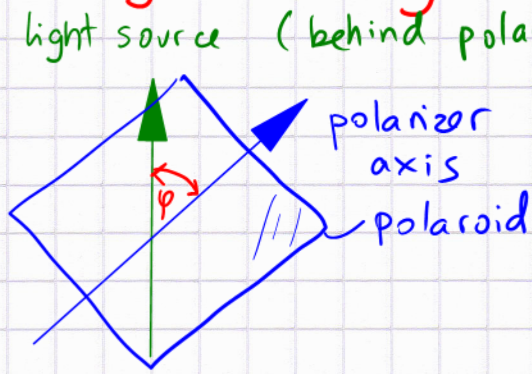
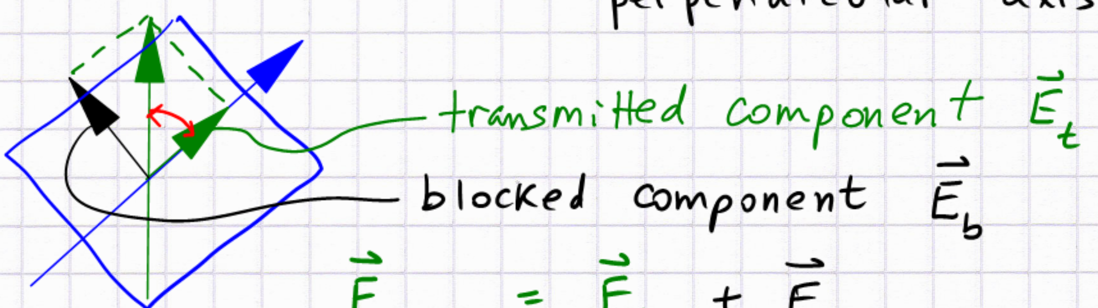
Three polarizers – a paradox?

· understand the law of Malus:

given a linearly polarized light source, and a polarizer which has orientation φ w.r.t the polarization axis, the light intensity behind the polarizer $I(\varphi) \sim \cos^2\varphi$



step 1: decompose the light polarization vector along polarizer axis and the perpendicular axis



$$\vec{E}_{light} = \vec{E}_t + \vec{E}_b$$

After the polarizer we have again linearly polarized light; however:
- reduced intensity
- new polarization dir'n

Clearly, from vector decomposition:

$$|\vec{E}_t| = E_t = E_{light} \cos\varphi \qquad E_b = E_{light} \sin\varphi$$

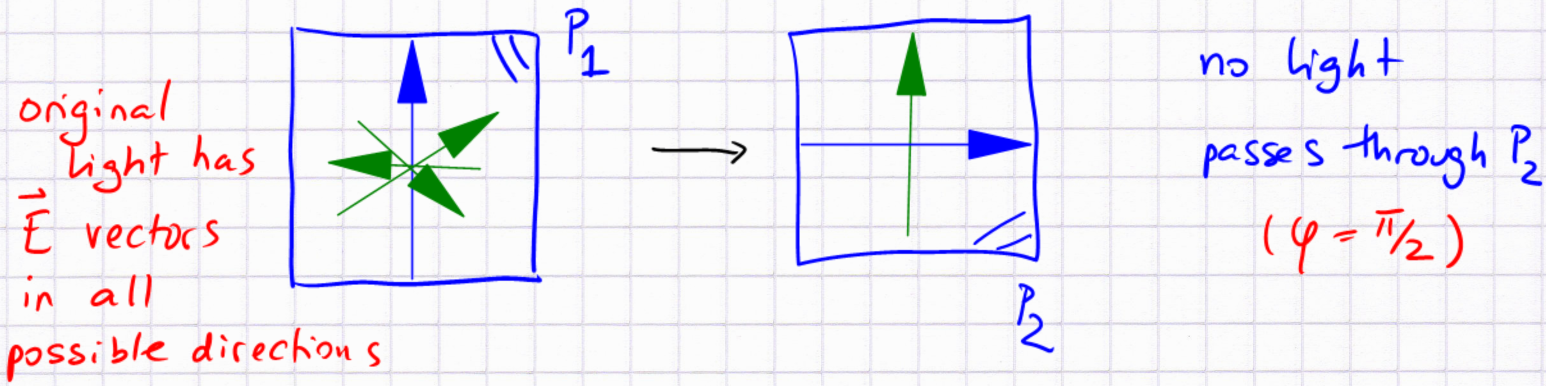
After the polarizer the intensity $I \sim |\vec{E}|^2$

$$\therefore \quad I(\varphi) = I_{Source} \cos^2\varphi \qquad \text{(Malus)}$$

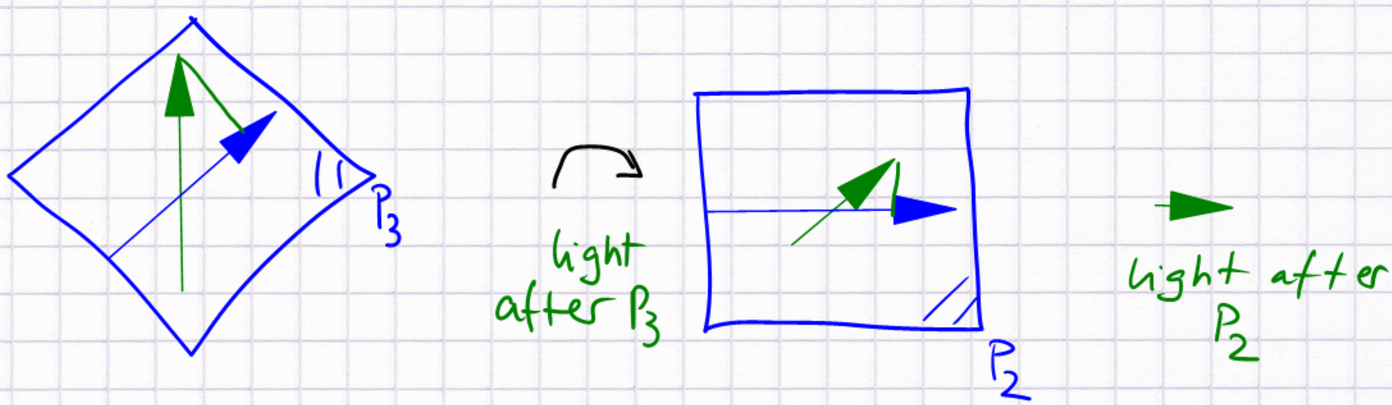
Two polarizers at right angles:

