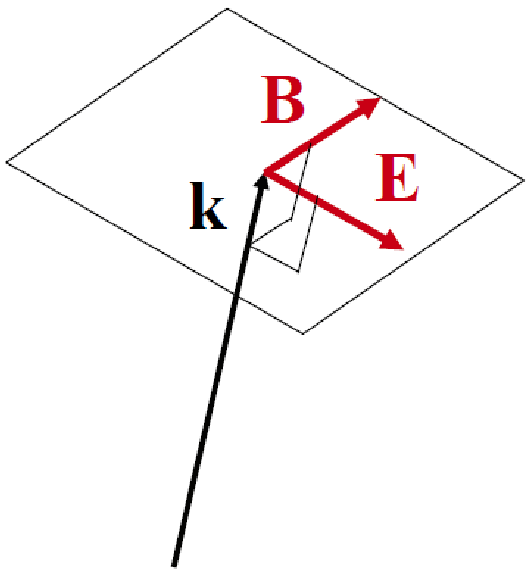
Propagation of EM Waves



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

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

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

Vectors **k**, **E**, **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.)

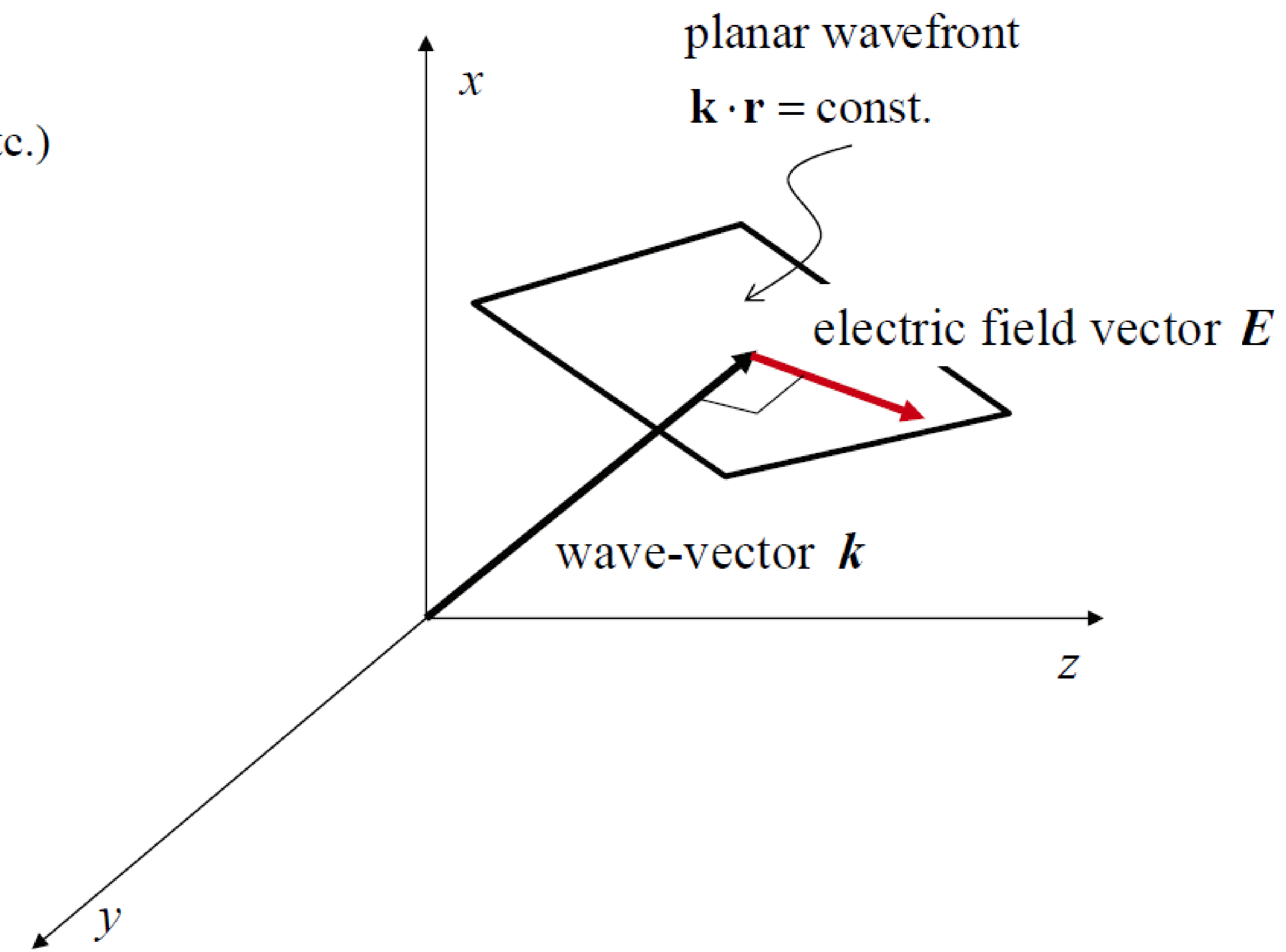
$\mathbf{k} \cdot \mathbf{E} = 0$

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

