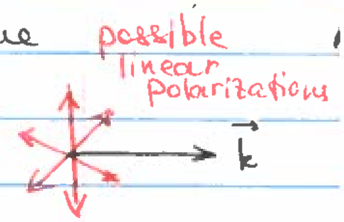
Polarization

The direction of polarization is defined by the direction in which the electric field of e-m wave is vibrating

$\vec{E}$ is always perpendicular to the light propagation direction $\vec{k}$ (e-m is a transverce wave)



Most naturally produced light is said to be unpolarized: that means that individual emitters produce light of same color, but in a random polarization direction so the global polarization cannot be defined, Most lasers, on the other hand, have distinct polarization.

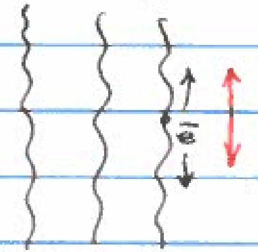
How to control the light polarization?

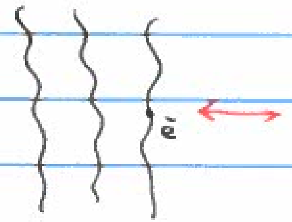
(polarization)
Selective absorption — only specific polarization is transmitted

Polarization-selective reflection — different polarizations are transmitted or reflected differently

Absorptive polarizers

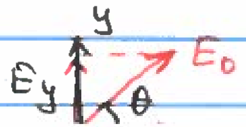
Made of long-chained molecules, oriented in a particular direction



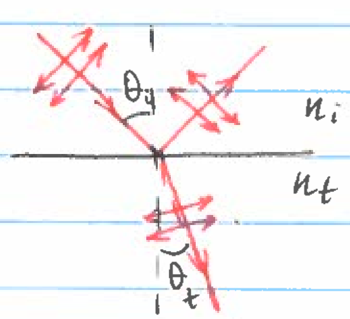


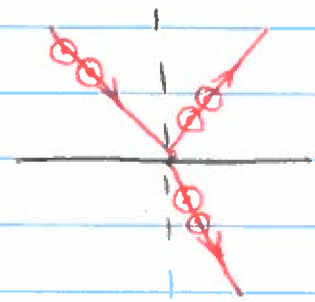
easy to move ē, light is absorbed

cannot move electron, light is not absorbed (transmission axis)



Polarization by reflection





p-polarization (parallel)

s-polarization (perpendicular, "sticking out")

$$r_p = \frac{n_i \cos\theta_t - n_t \cos\theta_i}{n_i \cos\theta_t + n_t \cos\theta_i}$$

$$r_s = \frac{n_i \cos\theta_i - n_t \cos\theta_t}{n_i \cos\theta_i + n_t \cos\theta_t}$$

if $n_i < n_t$ $\quad n_i \sin\theta_i = n_t \sin\theta_t \Rightarrow \theta_i > \theta_t$

$\cos\theta_i < \cos\theta_t$

$n_i \cos\theta_i < n_t \cos\theta_t$ for any θ_i, so there always be some reflection for s-polarization

But! We can find an angle for which

$r_p = 0$: $\quad n_i \cos\theta_t = n_t \cos\theta_i \quad \& \quad n_i \sin\theta_i = n_t \sin\theta_t$

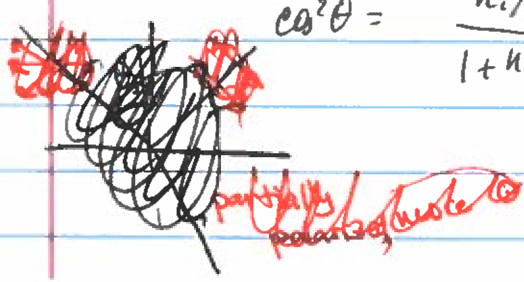
Solution (for your and my amusement)

