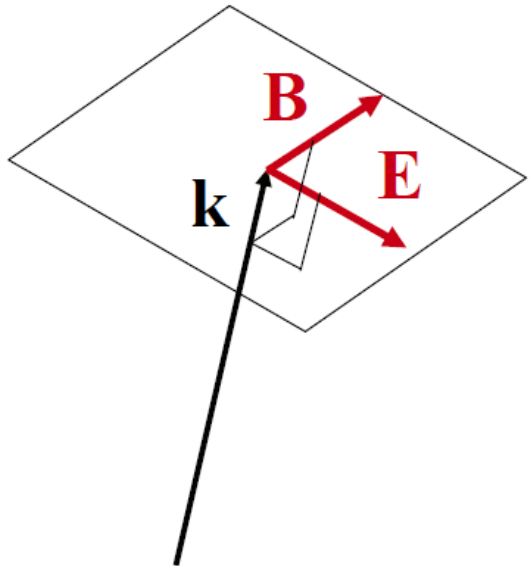


Propagation of EM Waves



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

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

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

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

Note: free space or isotropic media only

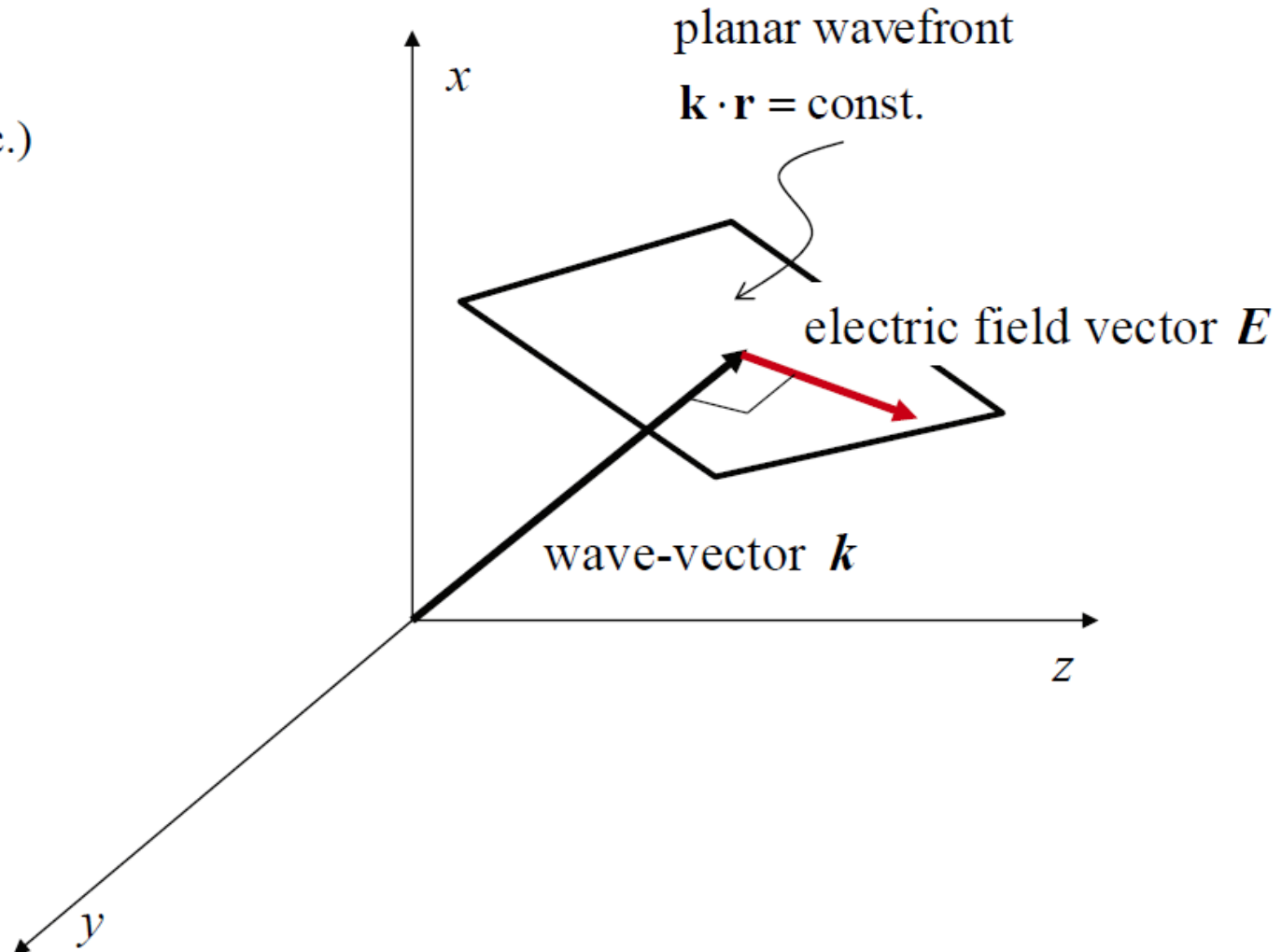
Polarization and Propagation

In isotropic media
(e.g. free space,
amorphous glass, etc.)

