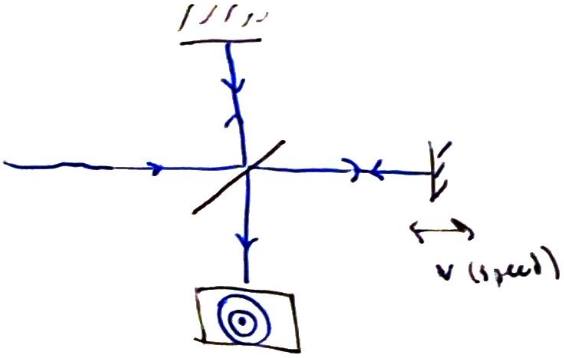
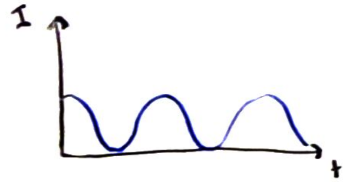
##Week 9##

Question



put a point detector



how many fringes per second will be seen?

1 fringe per $\frac{\lambda}{2} = d$

$\frac{2}{\lambda} \frac{\text{fringes}}{m} \, v \frac{m}{s} = \frac{2v}{\lambda} \frac{\text{fringes}}{s}$

$\frac{2}{\lambda} \frac{\text{fringes}}{m} \, v \frac{m}{s} = \frac{2v}{\lambda} \frac{\text{fringes}}{s}$

In terms of doppler emitting at f_0 and moving at $v \ll c$ $\quad \Delta f = f_0 \left(\frac{v}{c}\right)$

so for the moving mirror $\Delta f = 2 f_0 \, v/c$

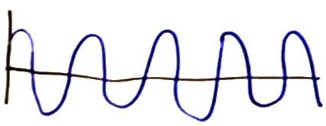
f_0 & $f_0 + \Delta f$ added together beats at Δf

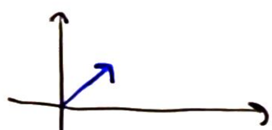
$$\Delta f = 2\left(\frac{c}{\lambda}\right)\left(\frac{v}{c}\right) = \frac{2v}{\lambda}$$

Polarization

Representation of polarization by Jones calculus

polarized light - transverse vibrations





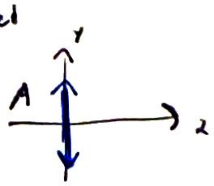
$$\tilde{E} = E_{0,x} e^{i(kz - \omega t + \phi_x)} \hat{x} + E_{0,y} e^{i(kz - \omega t + \phi_y)} \hat{y}$$

$$= \left(E_{0,x} e^{i\phi_x} \hat{x} + E_{0,y} e^{i\phi_y} \hat{y}\right) e^{i(kz - \omega t)}$$

$$= \tilde{E}_0 e^{i(kz - \omega t)}$$

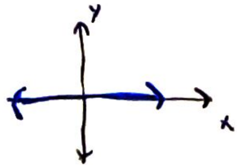
write the $\tilde{E}_0$ as $\underbrace{\begin{bmatrix} E_{0,x} e^{i\phi_x} \\ E_{0,y} e^{i\phi_y} \end{bmatrix}}_{\text{Jones vector}}$

vertical: y-polarized



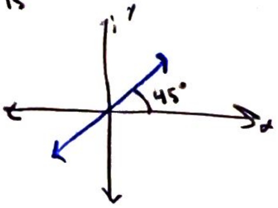
$$\tilde{E}_0 = \begin{bmatrix} 0 \\ A \end{bmatrix} = A \begin{bmatrix} 0 \\ 1 \end{bmatrix}$$

horizontal: x-polarized



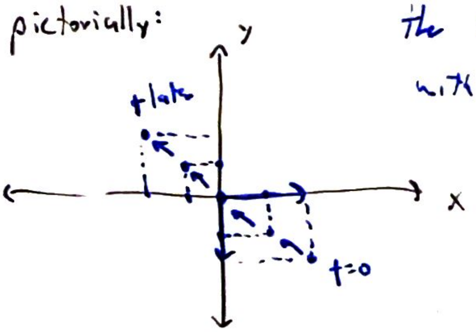
$$\tilde{E}_0 = \begin{bmatrix} A \\ 0 \end{bmatrix} = A \begin{bmatrix} 1 \\ 0 \end{bmatrix}$$

