( \sim 13.0 )</td>
<td>1.57</td>
<td>( \sim 6.2 )</td>
</tr>
<tr>
<td>KD³⁺P (KD₂PO₄)</td>
<td>( \sim 23.3 )</td>
<td>1.52</td>
<td>( \sim 3.4 )</td>
</tr>
</tbody>
</table>
Optical activity (circular birefringence)

In some chiral materials (like sugar), the polarizations that travel at different speeds are right and left circular polarization. When linearly polarized light is directed into such a medium, the plane of linear polarization will be rotated (i.e., the light emerges linearly polarized, but polarized in a different direction).

Concentration of chiral molecules $\rightarrow$ amount of rotation

This is one noninvasive method used by soft drink companies to monitor sugar content of their product.