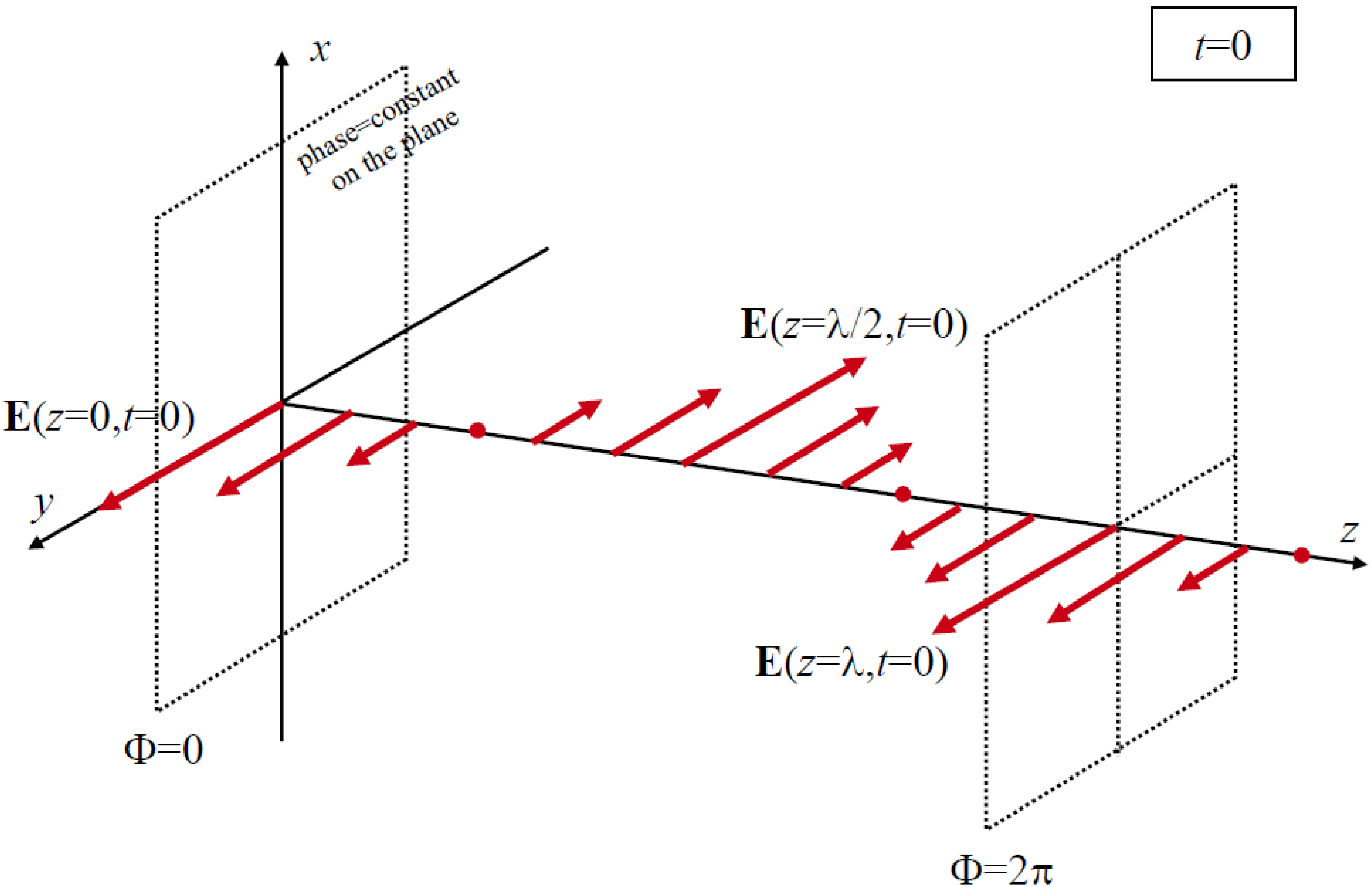
More generally,

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

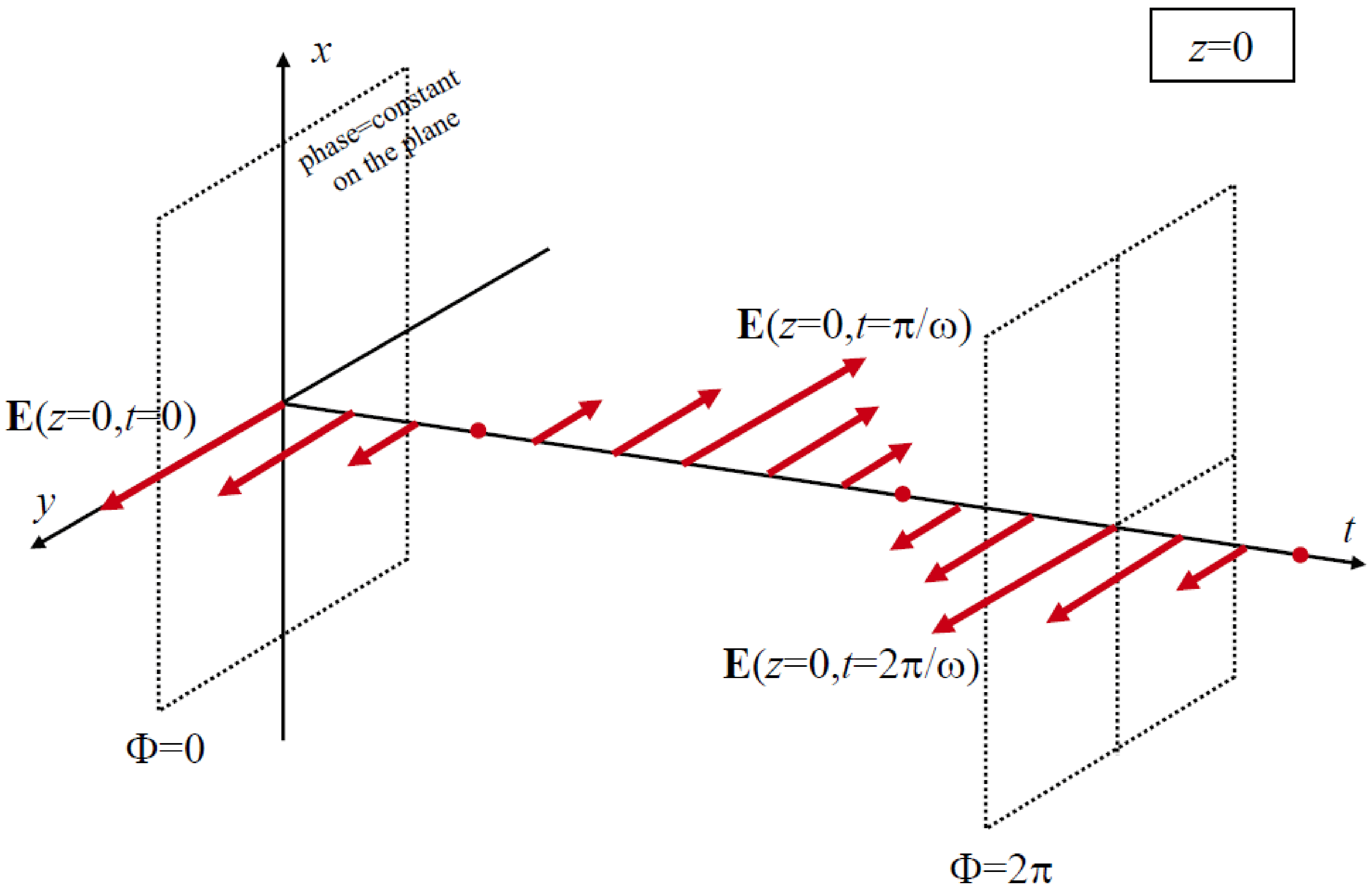
(reminder: in anisotropic media, e.g. crystals, one could have **E** not parallel to **D**)



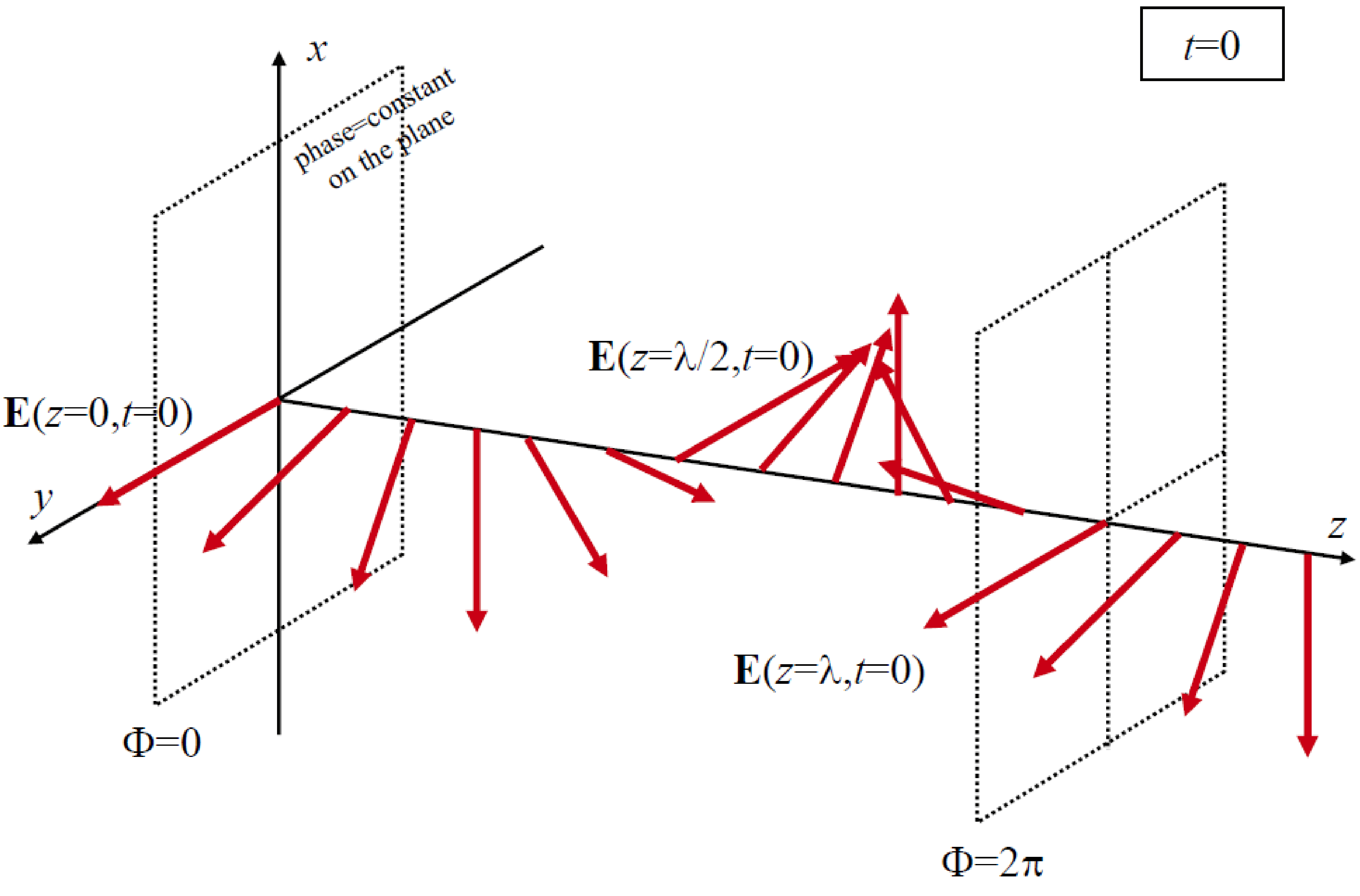
Linear polarization (frozen time)



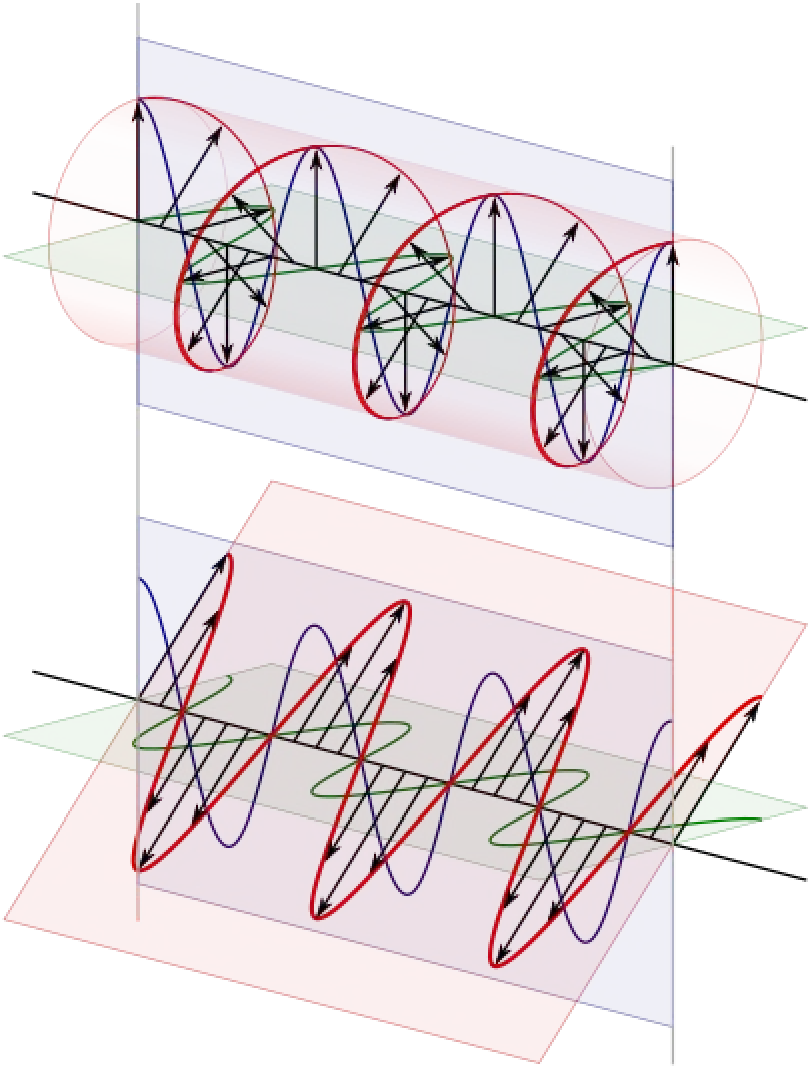
Linear polarization (fixed space)