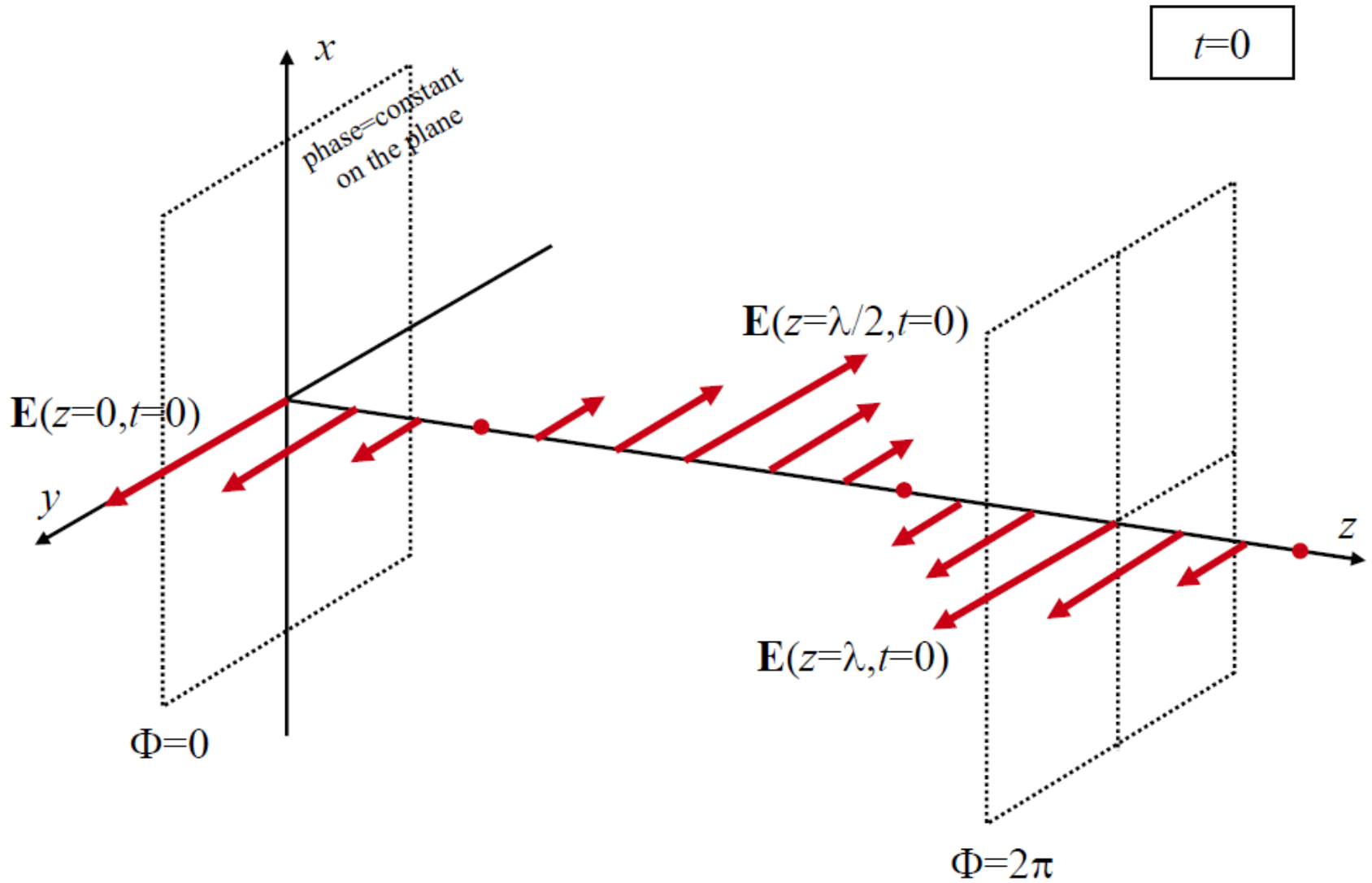
$$\mathbf{k} \cdot \mathbf{E} = 0$$

i.e. $\mathbf{k} \perp \mathbf{E}$

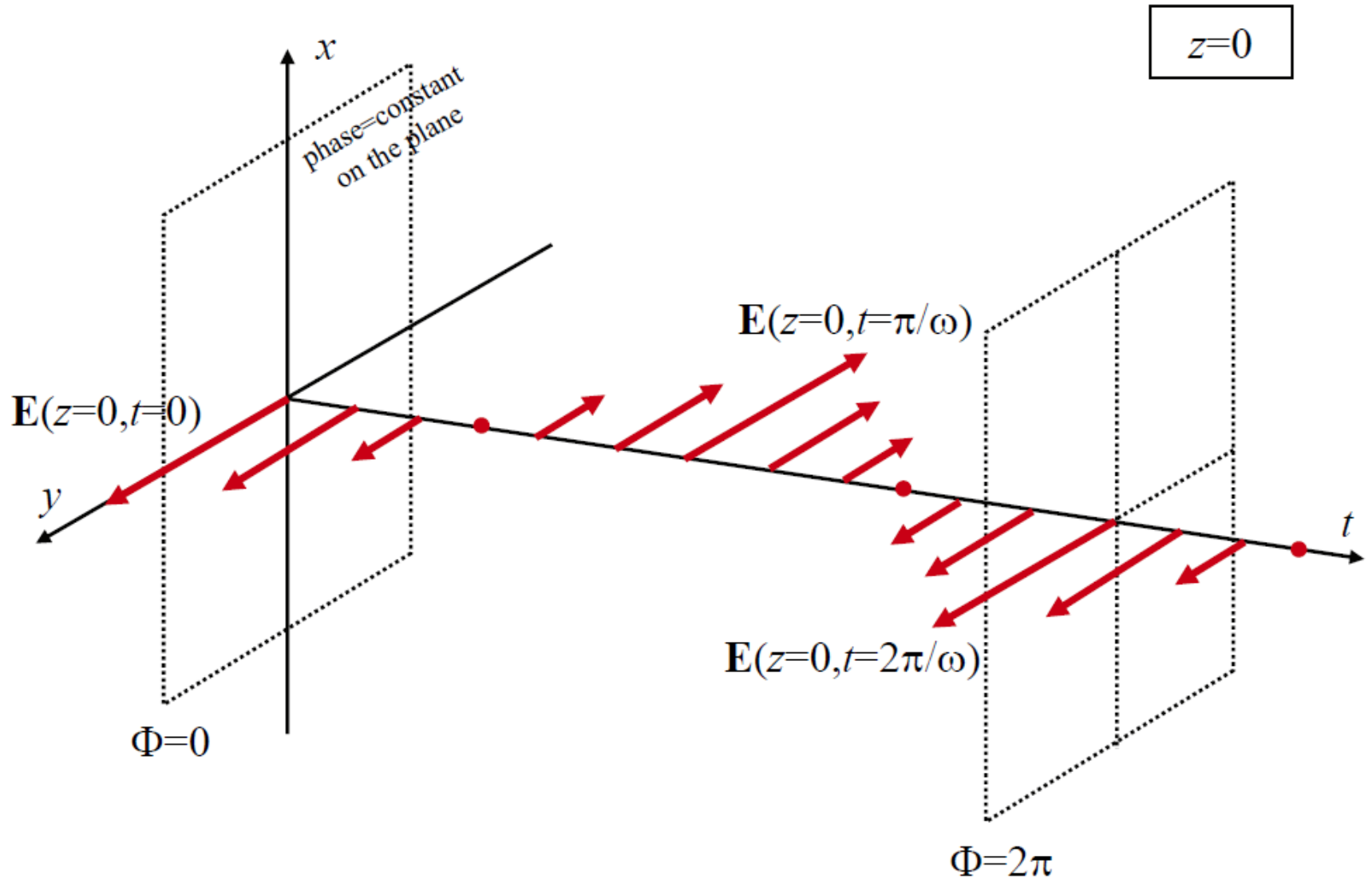
More generally,
 $\mathbf{k} \cdot \mathbf{D} = 0$
(reminder: in
anisotropic media,
e.g. crystals, one
could have
 \mathbf{E} not parallel to \mathbf{D})



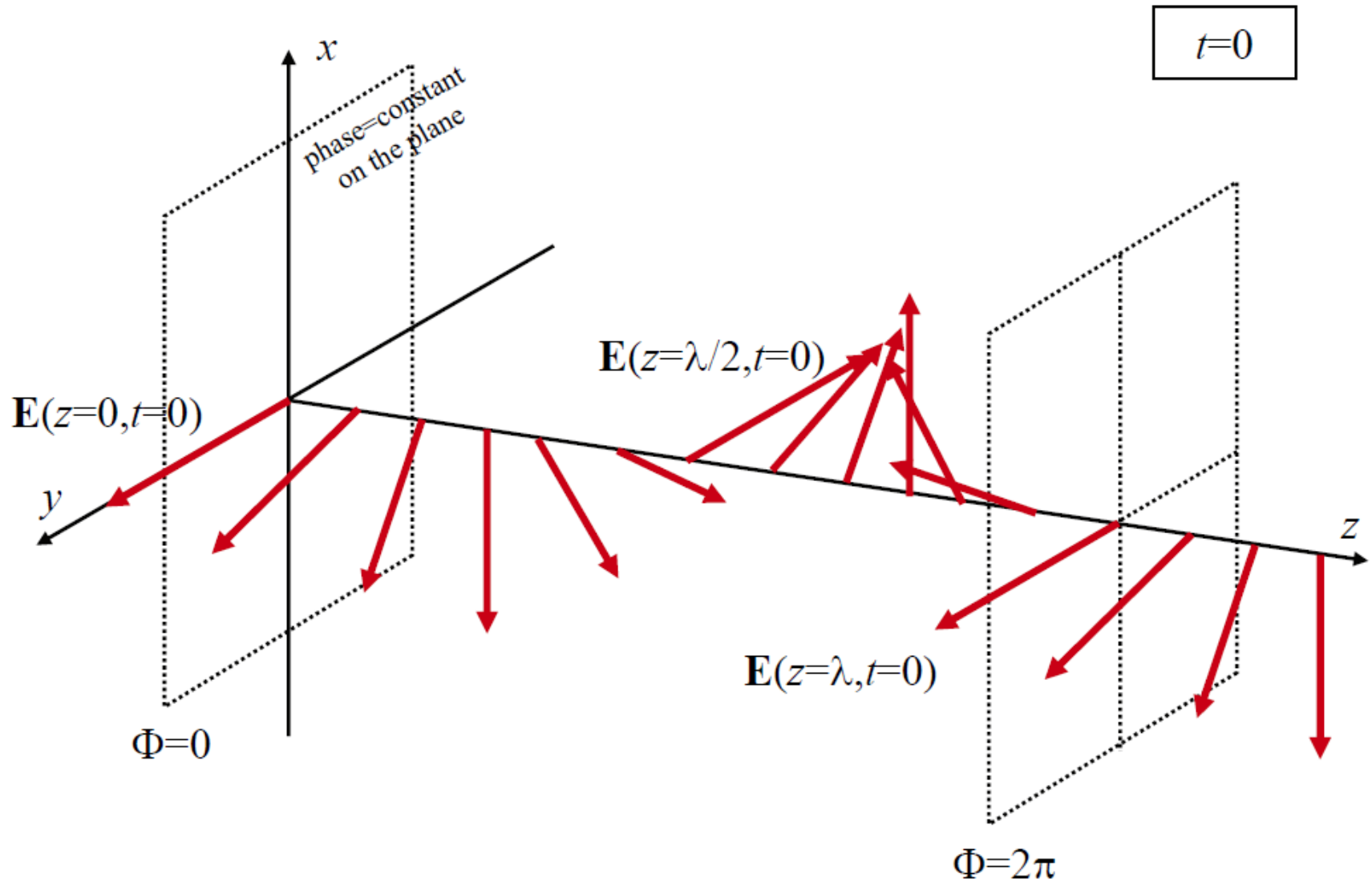
Linear polarization (frozen time)