$n_i^2 \cos^2\theta_t = n_t^2 \cos^2\theta_i \Rightarrow n_t^2 - n_i^2 = n_t^2 \sin^2\theta_i - n_i^2 \sin^2\theta_t$

$n_t^2 - n_i^2 = n_t^2 \sin^2\theta_i - \frac{n_i^4}{n_t^2} \sin^2\theta_i$

$\left(1 - \frac{n_i^2}{n_t^2}\right) = \left(1 - \frac{n_i^4}{n_t^4}\right) \sin^2\theta_i \Rightarrow \sin^2\theta_i = \frac{1}{1 + n_i^2/n_t^2}$

$\cos^2\theta = \frac{n_i^2/n_t^2}{1 + n_i^2/n_t^2} \qquad \tan^2\theta_i = n_t^2/n_i^2$

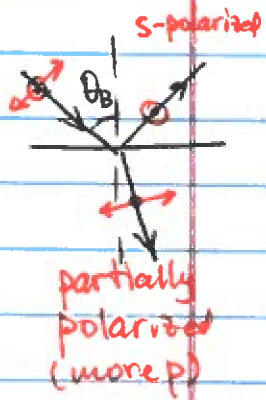


Answer: $\tan\theta_B = n_t/n_i$

Brewster angle

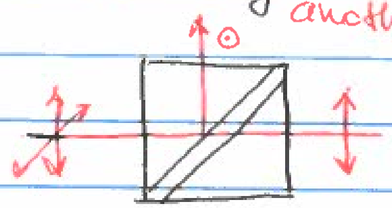
water $\theta_B \sim 53°$

If light of any polarization falls on the boundary at Brewster's angle, ~~only~~ ~~pass~~ the reflected beam is polarized (s-polarization)



Modern polarizers are designed to take advantage of this effect

Polarizing beam splitter



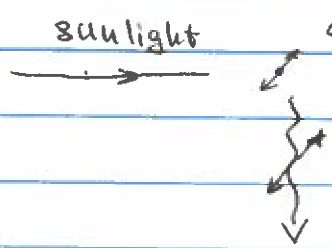
another is reflected

one polarization is transmitted

no losses of light

Polarization by scattering

Scattering means redirecting of the initial e-m wave due to interaction with molecules.
The amount of scattered light depends on the scattering direction



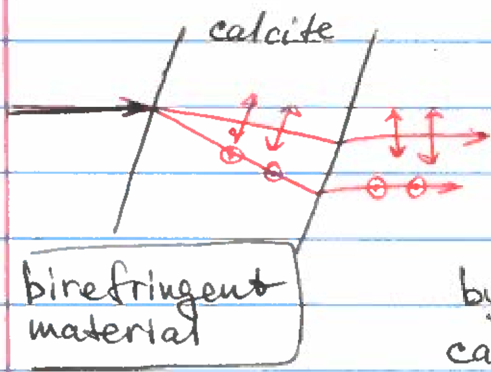
air molecules

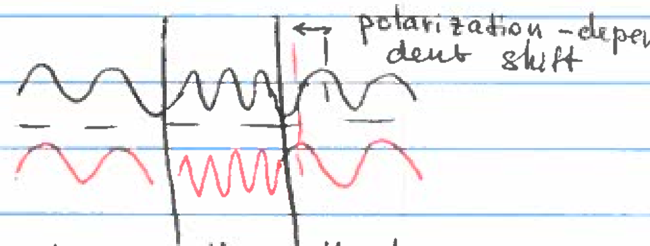
scattered light is polarized

This selectivity is often used to enhance images and highlight specific features

How to manipulate polarization

Some crystals have different refractive indices for two polarizations





by controlling the thickness, one can control how polarization is modified

Liquid crystal are strongly birefringent, and the refractive index difference depends on applied voltage, so one can control the output polarization by applying voltage.

Some crystals has voltage-dependent birefringence as well (Lithium Niobate) and use for fast switching of optical signals