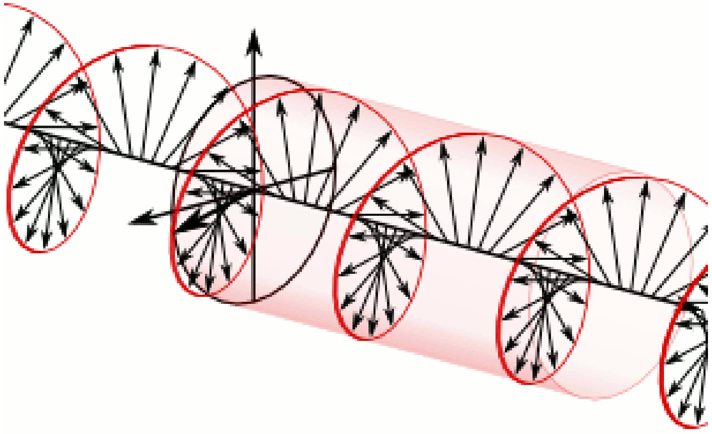


Circular polarization (frozen time)



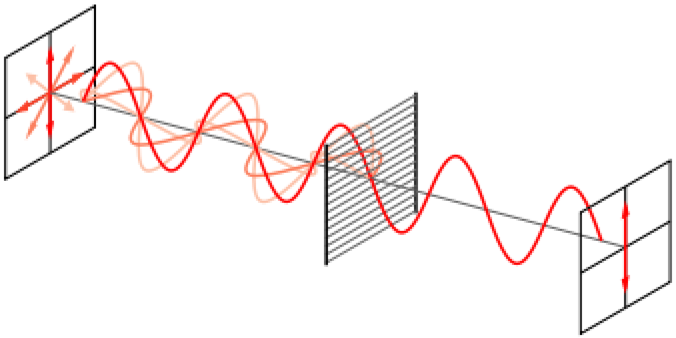
Linear vs. Circular Polarization

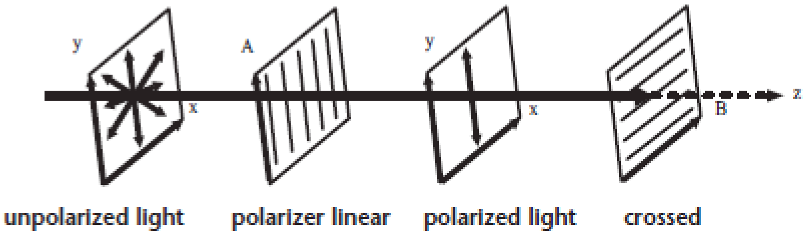


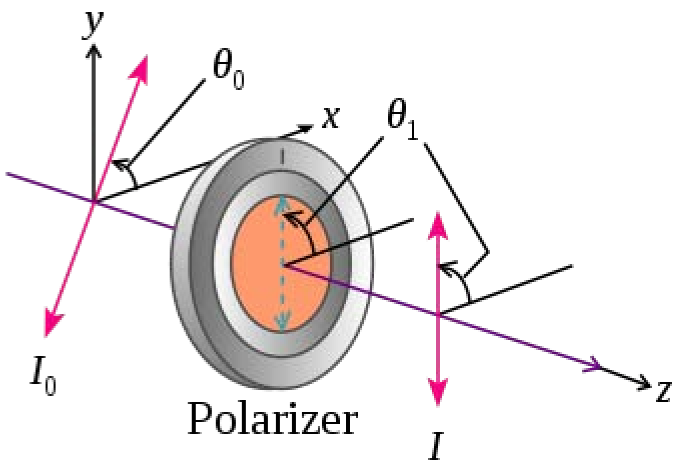


http://en.wikipedia.org/wiki/Polarizer

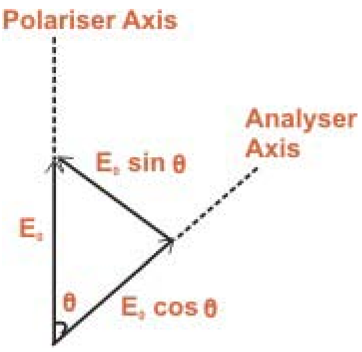
Working with Polarizers



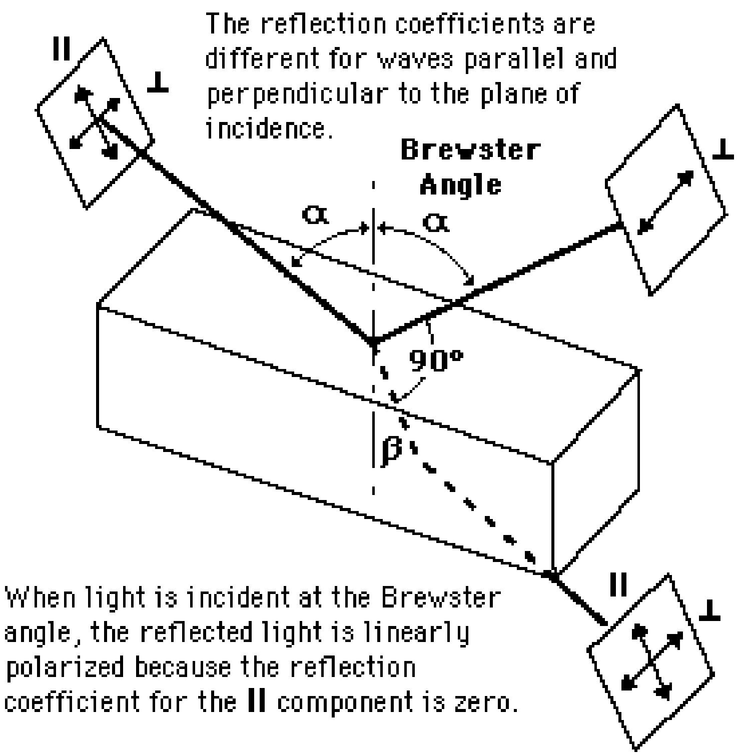


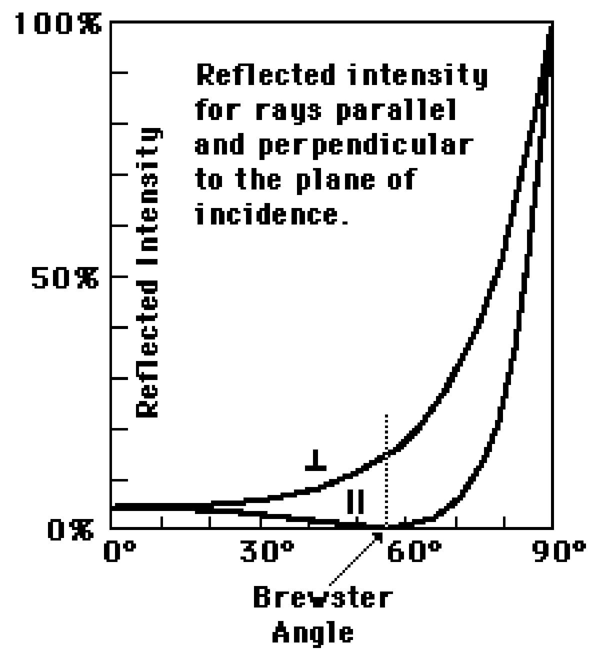


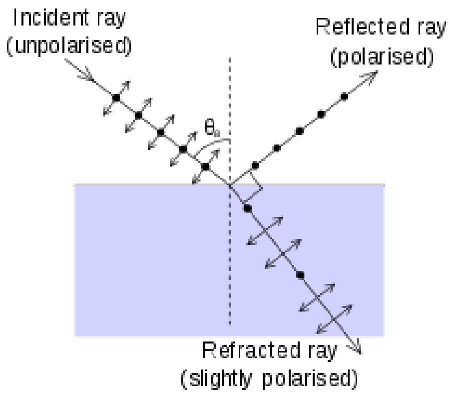
$$I = \frac{1}{2} c \epsilon_0 E_0^2 \cos^2 \theta = I_0 \cos^2 \theta,$$