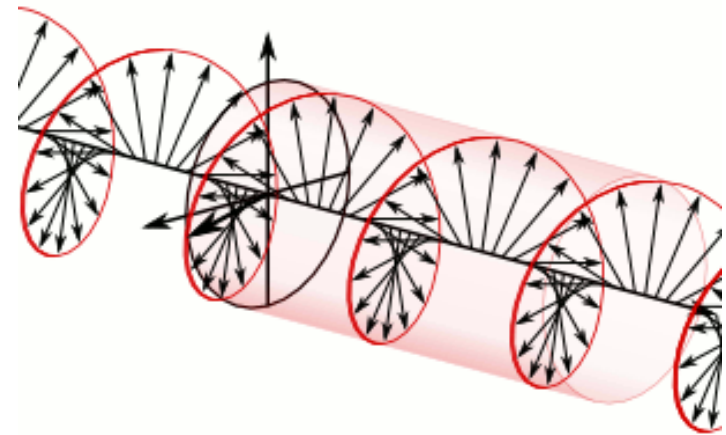
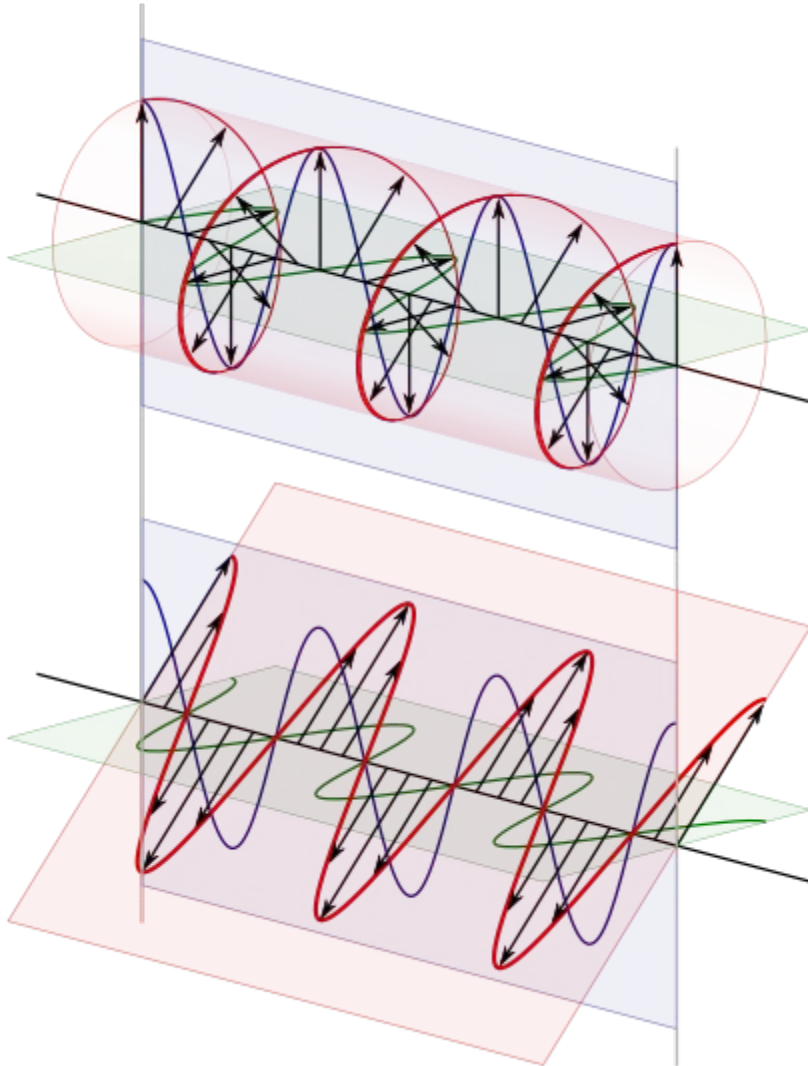
Linear polarization (fixed space)



Circular polarization (frozen time)

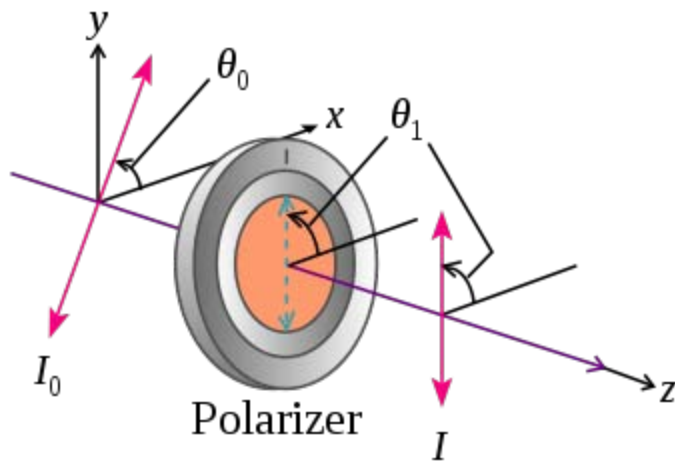
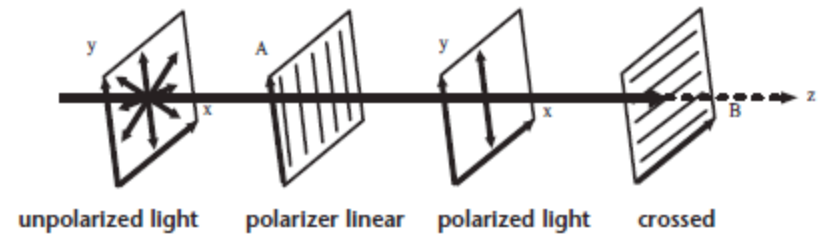
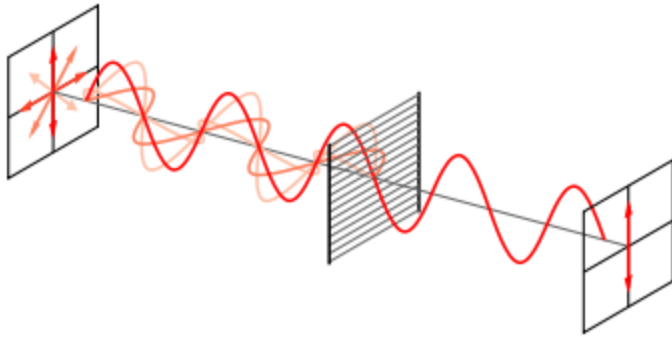


Linear vs. Circular Polarization

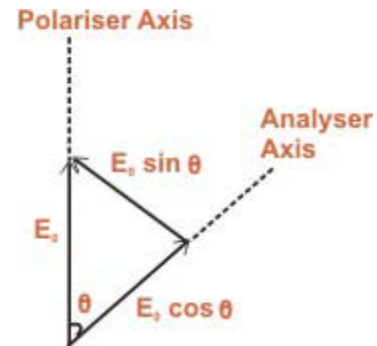


<http://en.wikipedia.org/wiki/Polarizer>

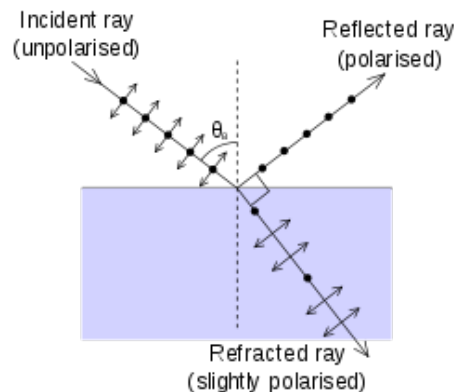
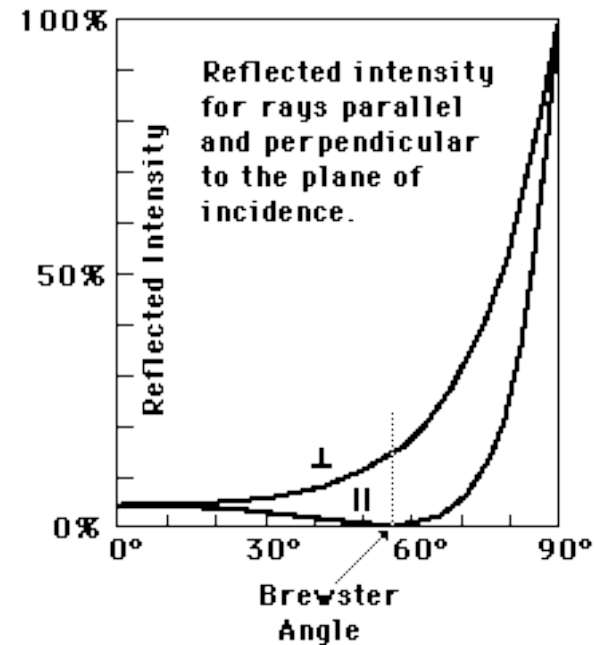
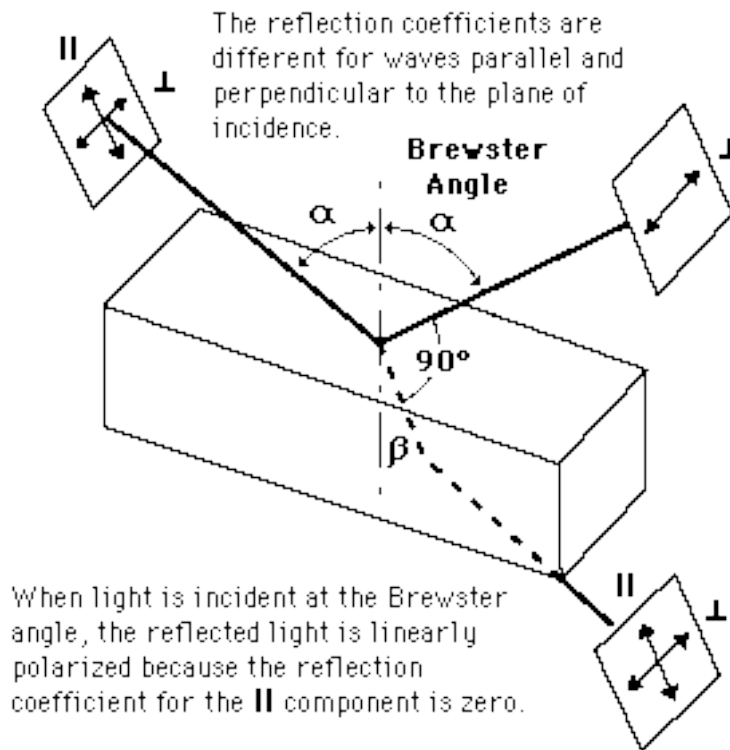
Working with Polarizers