polarized at 45°

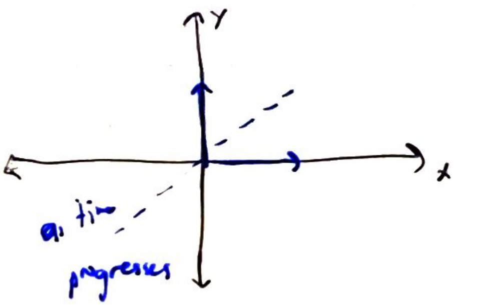


$$\tilde{E}_0 = \begin{bmatrix} A\cos 45° \\ A\sin 45° \end{bmatrix} = A \begin{bmatrix} 1/\sqrt{2} \\ 1/\sqrt{2} \end{bmatrix}$$

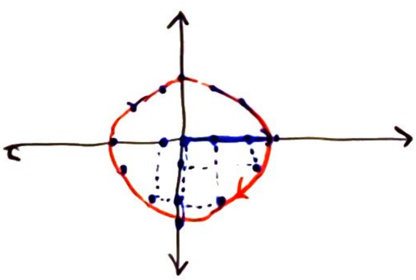
pictorially:



the x and y are vibrating 180° out of phase with each other



what if we make the y component jump ahead

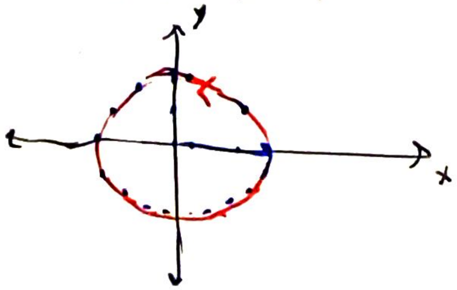


the resultant vector sweeps out a circle

vector is rotating clockwise

↳ rcp (right circularly polarized)

to tell polarization, always look <u>into</u> the beam jump y-component back by 90°



counter-clockwise rotation

↳ left circularly polarized (lcp)

ok, write the rcp as a Jone's vector $\begin{bmatrix} 1 \\ e^{i\pi/2} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ i \end{bmatrix}$?

no, does not work

but waves are represented by $e^{i(kz - \omega t)}$

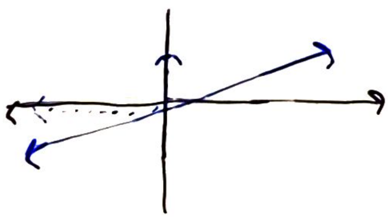
to represent rcp the jones vector is actually $\frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ -i \end{bmatrix} = \begin{bmatrix} 1 \\ e^{-i\pi/2} \end{bmatrix}$

linear vertical: $\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ cw (rcp): $\begin{bmatrix} 1 \\ -i \end{bmatrix}$

linear horizontal: $\begin{bmatrix} 1 \\ 0 \end{bmatrix}$ ccw (lcp): $\begin{bmatrix} 1 \\ i \end{bmatrix}$

linear @ 45°: $\begin{bmatrix} 1 \\ 1 \end{bmatrix}$

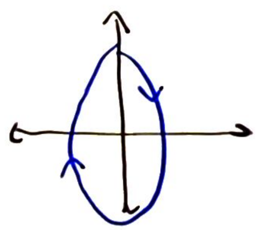
we can change the amplitudes of the components



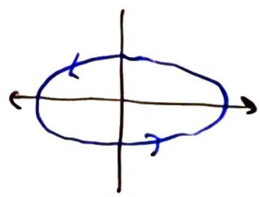
$\begin{bmatrix} 2 \\ 1 \end{bmatrix}$

we could have right and left polarization

eg: $\begin{bmatrix} A \\ iB \end{bmatrix}$



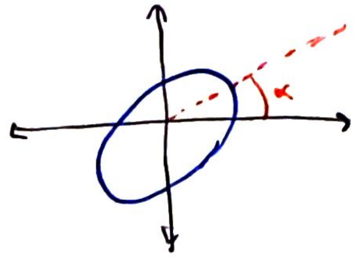
right elliptical polarization



left elliptical polarized

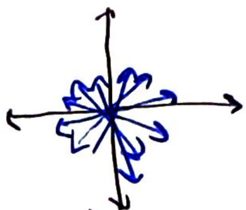
most general case

$$\begin{bmatrix} A \\ B+iC \end{bmatrix}$$



in unpolarized light

or natural light



(not dealt with in the Jones calculus)