Polarization by Reflection







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

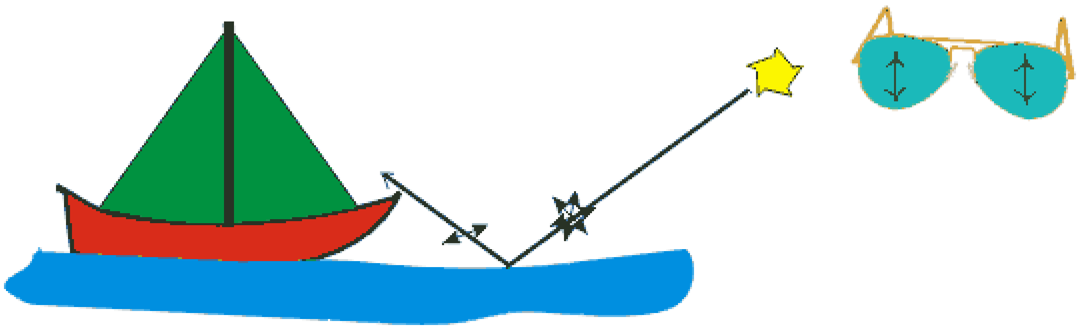
$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2),$$

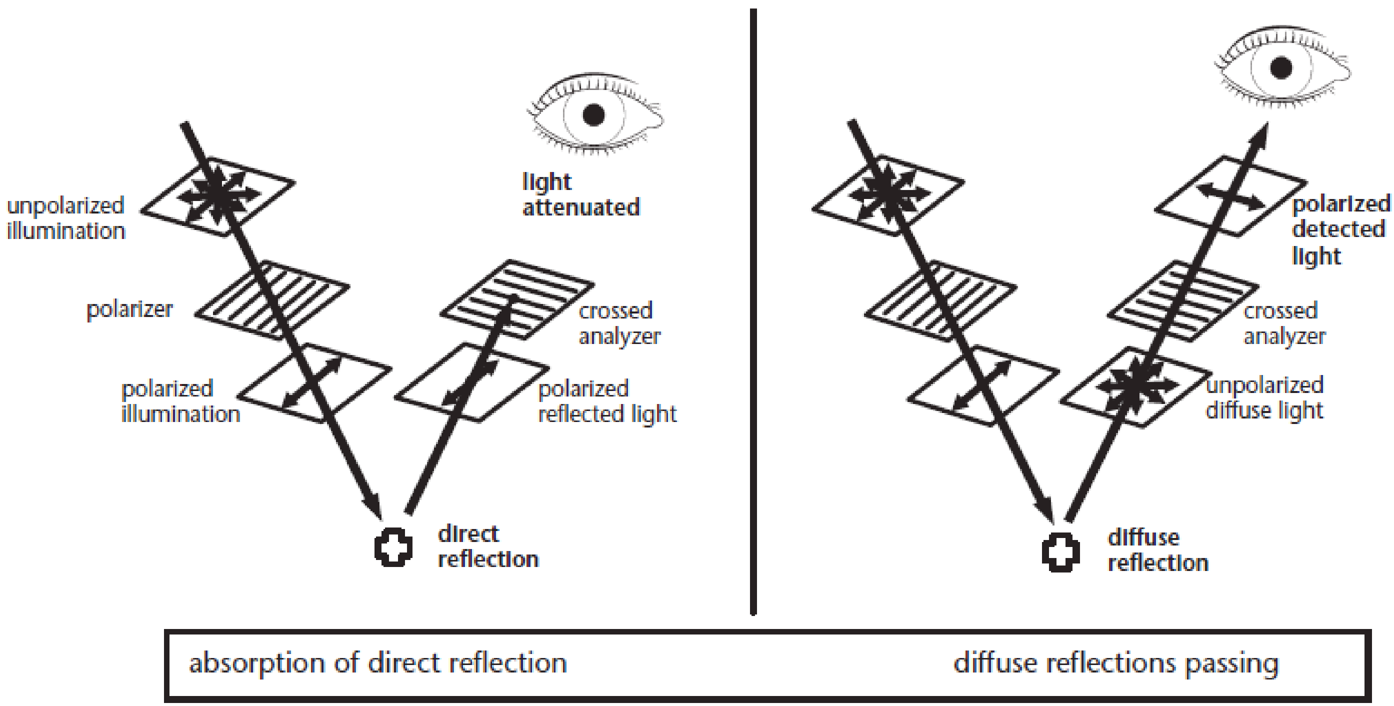
$$n_1 \sin(\theta_B) = n_2 \sin(90^\circ - \theta_B) = n_2 \cos(\theta_B).$$

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

Where is the turtle?

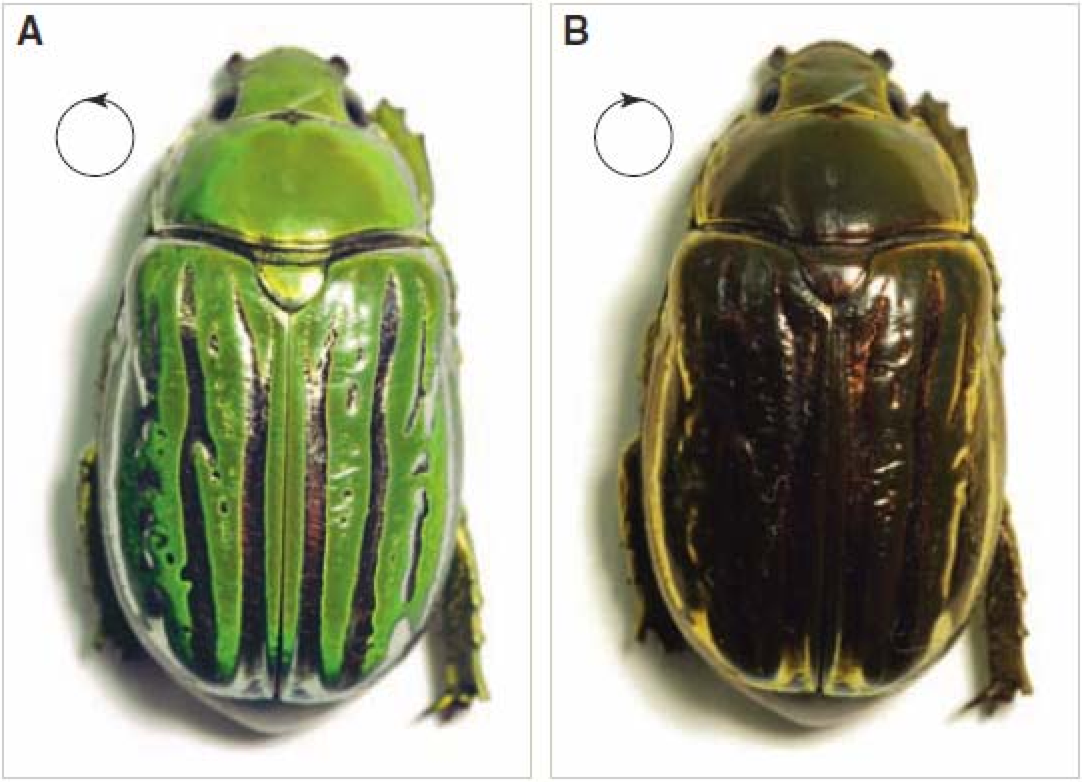
Polarized sunglasses





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.



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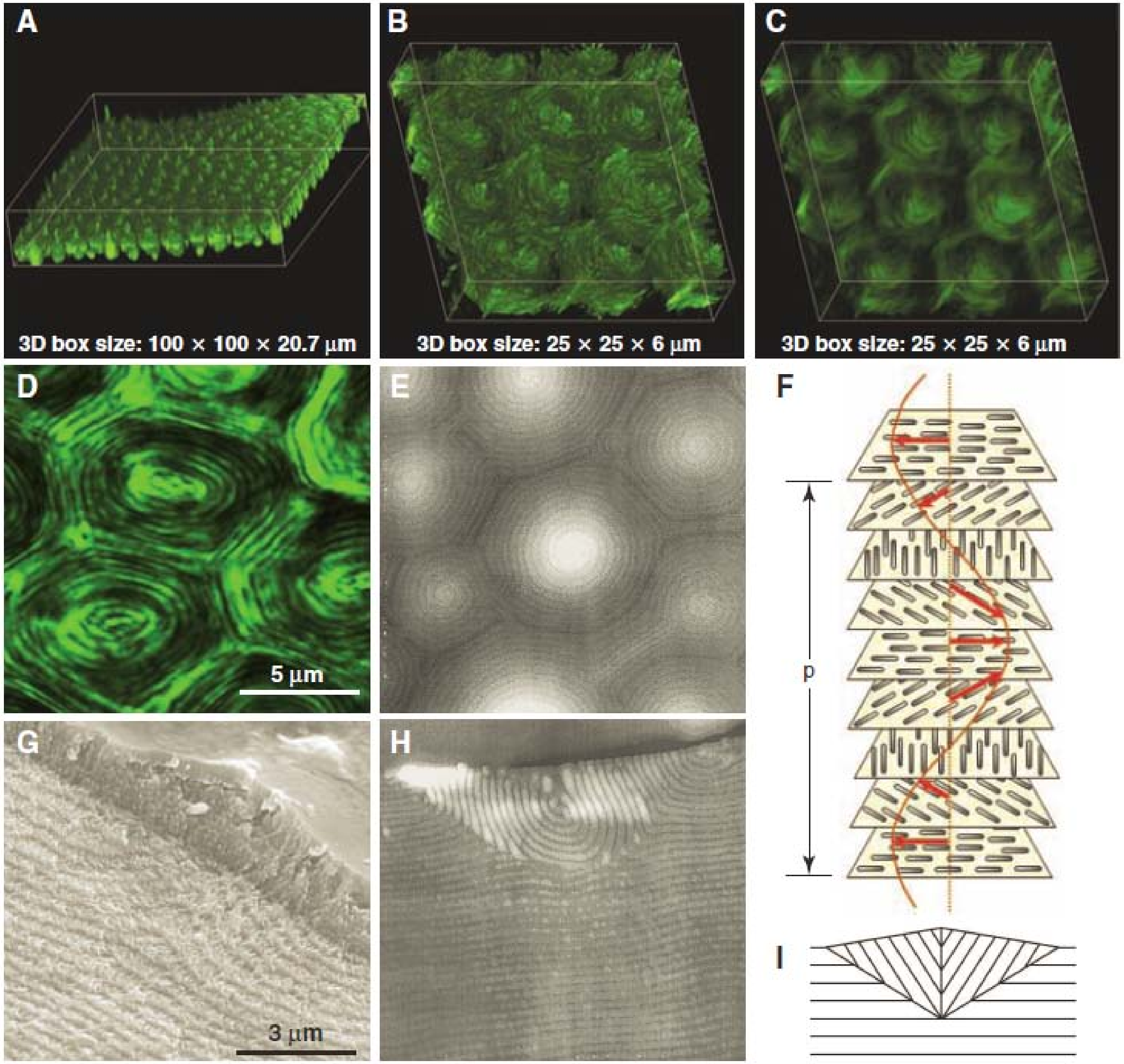
Morphology and microstructure of cellular pattern of C. gloriosa