$$I = \frac{1}{2} c \epsilon_0 E_0^2 \cos^2 \theta = I_0 \cos^2 \theta,$$



Polarization by Reflection



$$\theta_1 + \theta_2 = 90^\circ,$$

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2),$$

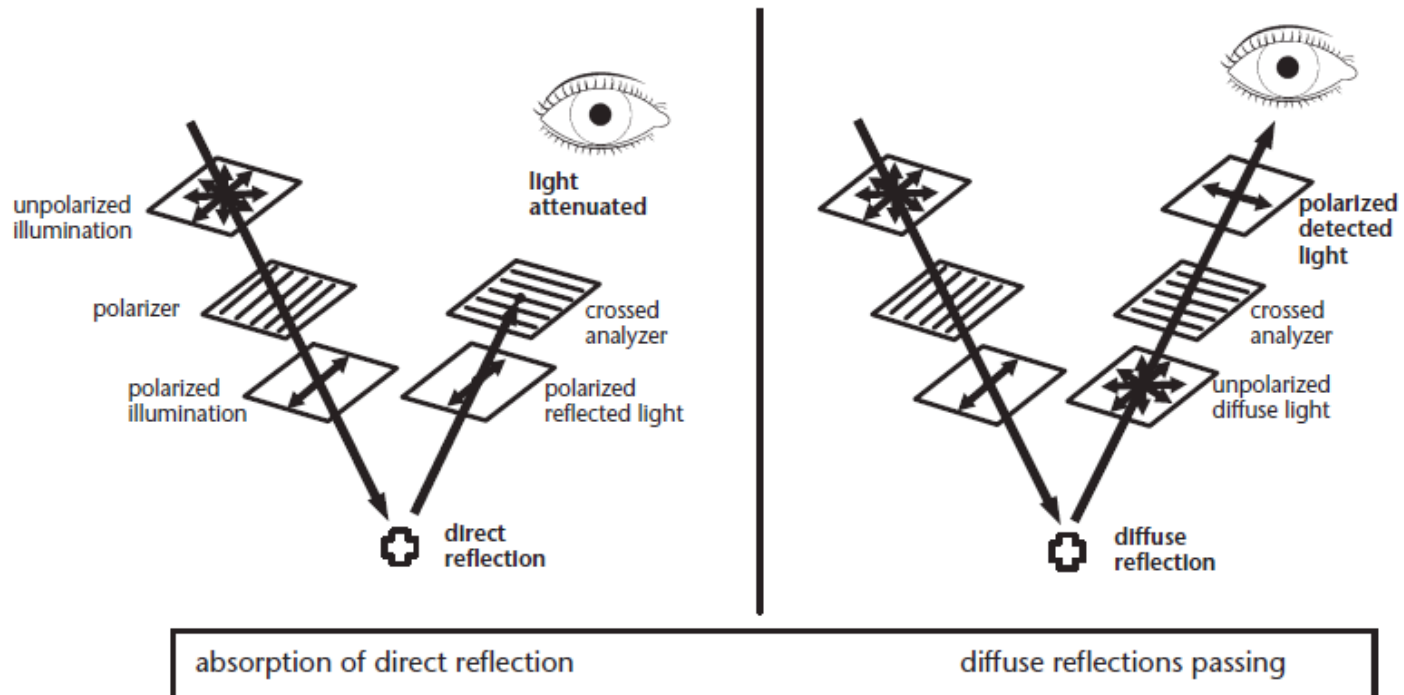
$$n_1 \sin(\theta_B) = n_2 \sin(90^\circ - \theta_B) = n_2 \cos(\theta_B).$$

$$\theta_B = \arctan\left(\frac{n_2}{n_1}\right),$$

Where is the turtle?