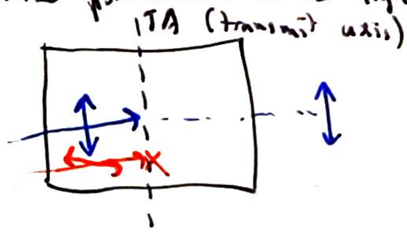
See table 14-1 for all the Jones vectors

we can follow the polarization through an optical path with Jones matrices

First: Some components

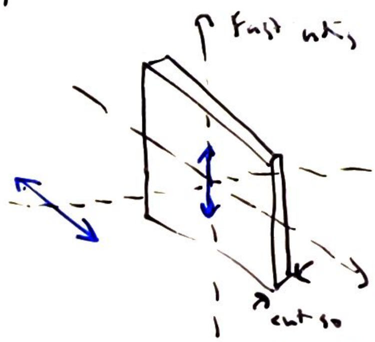
- polarizer (only transmits 1 component of the polarization of the light)

transmission parallel to TA is allowed



transmission perpendicular to TA is blocked

- wave plates (retarders)



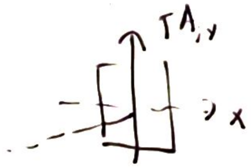
cut so that you can delay by various fractions of a wavelength

- we will not talk about rotaters

polarizer: TA vertical

put in $\begin{bmatrix} 1 \\ 0 \end{bmatrix}$ get out $\begin{bmatrix} 0 \\ 0 \end{bmatrix}$

put in $\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ get out $\begin{bmatrix} 0 \\ 1 \end{bmatrix}$



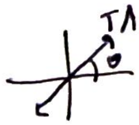
we can do this with a matrix like

$$\underbrace{\begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} \quad \\ \quad \end{bmatrix}}_{\text{this gives us the resulting pol.}}$$

polarizer, TA vertical : $\begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$

polarizer, TA horizontal : $\begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$

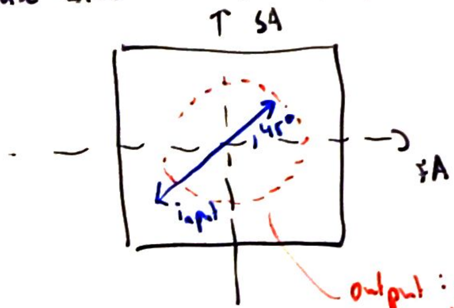
polarizer, TA 45° $\frac{1}{2}\begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$

if 

$\begin{bmatrix} \cos^2\theta & \sin\theta\cos\theta \\ \sin\theta\cos\theta & \sin^2\theta \end{bmatrix}$

wave plates: quarter wave plate with the slow axis vertical

if the input is $\begin{bmatrix} 1 \\ 1 \end{bmatrix}$, output is $\begin{bmatrix} 1 \\ i \end{bmatrix}$



output: counter-clockwise circularly polarized

$$\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 \\ i \end{bmatrix}$$

Quarter wave plate (QWP) with its slow axis vertical $\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$

QWP with fast axis vertical : $\begin{bmatrix} 1 & 0 \\ 0 & -i \end{bmatrix}$

More generally, write matrix as $\begin{bmatrix} e^{i\varepsilon_x} & 0 \\ 0 & e^{i\varepsilon_y} \end{bmatrix}$

for $\varepsilon_y - \varepsilon_x = \pi/2$ for slow axis ~~vertical~~ vertical QWP