Polarization by scattering (Rayleigh scattering/Blue Sky)

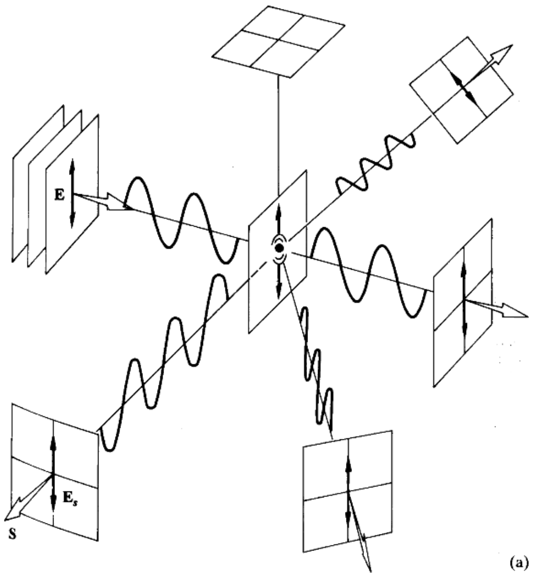


FIGURE 8.35*a* Scattering of polarized light by a molecule.

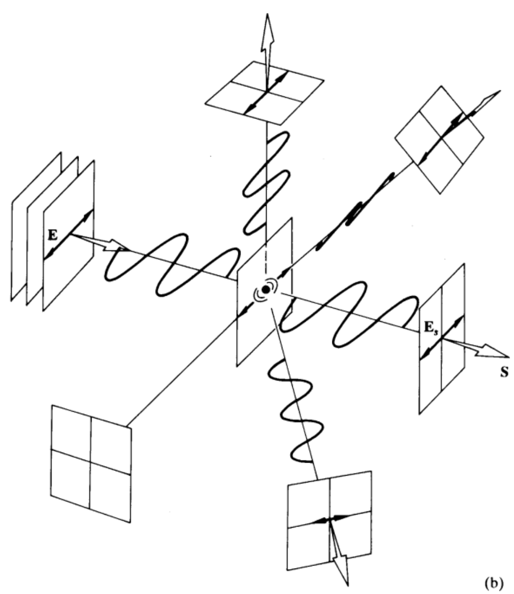


FIGURE 8.35*b*

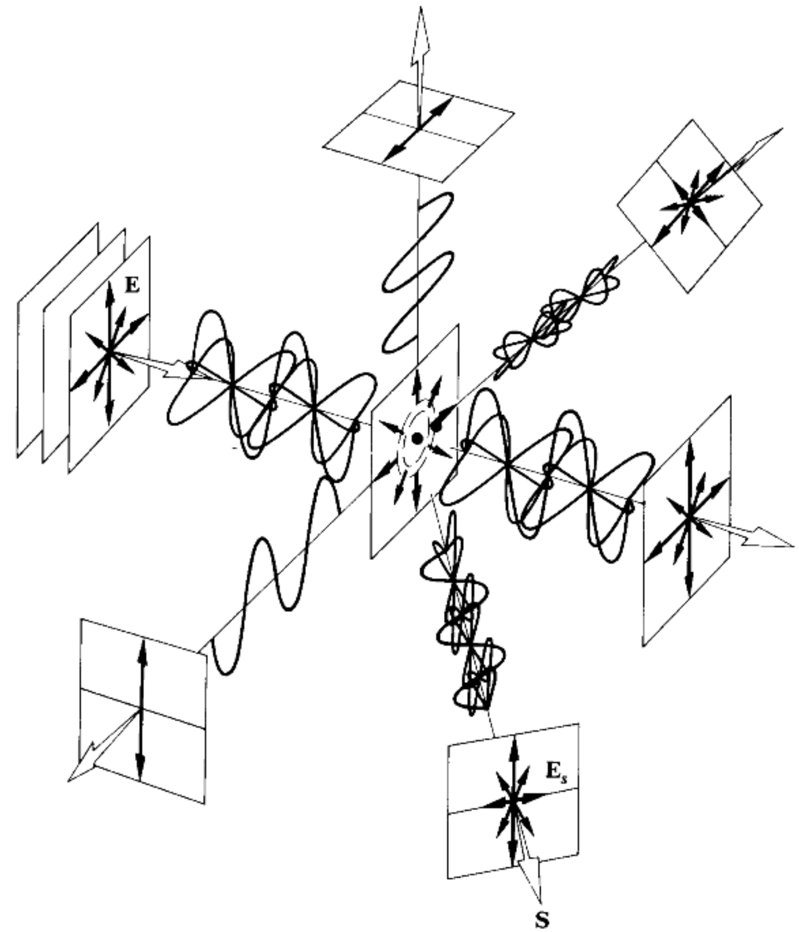
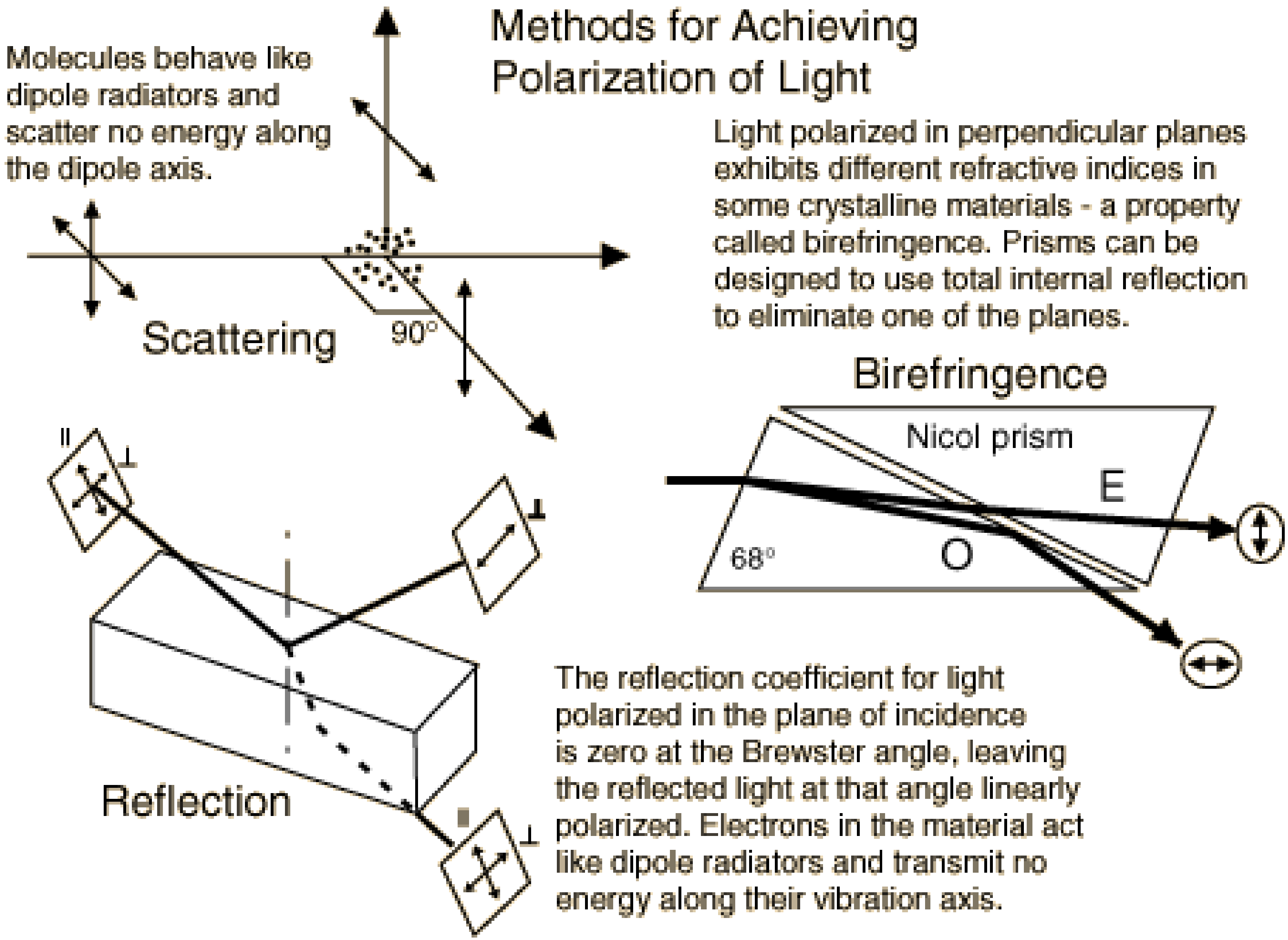