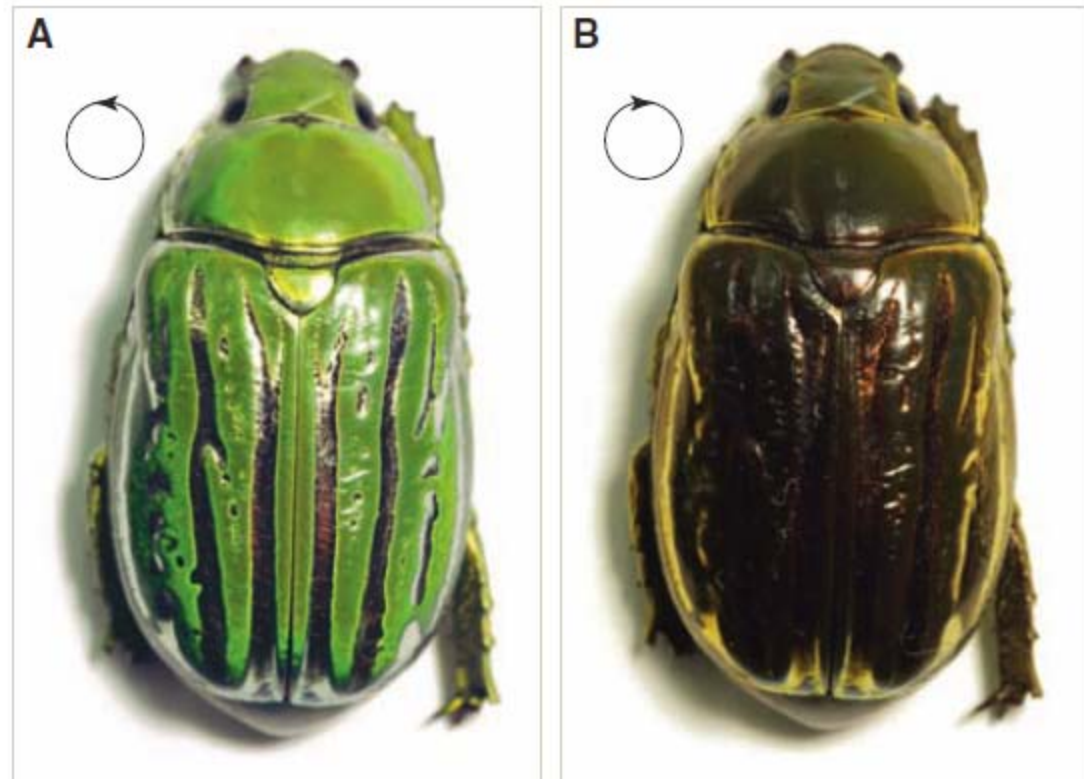


Polarized sunglasses

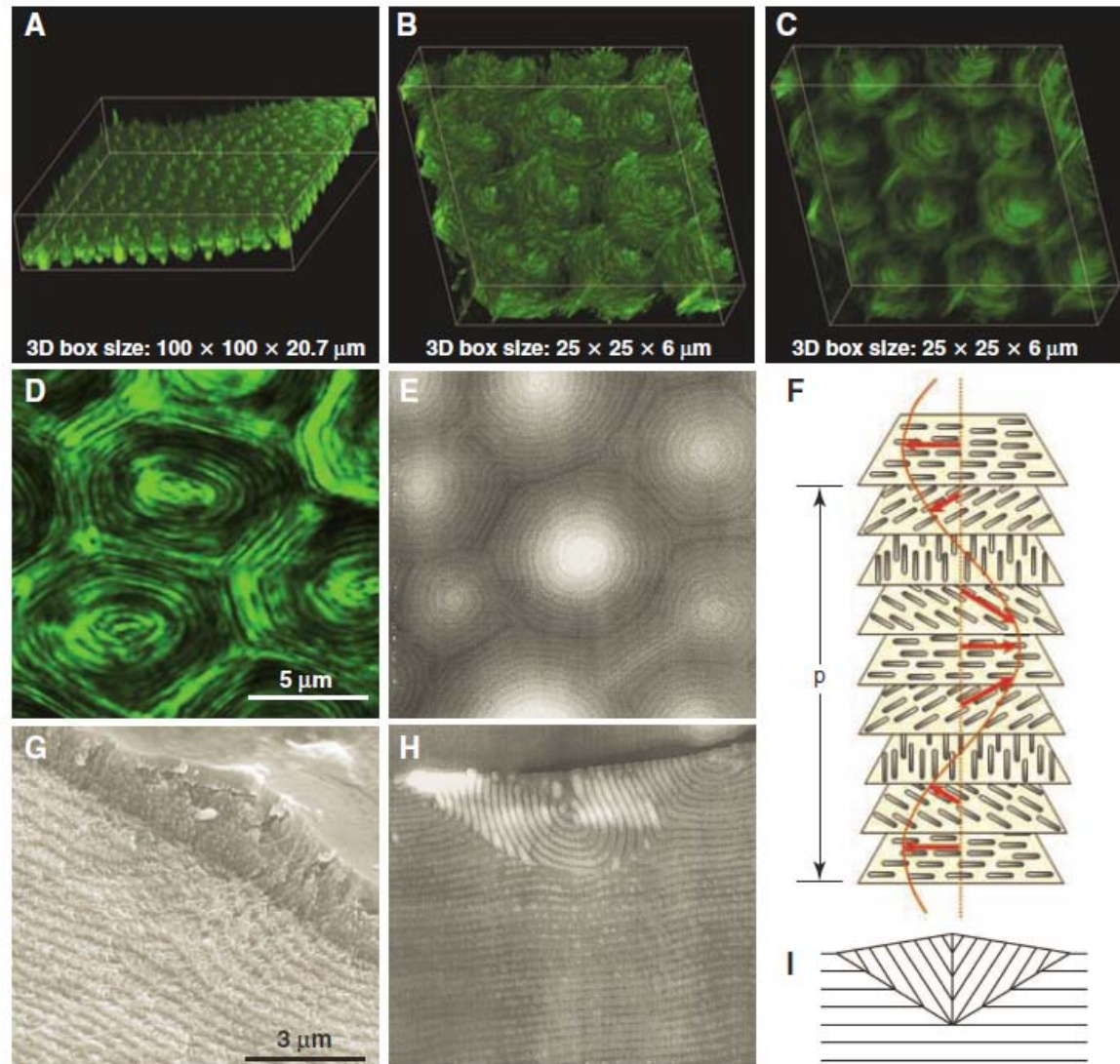


Circularly polarized light in nature

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)

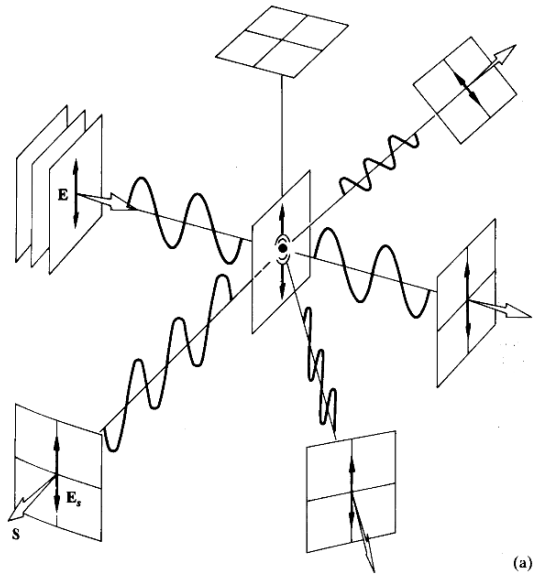


FIGURE 8.35a Scattering of polarized light by a molecule.

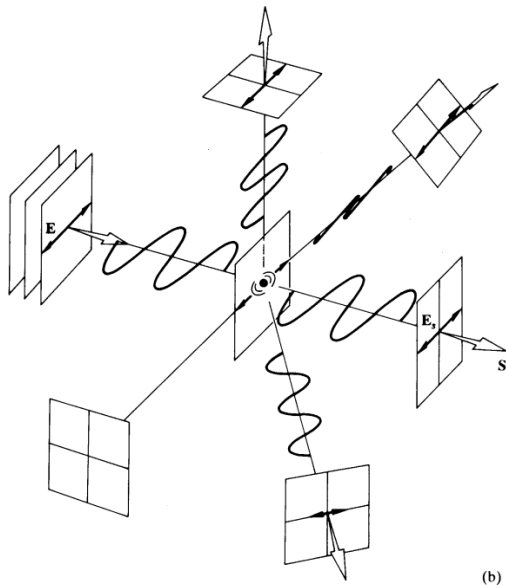


FIGURE 8.35b

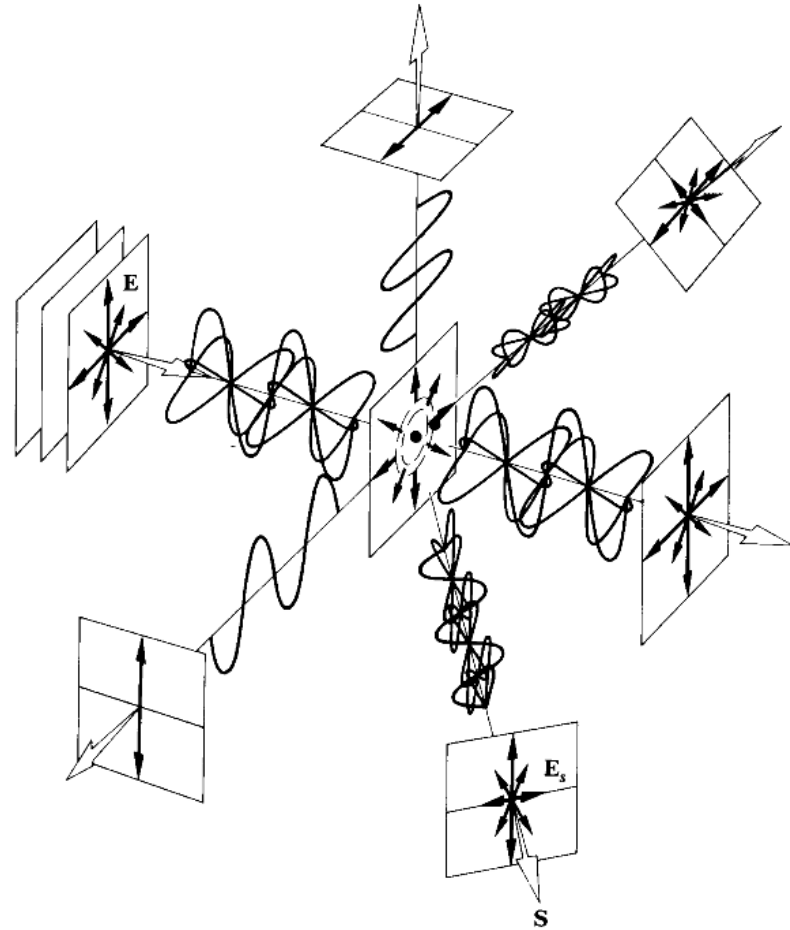
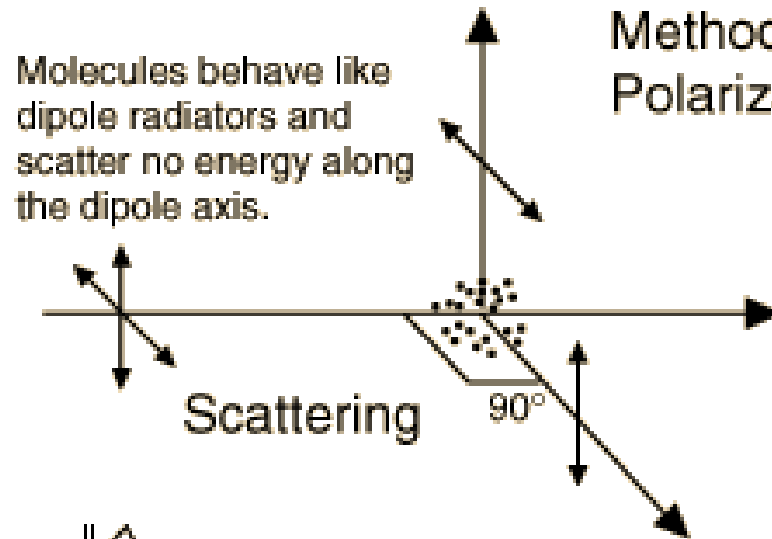


FIGURE 8.36 Scattering of unpolarized light by a molecule.

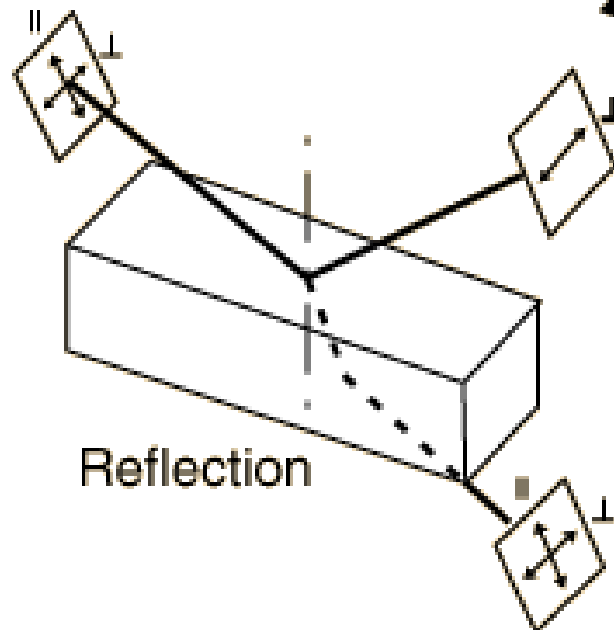
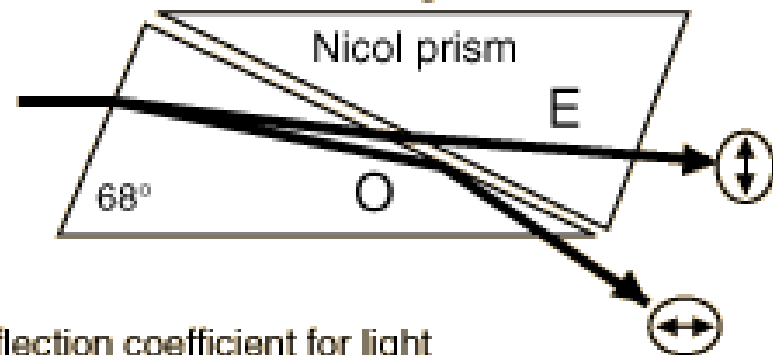
Methods for generating polarized light



