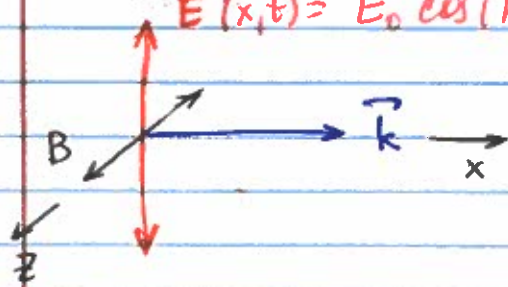


Light polarization*

polarization is a popular term in physics, even in optics / ~~even~~ electromagnetism it may have two different meanings. Beware!

Light polarization = direction along which electric component of EM wave oscillates

y ↑

$$\vec{E}(x,t) = \vec{E}_0 \cos(kx - \omega t) = E_0 \hat{y} \cos(kx - \omega t)$$


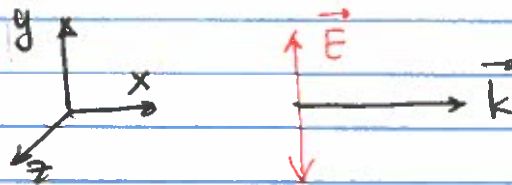
This particular wave is linearly polarized

(i.e. the $\vec{E}(x,t)$ oscillates ~~in~~ along one line)

Specifically, linearly polarized in y-direction.

For a wave propagating in x-direction $\vec{E}(x,t)$ must be in y-z plane

Vertically-polarized light (y-polarized)



Horizontally-polarized light (z-polarized)



Arbitrary angle (at angle θ to the vertical)



To say anything

Reminder: when we observe the light brightness (intensity), we measure absolute value squared of wave's amplitude

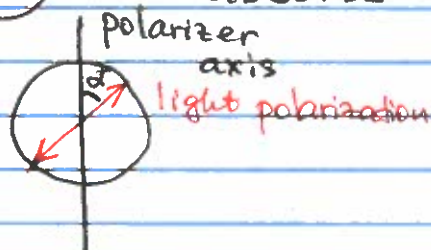
$$\vec{E} = E_0 \hat{y} \cos(kx - \omega t) \quad - \text{em wave}$$

Intensity $I = \frac{c\epsilon_0}{2} |E_0|^2$ independent of polarization

Polarizer - optical element that transmits (and sometimes reflects) light depending on its polarization

Simple (absorptive) polarizer - transmits light ~~at~~ that is parallel to its axis, and with polarization

absorbs light that is perpendicular



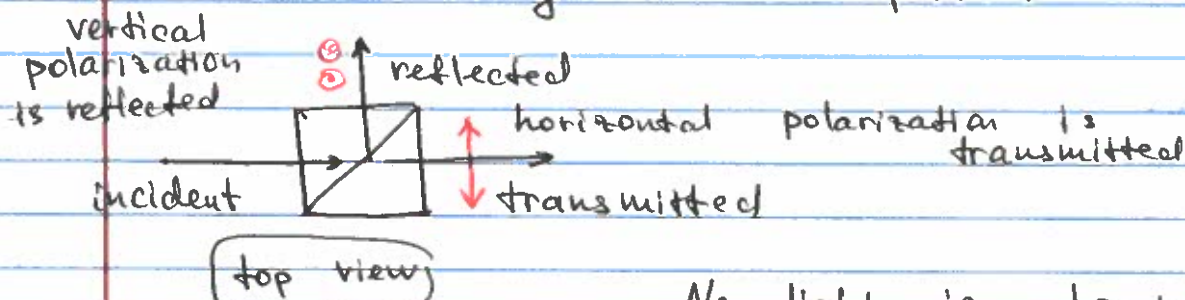
$$I_{\text{transm}} = I_{\text{initial}} \cos^2 \alpha$$

Malus law

$d=0$, $\cos d=1$, ~~all~~ light polarization is along the polarizer axis, all light is transmitted (for an ideal polarizer)

$d=90^\circ$, $\cos d=0$ no light is transmitted

Polarizing beam splitter



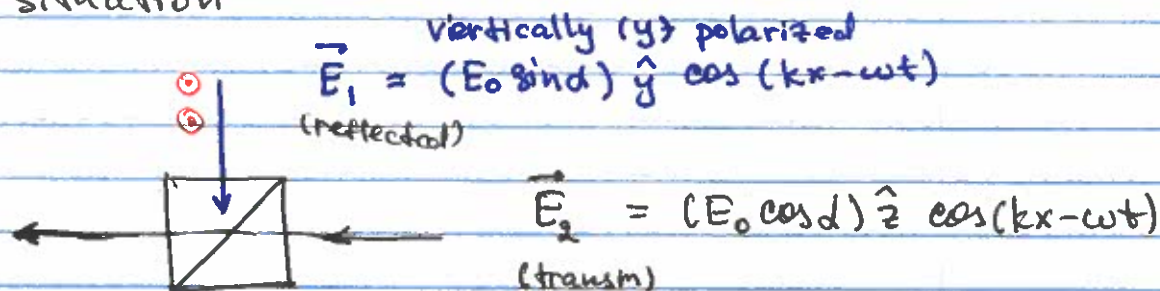
No light is absorbed, but it gets split/redirectioned depending on the polarization