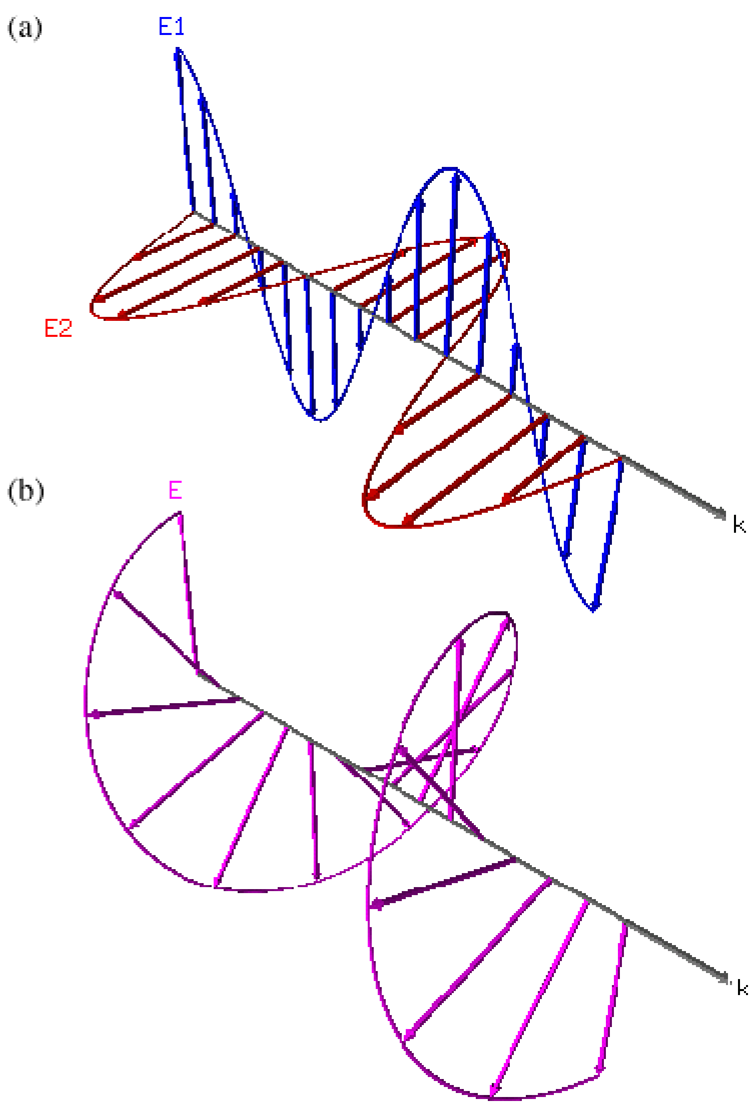
FIGURE 8.36 Scattering of unpolarized light by a molecule.

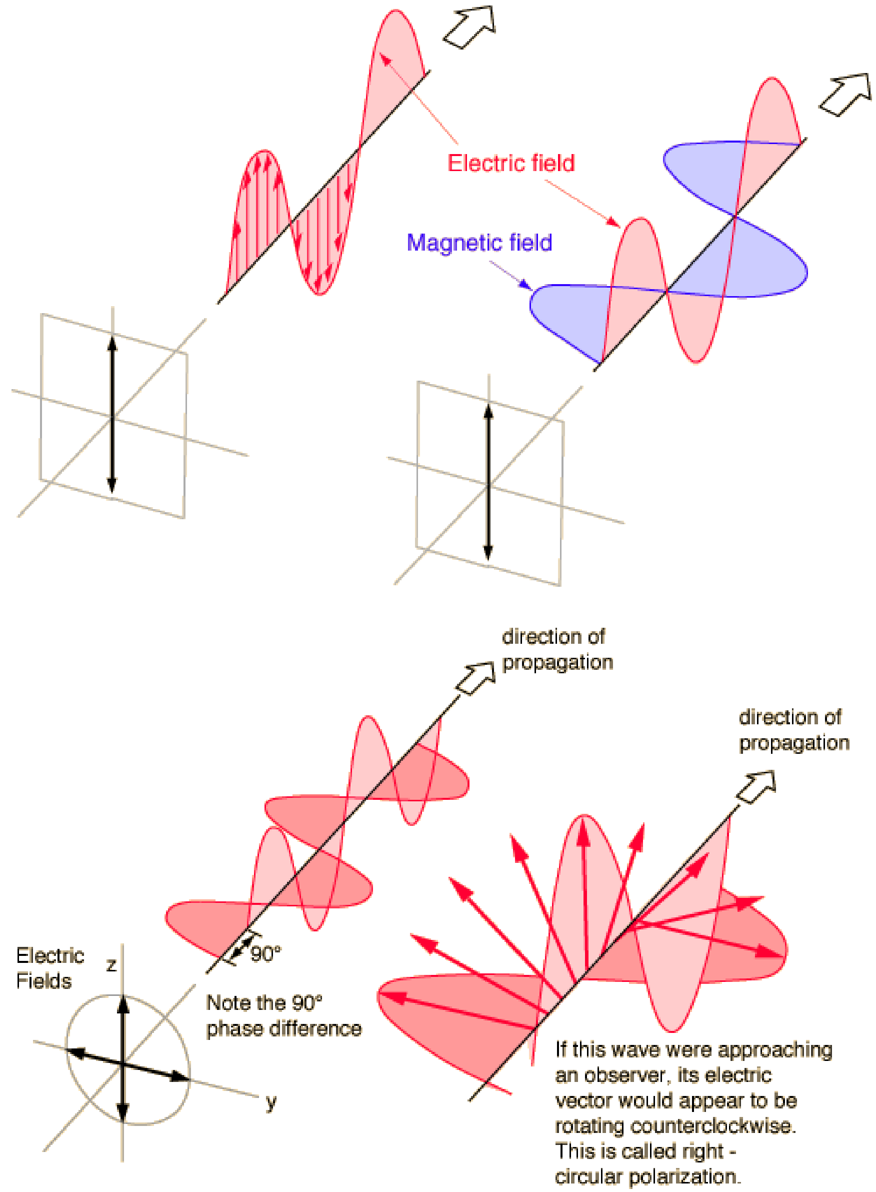
Methods for generating polarized light



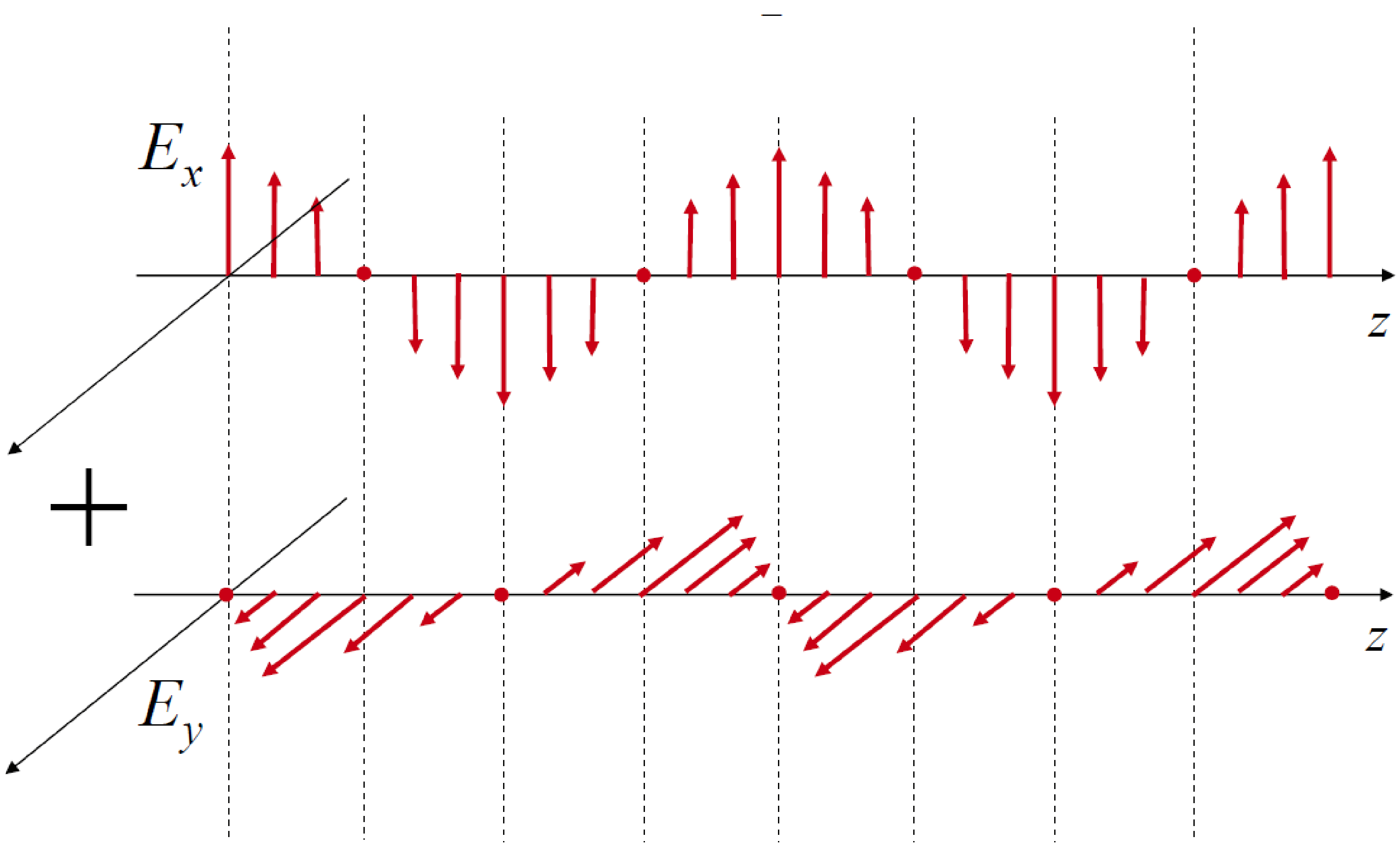
http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polar.html