Methods for Achieving Polarization of Light

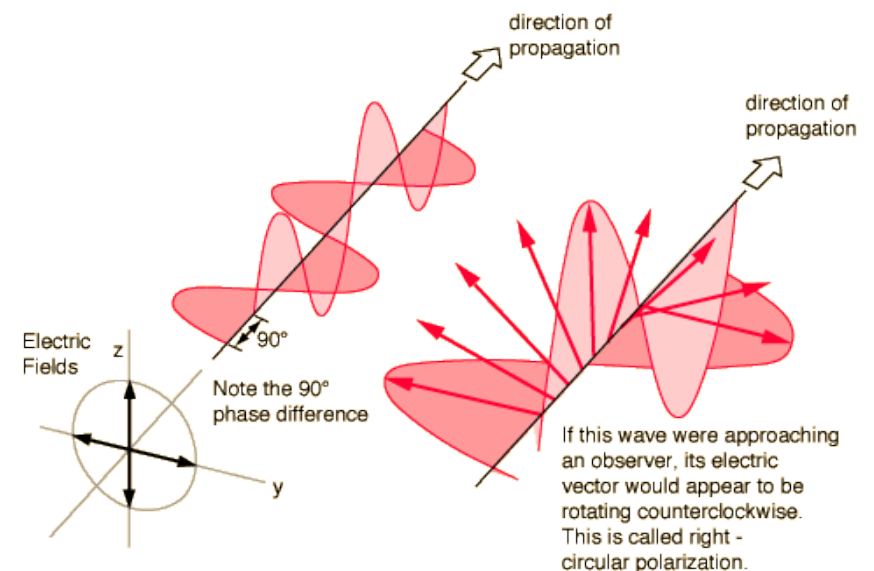
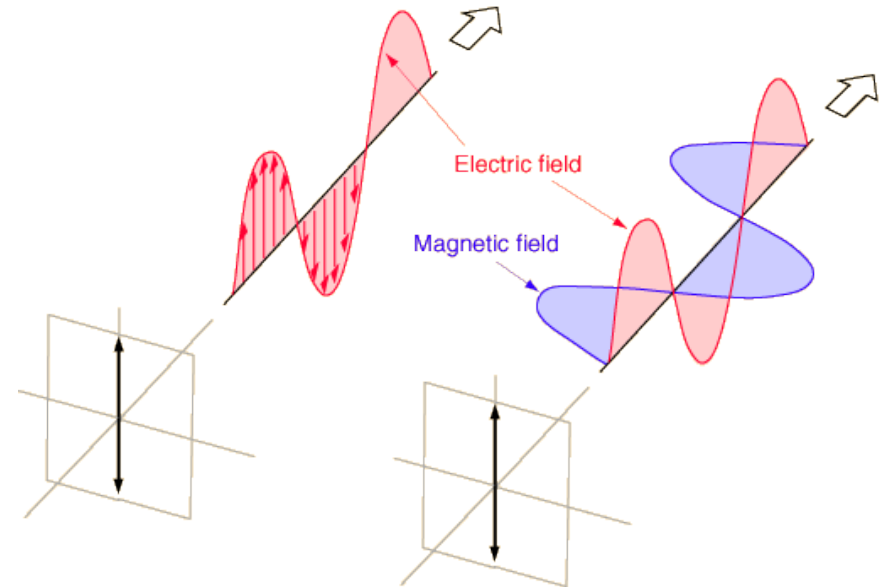
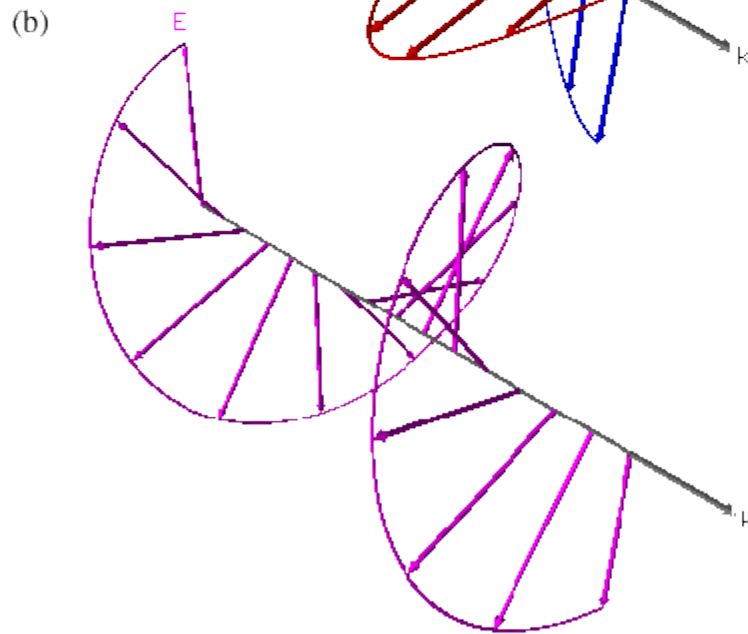
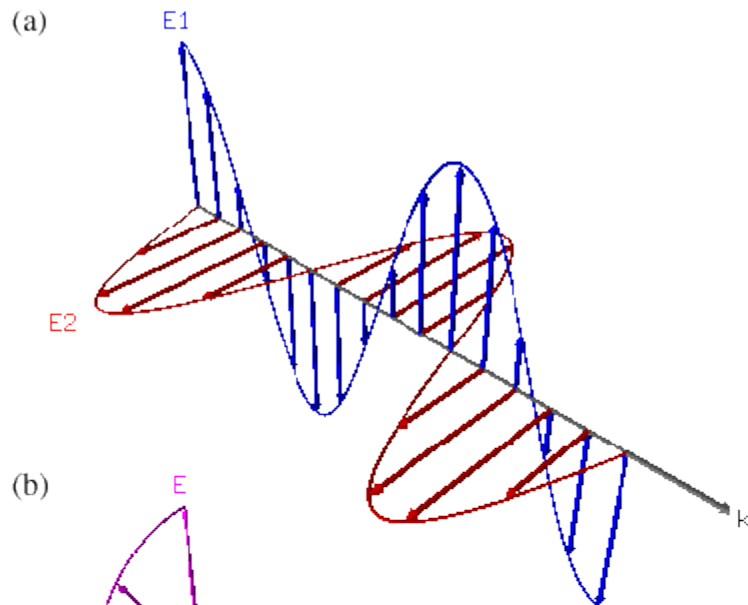
Light polarized in perpendicular planes exhibits different refractive indices in some crystalline materials - a property called birefringence. Prisms can be designed to use total internal reflection to eliminate one of the planes.