Suppose the source of light is unpolarized

$\Rightarrow$ first polarizer creates linearly polarized light



The paradox: slip a 3rd polarizer with orientation $\varphi_3 \approx 45°$ in between P_1 and P_2 and some light will get through P_2 $\rightarrow$ why?



Moral of the paradox:

- action of polarizer: allow only the $\vec{E}$ component aligned with the pol. axis to go through
- to understand this always decompose the original $\vec{E}$ along the polarizer axis and its perpendicular
- many polarizers in sequence $\rightarrow$ rotate the pol. axis!

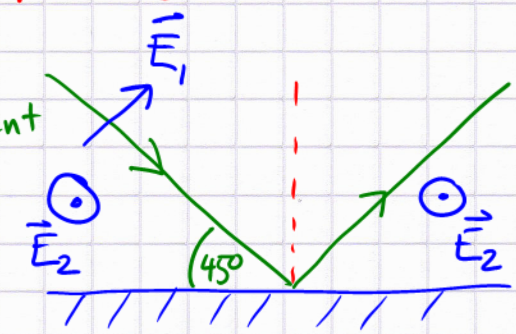
How do polarizing sunglasses work?

• also: photography → polarizer with adjustable pol. axis → eliminate glare

• Reflected light is often polarized → why?

EM wave propagation property:

$\vec{E}$ (and $\vec{B}$) oscillate at right angles to the wave propagation vector $\vec{k}$ (see G. Fig 23.3)



$\vec{E}_1$ part must be missing for $\varphi = 45°$, since it points along the propagation direction of the reflected light

think about it as any randomly oriented $\vec{E}$ field component as decomposed into $(\vec{E}_1, \vec{E}_2)$ basis

The $\vec{E}_1$ parts cannot be reflected

∴ light reflected under $\varphi = 45°$ is fully polarized, for $\varphi \approx 45°$ it is partially polarized

• if the reflecting surface is glass → $\vec{E}_1$ component is transmitted; otherwise it is absorbed

The reflected light is often a nuisance, we can't see the surface (well) → use a polarizer to cut $\vec{E}_2$

Applications:
- cut the glare when driving
- look / photograph through glass windows
- view the sky in deeper blue

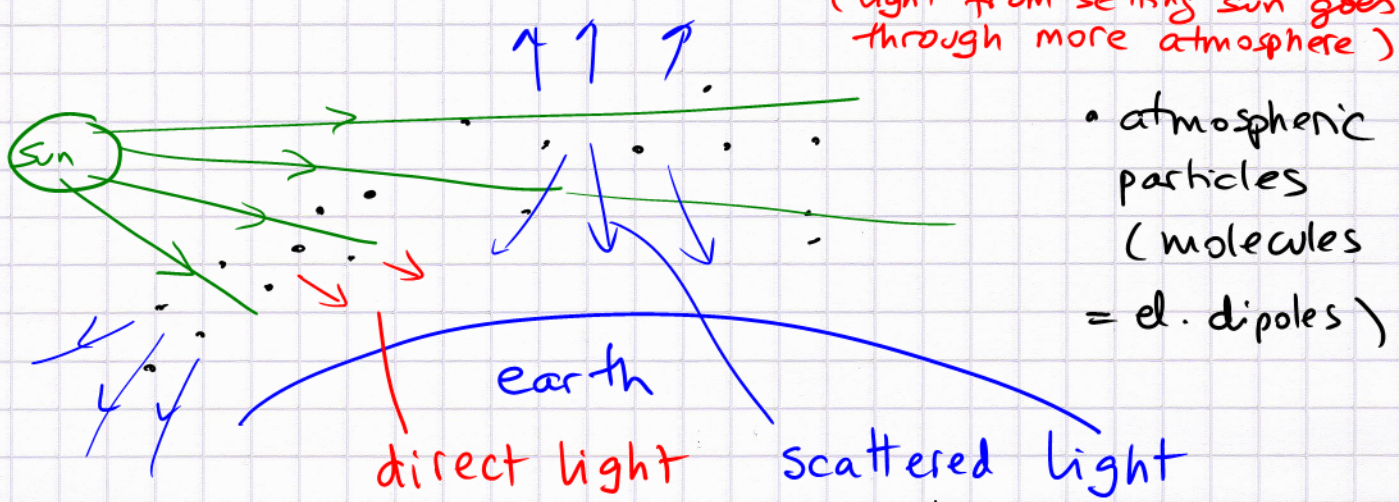
(blue sky is polarized, white clouds are not)

- "anti-application": professional sports sailors use the glare from wave crests to estimate winds

Why is the sky blue?

- light from the sun scatters from upper-atmosphere particles → indirect light (scattered light) has preferentially <u>high</u> frequencies

Corroboration: sunset → the direct light has the higher-frequency parts removed by scattering
→ setting sun appears to be red (not white)
(light from setting sun goes through more atmosphere)



direct light → higher frequencies removed

scattered light → higher frequencies preferred (also polarized, clouds de-polarize)