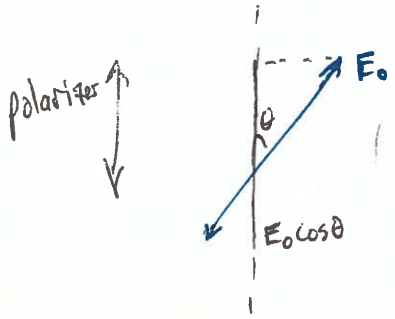
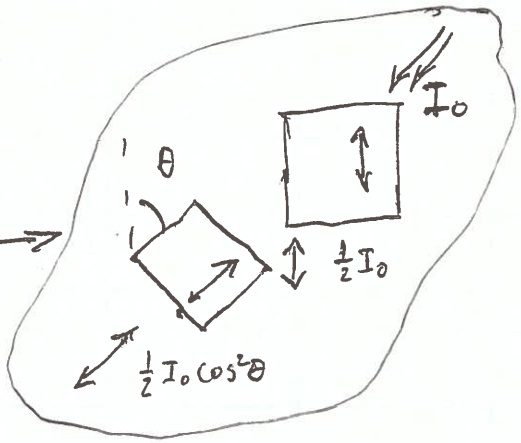
Polarizers, Malus' Law, light scattering, blue skies, red sunsets

Light from sun, lightbulbs is not polarized.

- think of this as a sum of many polarized photons



do this for all polarizations



Malus' Law

$I_{out} = \frac{1}{2} I_0 \cos^2\theta$

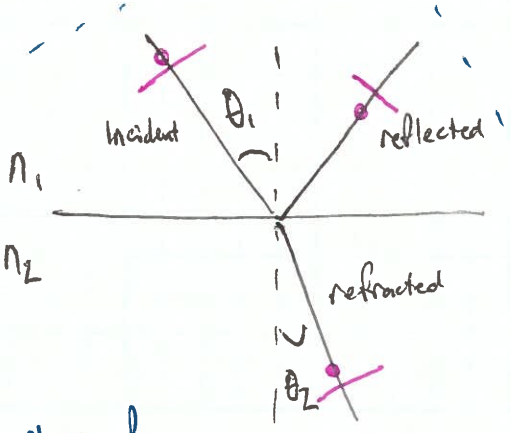
if $\theta = 0°$, $I_{out} = \frac{1}{2} I_0$

$\theta = 90°$, $I_{out} = 0$

Blue light has higher frequency than red light and so carries a greater energy than red light

Demo: linear polarizer showing Malus' Law

Polarization



to use Maxwell's Eqn's:

- must decompose incident signal at media boundary ($E_{\parallel}$, $E_{\perp}$)
- Incoming light is unpolarized ($|E_{\parallel}| = |E_{\perp}|$)
- reflected, refracted light is polarized

Parallel Component of Incident / Reflected E-field (from Maxwell)

$$E_{0,\parallel,\text{reflect}} = E_{0,\parallel,\text{incident}} \cdot \frac{n_1 \cos\theta_2 - n_2 \cos\theta_1}{n_1 \cos\theta_2 + n_2 \cos\theta_1}$$

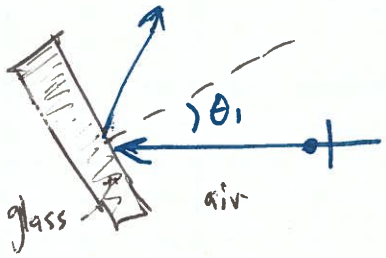
$$= E_{0,\parallel,\text{incident}} \cdot \frac{\tan(\theta_1 - \theta_2)}{\tan(\theta_1 + \theta_2)}$$

Intensity of polarization?

