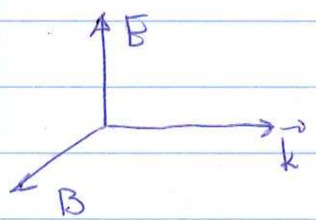
Polarization – direction of light's electric field

Up to now we often neglected the polarization, assuming that all the light we consider was polarized in the same direction. Let's be more careful now

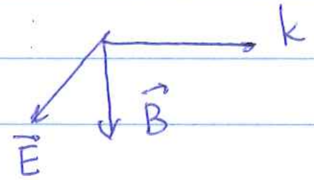
Assume the light propagates in z-direction
$\vec{E} \perp \vec{B} \perp \vec{k}$

One possibility $\vec{E}$ is in x-direction,
$\vec{B}$ —"— y-direction



$$\vec{E}_1 = E_1 \vec{e}_x \cos(kz - \omega t)$$

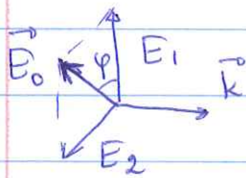
The other distinct possibility: $\vec{E}$ is in y-direction
$\vec{B}$ is in (-x)-direction



$$\vec{E}_2 = E_2 \vec{e}_y \cos(kz - \omega t)$$

In both cases the polarization is linear as $\vec{E}$ is always pointing along the same ~~dir~~ line
In fact, any combination of x- and y-linear polarizations is a linear polarization

$$\vec{E} = \vec{E}_1(z,t) + \vec{E}_2(z,t) = E_1 \vec{e}_x \cos(kz-\omega t) + E_2 \vec{e}_y \cos(kz-\omega t) =$$
$$= (E_1 \vec{e}_x + E_2 \vec{e}_y) \cos(kz-\omega t) = \vec{E}_0 \cos(kz-\omega t)$$



$$|E_0| = \sqrt{E_1^2 + E_2^2}$$
$$\tan\varphi = E_2 / E_1$$

Distinctly different polarization basis - circular polarizations, in which the direction of $\vec{E}$ changes, rotating around $\vec{k}$ direction (so $\vec{E}$ always stays $\perp$ to $\vec{k}$)

We can present a circular polarization as a combination of two orthogonal linear polarizations, offset by a quater-cycle.

$$\vec{E}_+ = \cancel{\tfrac{1}{\sqrt{2}}}(E_0 \vec{e}_x \cos(kz-\omega t) + E_0 \vec{e}_y \sin(kz-\omega t)) \qquad \sigma_+ \text{ polarized}$$
$$\vec{E}_- = \cancel{\tfrac{1}{\sqrt{2}}}(E_0 \vec{e}_x \cos(kz-\omega t) - E_0 \vec{e}_y \sin(kz-\omega t)) \qquad \sigma_- \text{ polarized}$$

$$|E_\pm(z,t)| = \sqrt{\left(\cancel{\tfrac{1}{\sqrt{2}}} E_0 \cos(kz-\omega t)\right)^2 + \left(\cancel{\tfrac{1}{\sqrt{2}}} E_0 \sin(kz-\omega t)\right)^2} =$$

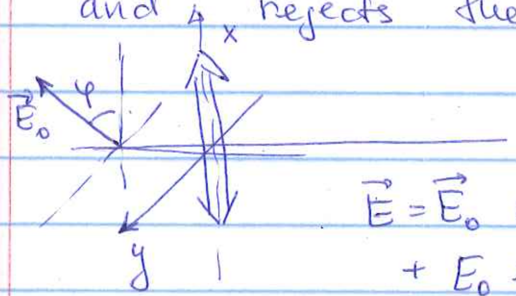
$$= E_0 \sqrt{\cos^2(kz-\omega t) + \sin^2(kz-\omega t)} = E_0$$

The magnitude of the electric field is always the same, but its direction makes a full revolution during each optical cycle.

In general, elliptically polarized light
$$E = E_1 \vec{e}_x \cos(kz-\omega t) \pm E_2 \vec{e}_y \sin(kz-\omega t) \qquad E_1 \neq E_2$$
can be presented as a combination of a linear and circular polarization.

Polarizer — a device that ~~transmits~~ discriminate light on the basis of its polarization

Linear polarizer — transmits one linear polarization and rejects the other



Let the polarizer transmit only x-polarized light

$$\vec{E} = \vec{E}_0 \cos(kz-\omega t) = E_0 \cos\varphi\, \vec{e}_x \cos(kz-\omega t) + \underbrace{E_0 \sin\varphi\, \vec{e}_y \cos(kz-\omega t)}_{\text{killed by the polarizer}}$$

After the polarizer $\vec{E}_{tr} = E_0 \cos\varphi\, \vec{e}_x \cos(kz-\omega t)$

Intensity $I \propto \langle |E|^2 \rangle_{time}$

Initial light intensity $I_0 \propto E_0^2$

After the polarizer $I_{tr} \propto E_0^2 \cos^2\varphi$

$$\boxed{I_{tr} = I_0 \cos^2\varphi}$$

Aligned polarizer $\varphi = 0$ $I_{tr} = I_0$

Crossed polarizers $\varphi = 90°$ $I_{tr} = 0$

Circularly polarized light — $I_{tr} = \frac{1}{2} I_0$ for any orientation of the polarizer!