Propagation of EM Waves

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad \text{where} \quad \mathbf{E} = \hat{x}E_0 e^{i(k \cdot r - \omega t)} \]

\[ \Rightarrow \nabla \times \equiv i\mathbf{k} \times \quad \text{and} \quad \frac{\partial}{\partial t} \equiv -i\omega \]

\[ \Rightarrow \mathbf{B} = \frac{1}{\omega} \mathbf{k} \times \mathbf{E} \]

Vectors \( \mathbf{k}, \mathbf{E}, \mathbf{B} \) form a right-handed triad.

Note: free space or isotropic media only
In isotropic media
(e.g. free space, amorphous glass, etc.)

\[ k \cdot E = 0 \]
i.e. \( k \perp E \)

More generally,
\[ k \cdot D = 0 \]
(reminder: in anisotropic media, e.g. crystals, one could have \( E \) not parallel to \( D \))
Linear polarization (frozen time)

$E(z=0, t=0)$

$E(z=\lambda/2, t=0)$

$E(z=\lambda, t=0)$

$\Phi=0$

$\Phi=2\pi$

Phase constant on the plane
Linear polarization (fixed space)
Circular polarization (frozen time)
Linear vs. Circular Polarization

http://en.wikipedia.org/wiki/Polarizer
Working with Polarizers

\[ I = \frac{1}{2} \varepsilon_0 E_0^2 \cos^2 \theta = I_0 \cos^2 \theta, \]
Polarization by Reflection

The reflection coefficients are different for waves parallel and perpendicular to the plane of incidence.

When light is incident at the Brewster angle, the reflected light is linearly polarized because the reflection coefficient for the II component is zero.

\[ \theta_1 + \theta_2 = 90^\circ, \]

\[ n_1 \sin(\theta_1) = n_2 \sin(\theta_2), \]

\[ n_1 \sin(\theta_B) = n_2 \sin(90^\circ - \theta_B) = n_2 \cos(\theta_B). \]

\[ \theta_B = \arctan\left(\frac{n_2}{n_1}\right), \]
Where is the turtle?
Polarized sunglasses

Diagram showing the interaction of light with polarized sunglasses and unpolarized illumination.
Circularly polarized light in nature

Fig. 1. Photographs of the beetle C. gloriosa. (A) The bright green color, with silver stripes as seen in unpolarized light or with a left circular polarizer. (B) The green color is mostly lost when seen with a right circular polarizer.
Morphology and microstructure of cellular pattern of C. gloriosa
Polarization by scattering (Rayleigh scattering/Blue Sky)

**FIGURE 8.35a** Scattering of polarized light by a molecule.

**FIGURE 8.35b**

**FIGURE 8.36** Scattering of unpolarized light by a molecule.
Methods for generating polarized light

Molecules behave like dipole radiators and scatter no energy along the dipole axis.

Methods for Achieving Polarization of Light

Light polarized in perpendicular planes exhibits different refractive indices in some crystalline materials - a property called birefringence. Prisms can be designed to use total internal reflection to eliminate one of the planes.

Scattering

90°

Birefringence

Nicol prism

The reflection coefficient for light polarized in the plane of incidence is zero at the Brewster angle, leaving the reflected light at that angle linearly polarized. Electrons in the material act like dipole radiators and transmit no energy along their vibration axis.

http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polar.html
Linear versus Circular polarization

(a)

(b)

Electric field
Magnetic field

direction of propagation
direction of propagation

If this wave were approaching an observer, its electric vector would appear to be rotating counterclockwise. This is called right-circular polarization.
Circular polarization (linear components)
Circular polarization (fixed space)
Quarter wave plate
Half wave plate

\( \frac{\lambda}{2} \) plate

Linear polarization

Birefringent \( \frac{\lambda}{2} \) plate

Linear (90°-rotated) polarization
Polarization: Summary and Quiz

\[ \mathbf{E} = E_x e^{i\delta_1} \hat{x} + E_y e^{i\delta_2} \hat{y} \]

linear polarization
y-direction

right circular
polarization

left circular
polarization

left elliptical
polarization

Phase difference = 0°

Phase difference \(\rightarrow\) 90° (\(\pi/2, \lambda/4\))

Phase difference \(\rightarrow\) 180° (\(\pi, \lambda/2\))
Polarization Applets

• Polarization Exploration
  http://webphysics.davidson.edu/physlet_resources/dav_optics/Examples/polarization.html

• 3D View of Polarized Light
  http://fipsgold.physik.uni-kl.de/software/java/polarisation/index.html
Quiz for the 2nd Optics Lab – Bonus Credit 0.25 pts