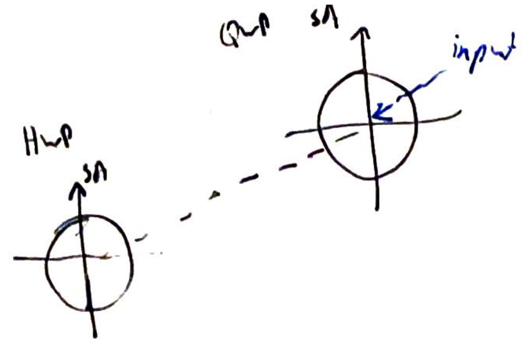
we could use $\varepsilon_x = -\pi/4$ $\varepsilon_y = \frac{\pi}{4}$

$$\begin{bmatrix} e^{-i\pi/4} & 0 \\ 0 & e^{i\pi/4} \end{bmatrix} = e^{i\pi/4}\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$$

Half wave plate (HWP)

for the case of a HWP, SA vertical $e^{\frac{-i\pi}{2}}\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

eg:



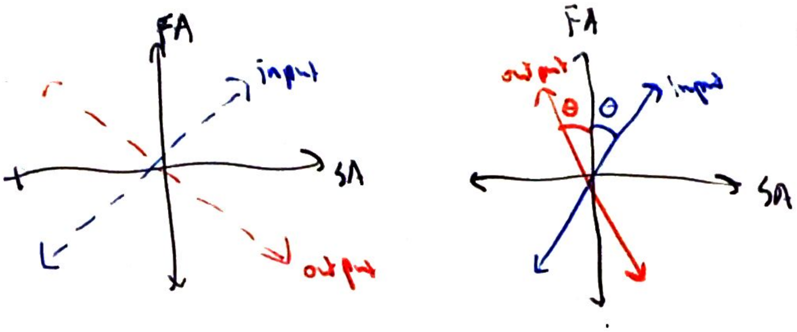
then the overal matrix would be

$$\begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}\begin{bmatrix} \\ \end{bmatrix}$$

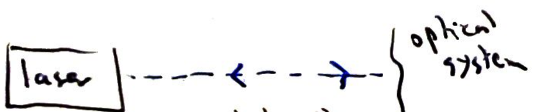
input

$$= \begin{bmatrix} 1 & 0 \\ 0 & -i \end{bmatrix}$$

for a halfwave plate

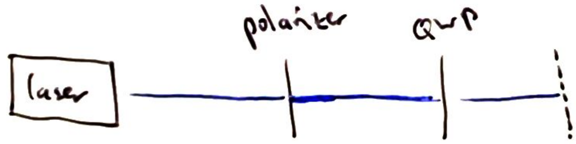


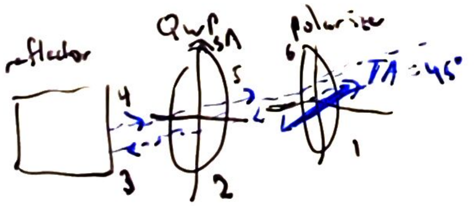
An <u>optical</u> <u>isolator</u>



want to stop reflecting light going back into the laser

an optical isolator can effectively stop this reflection





1. light through the polarizer $\begin{bmatrix} 1 \\ 1 \end{bmatrix}$
2. light through QWP with SA vertical $\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}$
3. light is $\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 1 \\ i \end{bmatrix}$
4. Reflected light returns now rcp (since it bounded off the mirror) $\begin{bmatrix} 1 \\ -i \end{bmatrix}$
5. pass back through the QWP, so $\begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix}\begin{bmatrix} 1 \\ -i \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$
6. The polarization angle of the polarizer now, to the beam loops like its a $-45°$ (looks like $\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}$)

so the light is totally absorbed by the beam $\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix}\begin{bmatrix} 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$

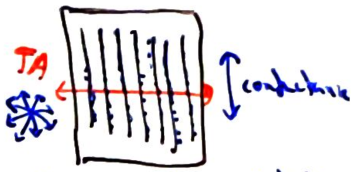
Production of polarized light

production of linearly polarized light

Absorption – polaroid: absorbs one of the polarizations

Reflection

Scattering



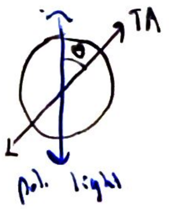
put in unpolarized light

electrons are free to move along the conduction direction

(light absorbed)

↳ output horizontal polarized light

If we rotate the polaroid with the input light polarized,



$E_0 \rightarrow E_0 \cos\theta \qquad I_0 \rightarrow I_0 \cos^2\theta$

$I = I_0 \cos^2\theta$ Malus' law