Birefringence

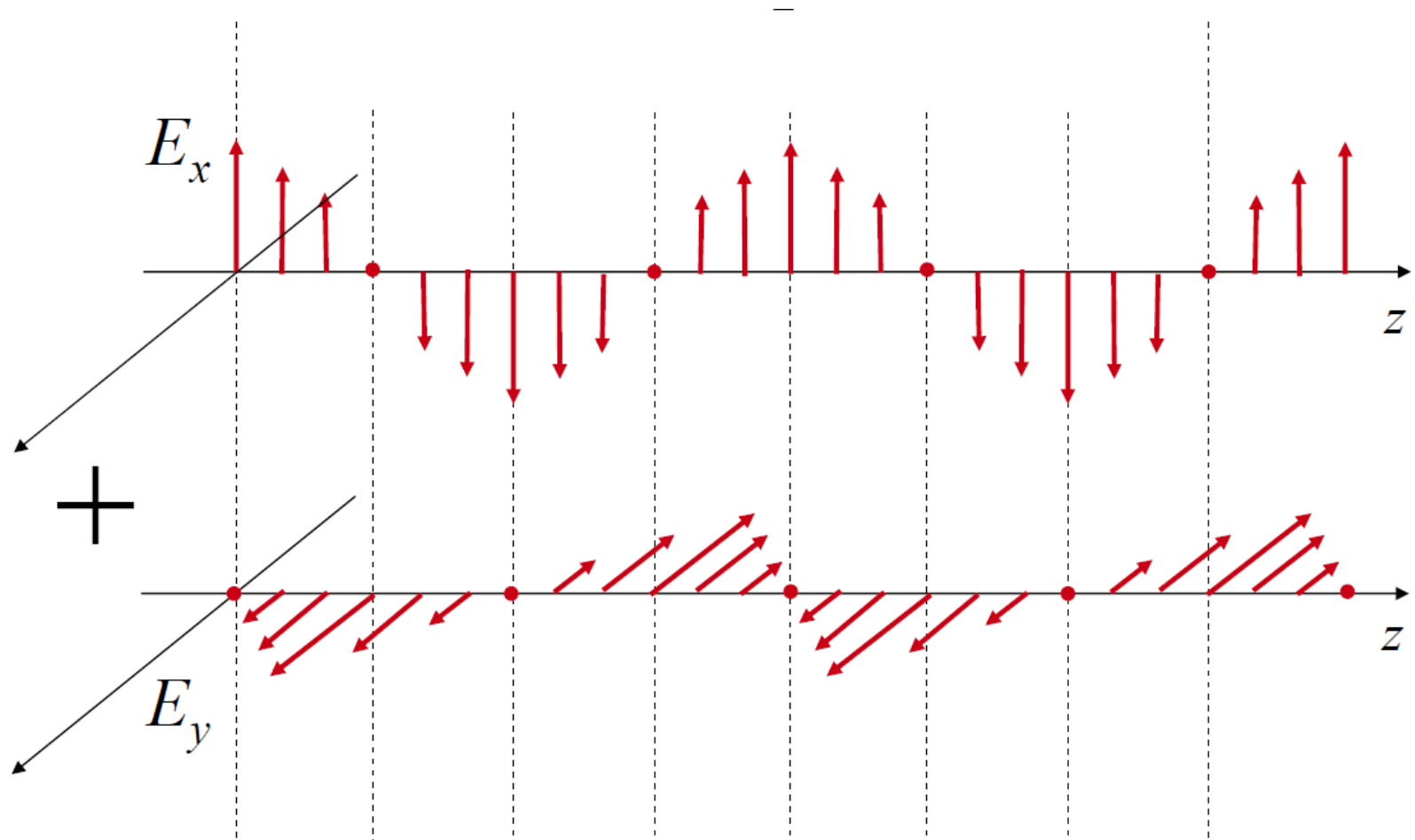


The reflection coefficient for light polarized in the plane of incidence is zero at the Brewster angle, leaving the reflected light at that angle linearly polarized. Electrons in the material act like dipole radiators and transmit no energy along their vibration axis.

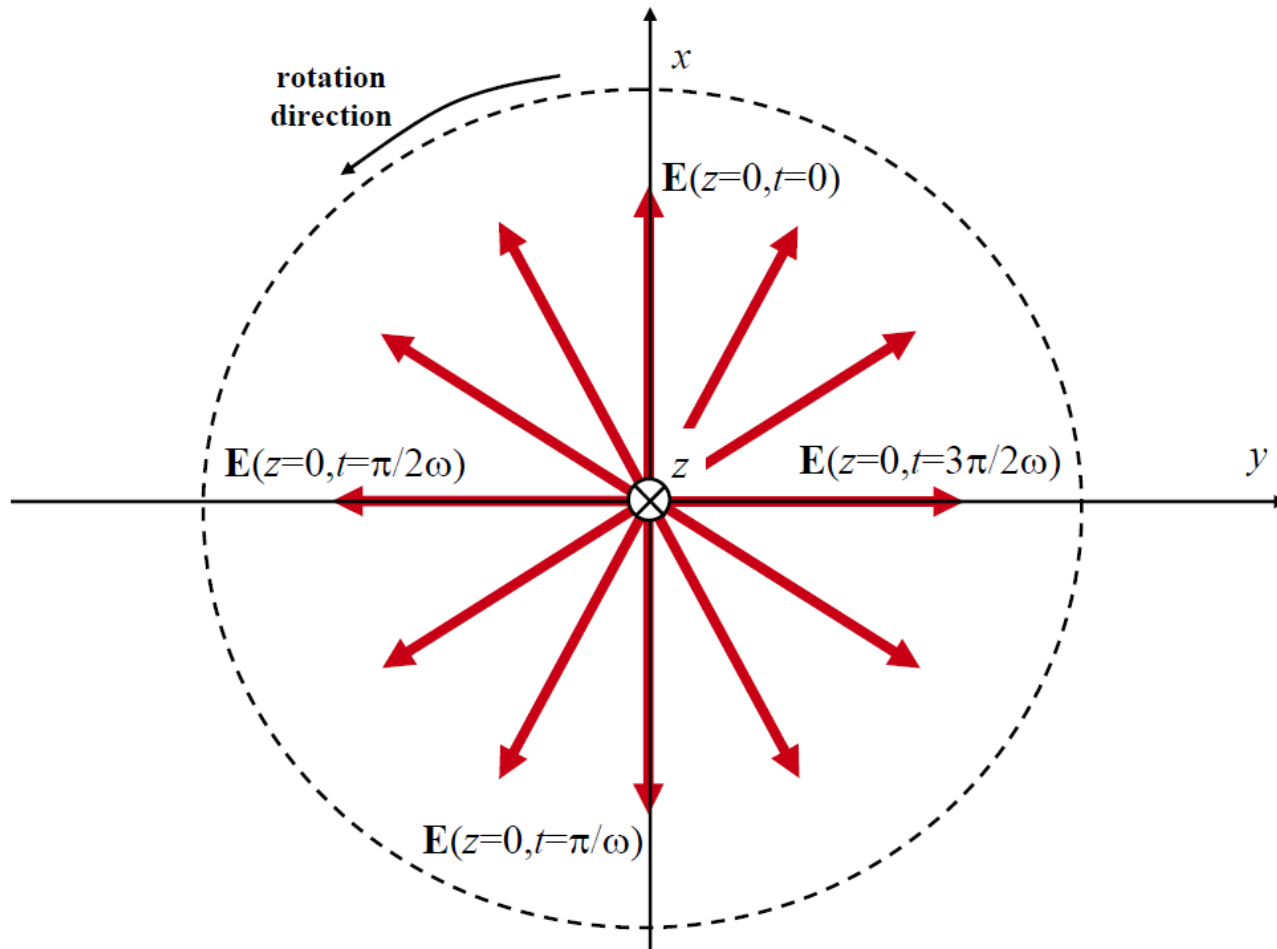
Linear versus Circular polarization



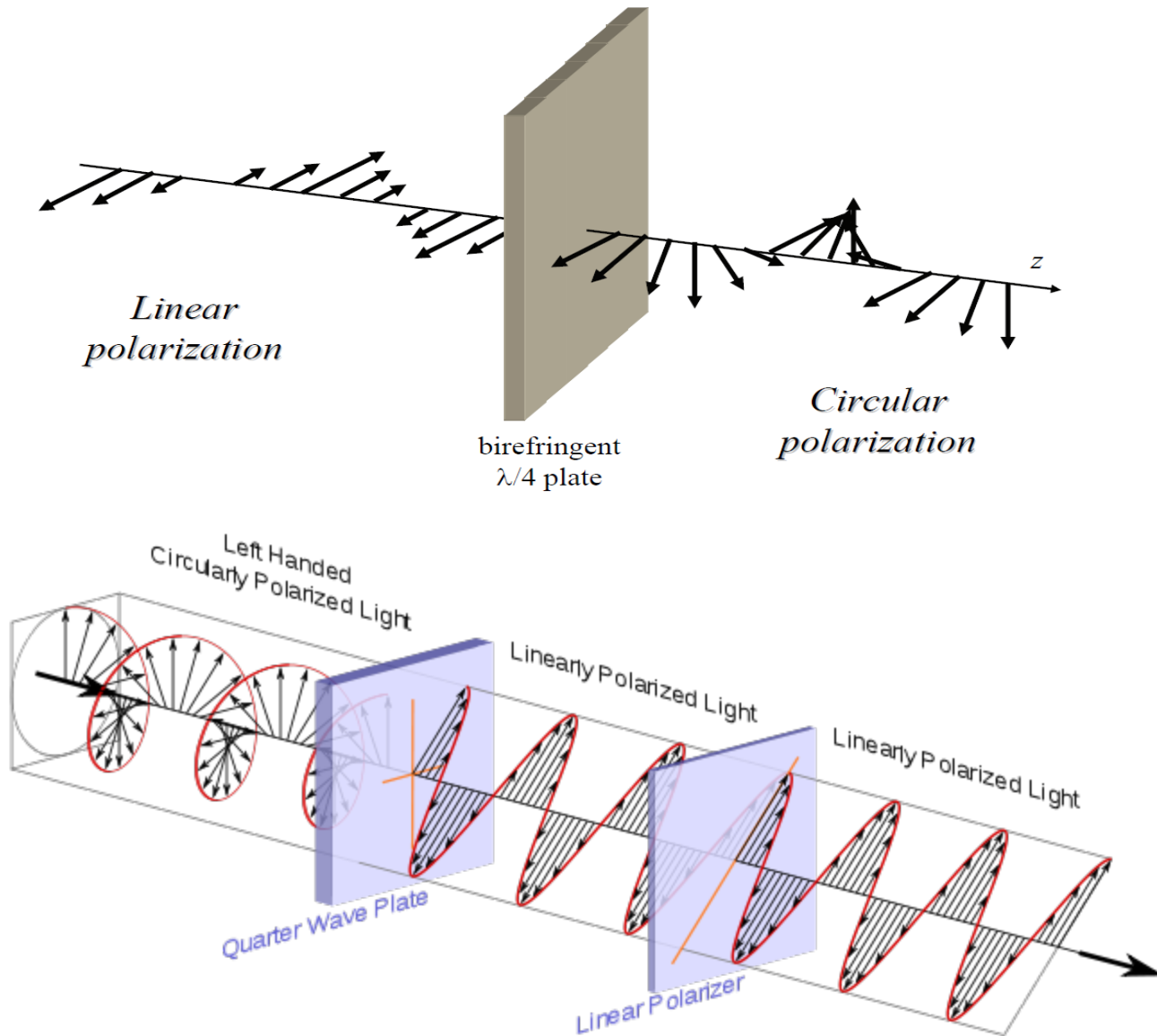
Circular polarization (linear components)