Malus law still works : $I_{\text{transm}} = I_0 \cos^2 d$

$$\begin{aligned} \text{Reflected intensity } I_{\text{ref}} &= I_0 - I_{\text{transm}} = \\ &= I_0 - I_0 \cos^2 d = I_0 (1 - \cos^2 d) = I_0 \sin^2 d \\ \underline{I_{\text{ref}} &= I_0 \sin^2 d} \end{aligned}$$

Any linear polarization can be represented as a combination of two orthogonal linear polarization with different amplitudes

Let's mentally invert the beamsplitter situation



$$\begin{aligned} \vec{E} &= \vec{E}_1 + \vec{E}_2 = \left(E_0 \sin d \hat{y} + E_0 \cos d \hat{z} \right) \cos(kx - \omega t) \\ &\quad \underbrace{\hspace{10em}}_{\vec{E}_0} \end{aligned}$$

For any e-m wave, linearly polarized in y-z plane:

$$\vec{E}_0 = E_0 (\sin d \hat{y} + \cos d \hat{z})$$

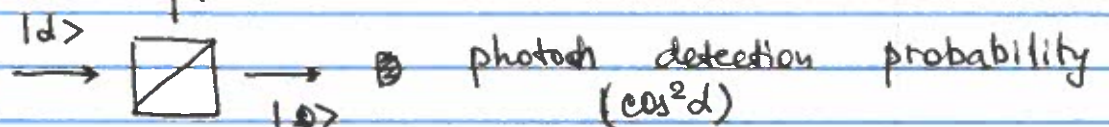
polarization vector

	$d=0$	$\sin d=1$	$\cos d=0$	$\vec{E}_0 = E_0 \hat{y}$	vertical
	$d=90^\circ$	$\sin d=0$	$\cos d=1$	$\vec{E}_0 = E_0 \hat{z}$	horizontal
	$d=45^\circ$	$\sin d = \cos d = \frac{1}{\sqrt{2}}$		$\vec{E}_0 = E_0 \frac{\hat{y} + \hat{z}}{\sqrt{2}}$	diagonal
	$d=-45^\circ$	$\sin d = -\frac{1}{\sqrt{2}}$	$\cos d = \frac{1}{\sqrt{2}}$	$\vec{E}_0 = E_0 \frac{-\hat{y} + \hat{z}}{\sqrt{2}}$	other diagonal

In quantum information polarizations are often used to create qubits

vertically polarized photon	$ \uparrow\rangle$	logical "1"
horizontally — " —	$ \rightarrow\rangle$	logical "0"

polarization at angle d : $|d\rangle = \sin d |\uparrow\rangle + \cos d |\rightarrow\rangle$
 photon detection prob ($\sin^2 d$) quantum superposition



$$|\nearrow\rangle = \frac{1}{\sqrt{2}} |\uparrow\rangle + \frac{1}{\sqrt{2}} |\rightarrow\rangle$$

$$|\searrow\rangle = -\frac{1}{\sqrt{2}} |\uparrow\rangle + \frac{1}{\sqrt{2}} |\rightarrow\rangle$$

$\Leftrightarrow$

$$|\leftrightarrow\rangle = \frac{1}{\sqrt{2}} |\nearrow\rangle + \frac{1}{\sqrt{2}} |\searrow\rangle$$

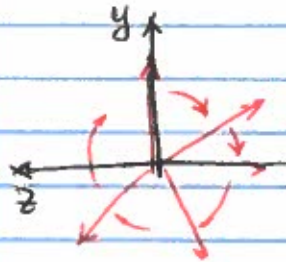
$$|\downarrow\rangle = \frac{1}{\sqrt{2}} |\nearrow\rangle - \frac{1}{\sqrt{2}} |\searrow\rangle$$

basis change

Circular polarization: $\vec{E}$ vector rotates

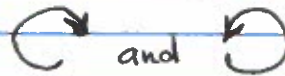
$$\vec{E}_{cw}(x,t) = E_0 \hat{y} \cos(kx - \omega t) + E_0 \hat{z} \sin(kx - \omega t)$$

clockwise



$$\vec{E}_{ccw}(x,t) = E_0 \hat{y} \cos(kx - \omega t) - E_0 \hat{z} \sin(kx - \omega t)$$

cw and ccw polarizations are orthogonal as well!



After the ^{linear} polarizer the 50% of light intensity is transmitted independently of the polarizer orientation

Unpolarized / randomly polarized light: a mix of photons of different polarizations.

A polarizer also transmits 50% of light intensity (but for a different reason)
Many natural sources emit unpolarized light.