Linear versus Circular polarization

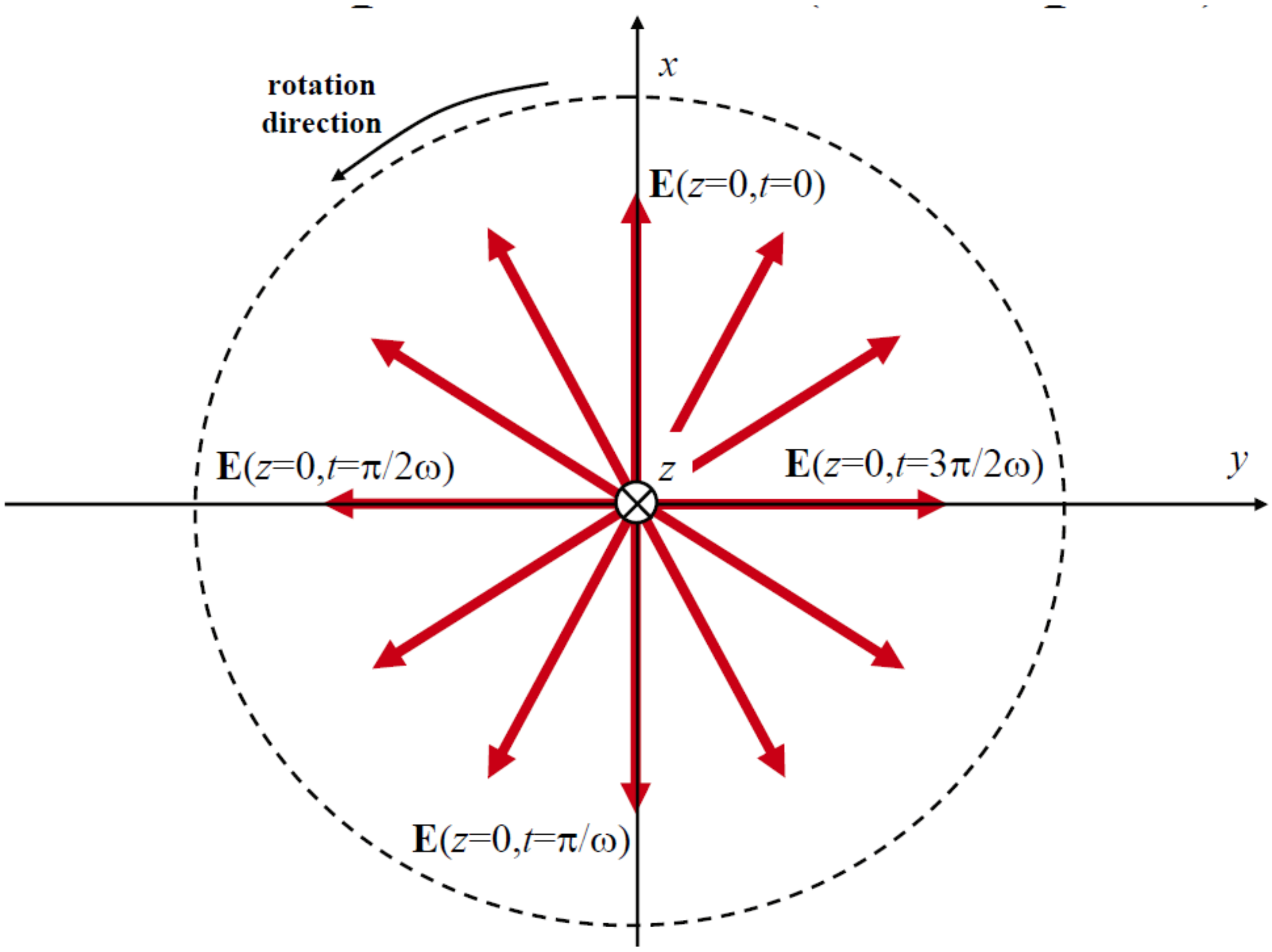




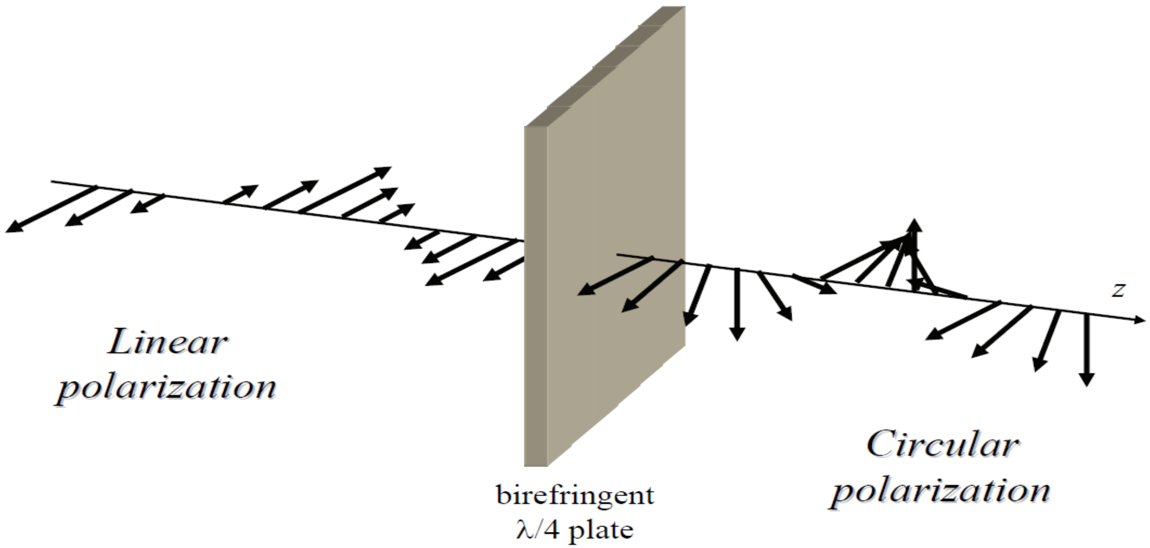
Circular polarization (linear components)

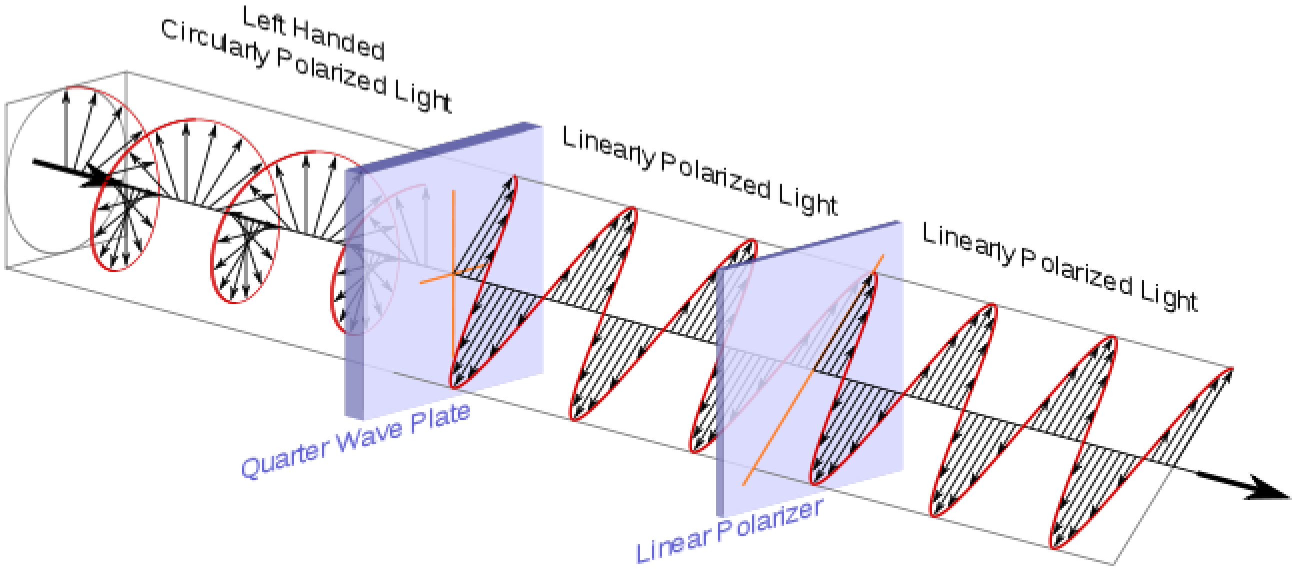


Circular polarization (fixed space)