Circular polarization (fixed space)

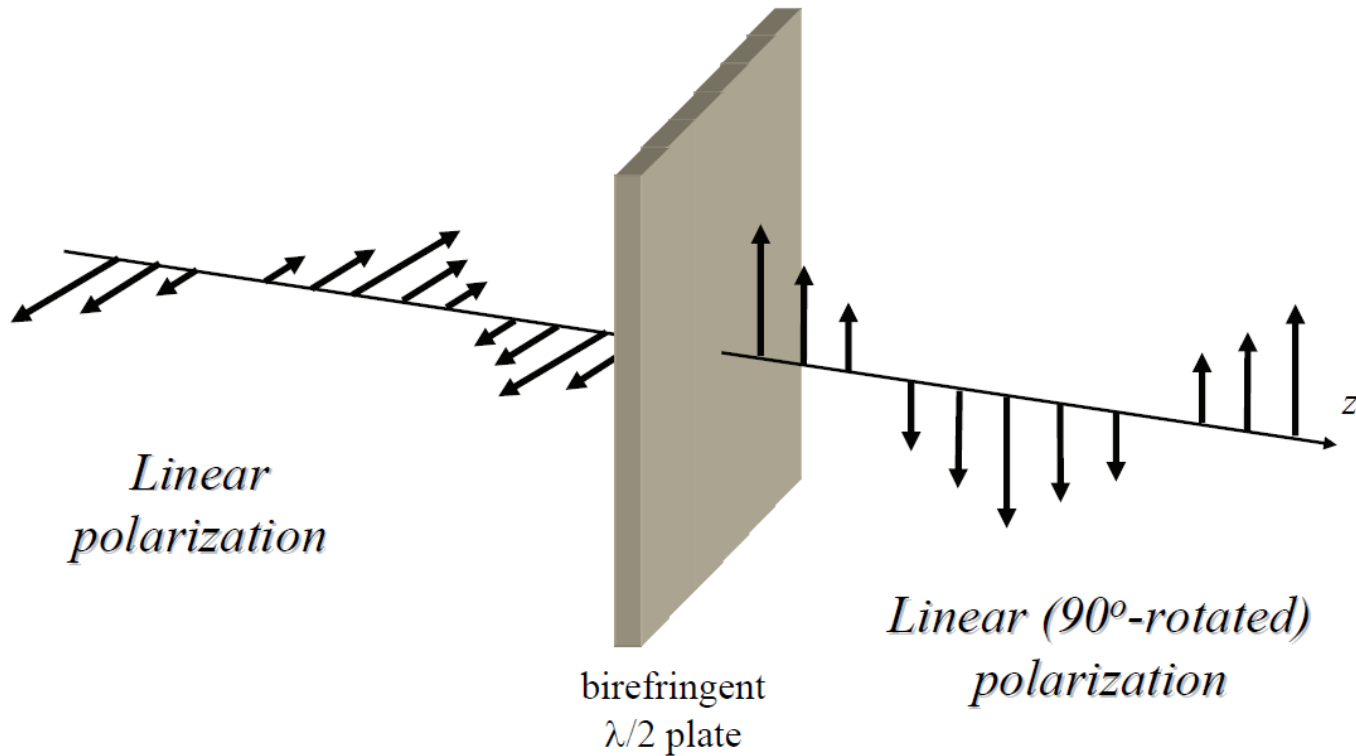


Quarter wave plate

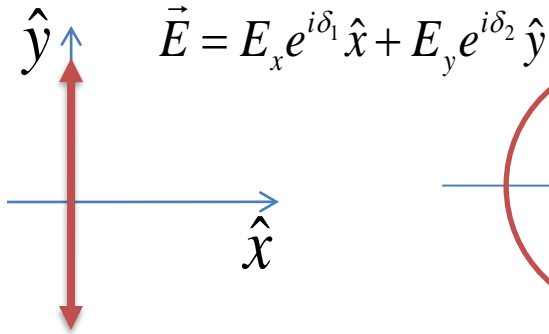


Half wave plate

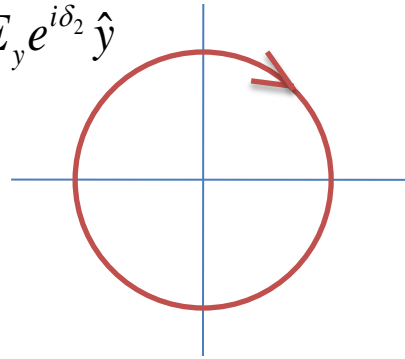
$\lambda/2$ plate



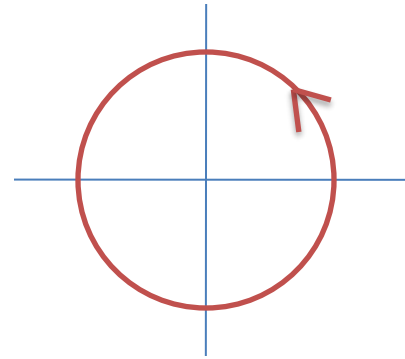
Polarization: Summary and Quiz



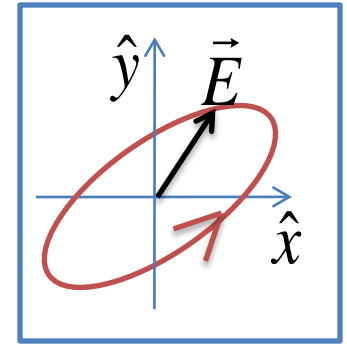
linear polarization
y-direction



right circular
polarization

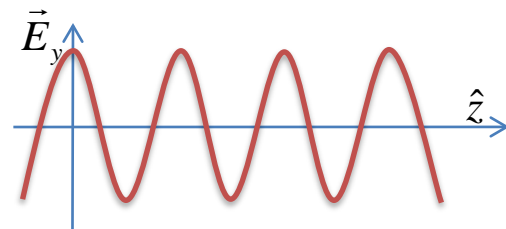
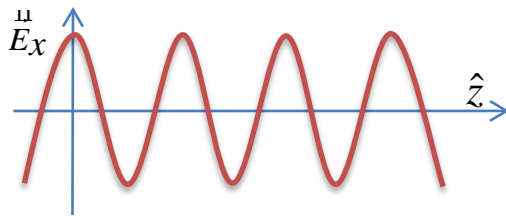


left circular
polarization

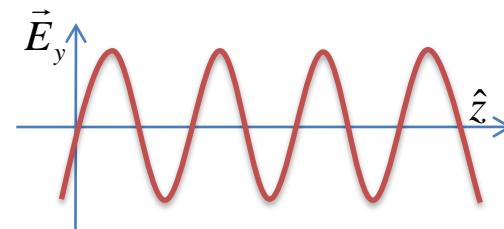
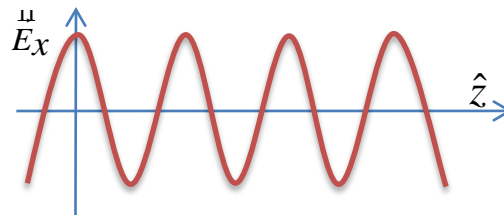


left elliptical
polarization

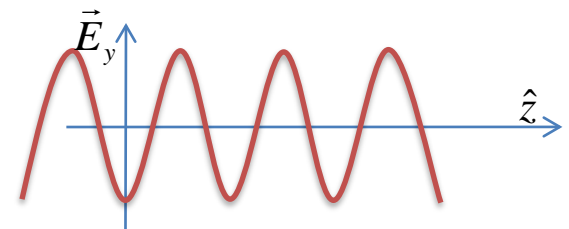
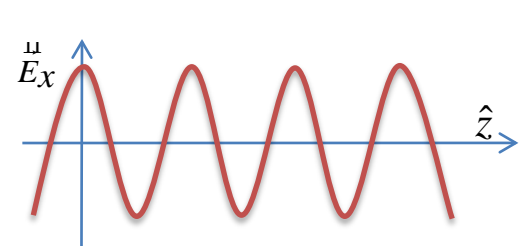
Phase difference = 0°



Phase difference \rightarrow
 $90^\circ (\pi/2, \lambda/4)$



Phase difference \rightarrow
 $180^\circ (\pi, \lambda/2)$



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