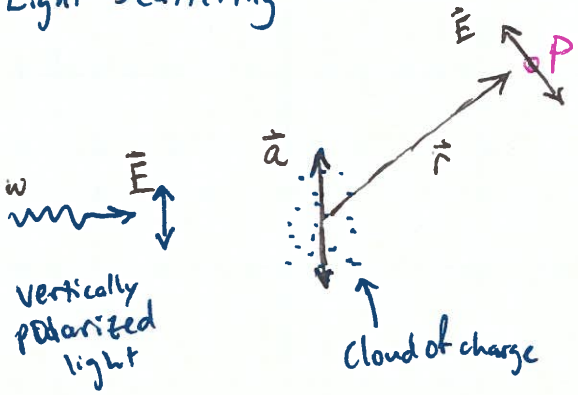
Recall Poynting vector is $\propto E_0^2$ $\left(\langle S \rangle = \frac{1}{2}\frac{1}{\mu_0 c} E_0^2\right)$

Demo: Brewster angle

- From above, when $\theta_1 + \theta_2 = 90°$ then $\tan 90° \to 0$ so $E_{0,\parallel,\text{reflected}} \to \infty$. Snell's Law says $\frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1}$ but because $\theta_1 + \theta_2 = 90°$ we can write $\tan\theta_1 = n_2/n_1$ for this special case.
- If we go from air ($n=1$) to glass ($n=1.5$) then Brewster angle (∠ of 100% polarized) is $\sim 56°$

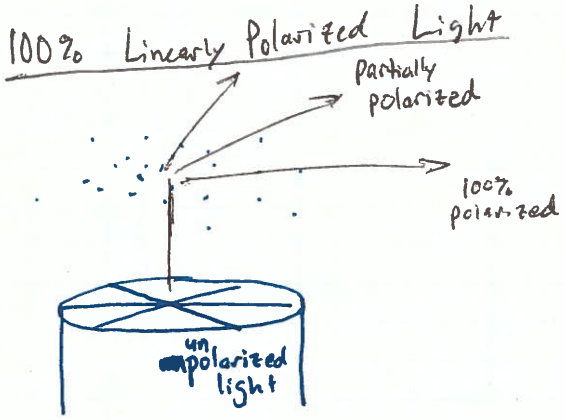


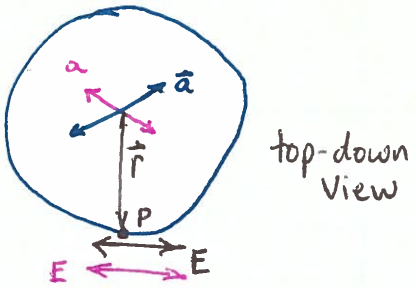
Light Scattering



$$\vec{a} = \frac{\vec{F}}{m} = \frac{q\vec{E}}{m}$$

we have $\vec{E} \perp \vec{r}$,
$\vec{E}, \vec{r}, \vec{a}$ in one plane

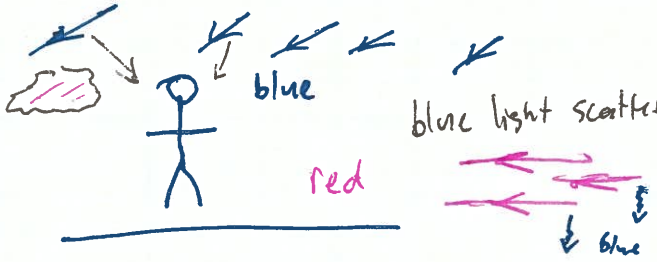




blue light scatters much better than red light

DEMO: Light scattering off of cigarette smoke

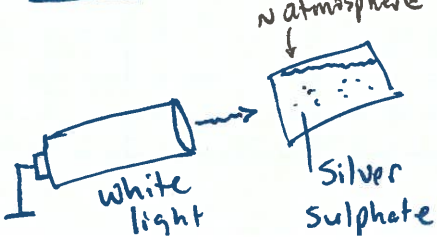
- Smoke burned from cig. is blue (linearly polarized)
- Smoke inhaled/exhaled w/ water droplets from lungs appears white!



Sky is blue when sun is high, rises

Sky is red at sunset

DEMO:



- the white light appears blue (at 90°) and is linearly polarized
- Sun appears red when blue/green light scatters away from our eyes (off 90°)