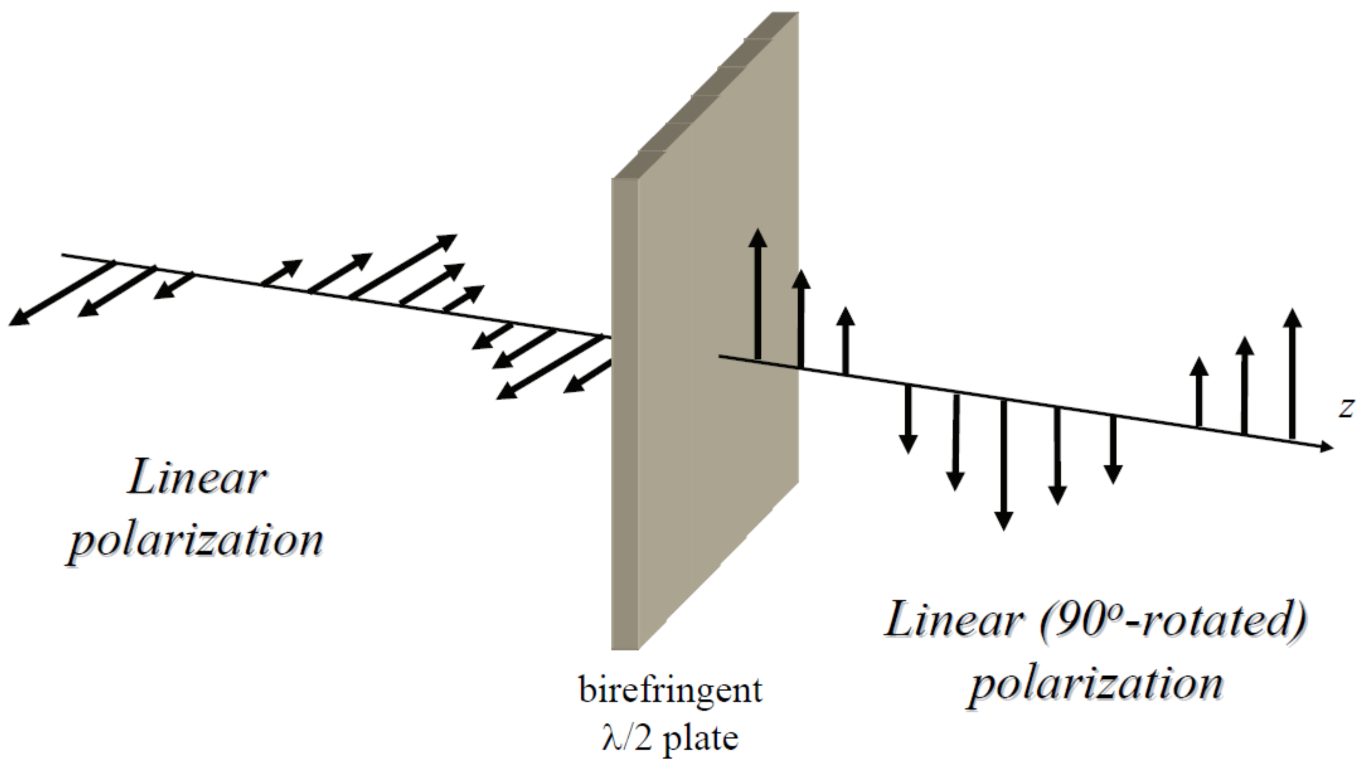
Quarter wave plate





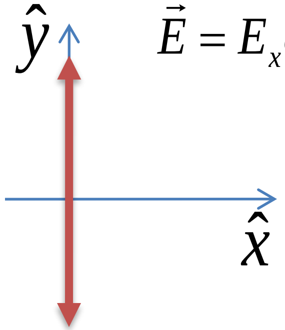
Half wave plate

λ/2 plate

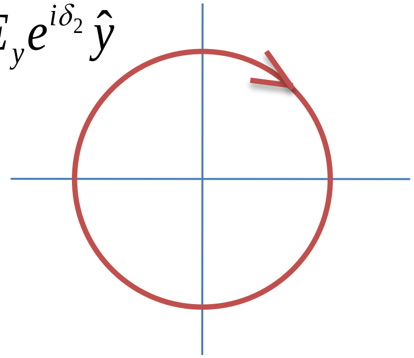


Polarization: Summary and Quiz

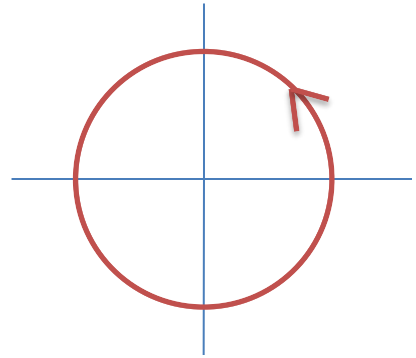
$$\vec{E} = E_x e^{i\delta_1}\hat{x} + E_y e^{i\delta_2}\hat{y}$$



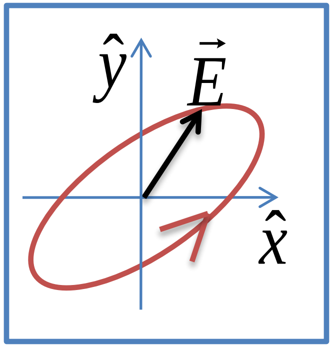
linear polarization
y-direction



right circular
polarization

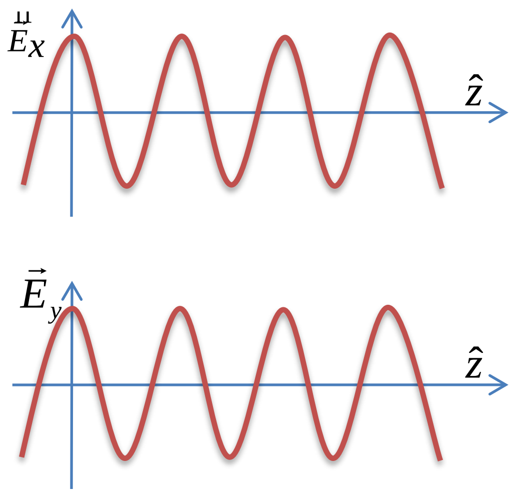


left circular
polarization

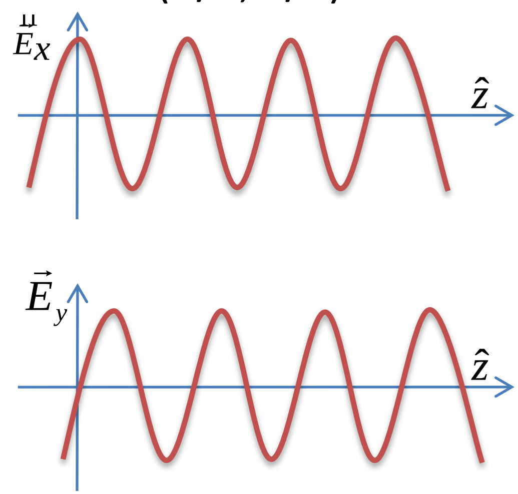


left elliptical
polarization

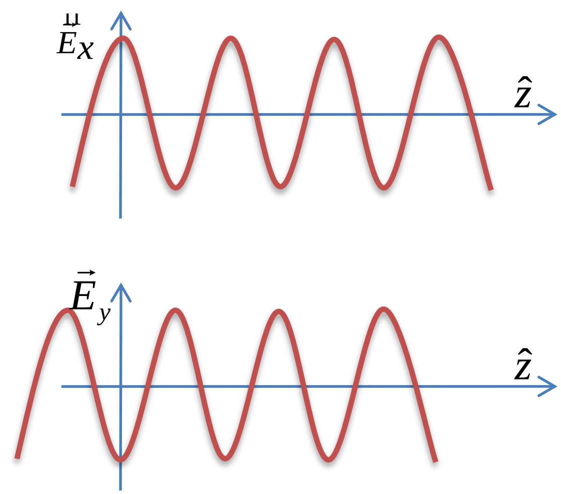
Phase difference = 0^0



Phase difference ➔
90^0 ($\pi/2$, $\lambda/4$)



Phase difference ➔
180^0 (π, $\lambda/2$)



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