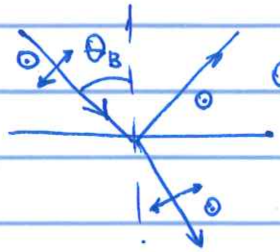
How to make a polarizer

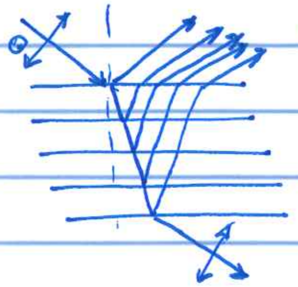
Ideal polarizer : transmits 100% of one polarization
rejects 100% of the orthogonal polarization

1. Brewester angle



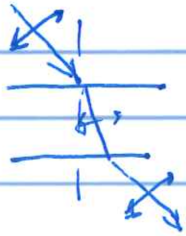
Only s-polarization is reflected
(but only a fraction is reflected)
transmitted light is more polarized
(but not completely polarized)

Possible – multy layer structure
(pile-of-plates polarizer)



only s-polarization is refleted
so that after many reflections
only p-polarization is transmitted

A side-note: if you need to make a slab of material transparent for a linearly polarized light, you can achieve that by placing it at Brewester angle

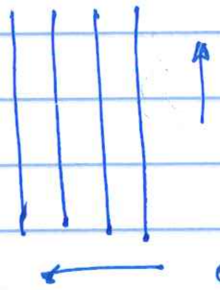


100% transmission
Routinely used in gas lasers to avoid optical losses → output is polarized

2. Dichroic material: absorption is different for two polarizations

Example - film polarizers

Physical model: metallic wire grid



electric field can easily move electrons (em wave loses energy through electrons → absorption)

(em wave hardly absorbed)

electric field cannot move electrons

In practice, metal wires are replaced with aligned molecular chains, but the effect is the same: one polarization is absorbed as its energy is used up by moving free electrons along the chain, but the other is mostly transmitted, as the electrons campot move across.

Cheap, easy polarizers - most commongly used!

Extinction ratio is not very hight

$$E = \frac{I_{crossed}}{I_{aligned}}$$

In ideal polarize $E=0$, in a polaroid polarizer $E \sim$ a few percent, and max transmission is 50-70%.

3. Birefringent materials: the material is transparent for both polarizations, but the refractive indices for two polarizations are different

Usually this effect occures in crystals with anisotropic structure, so that the electron's response of em wave in different directions is different

Cannot write $\vec{D} = \varepsilon_0 \varepsilon \vec{E}$ - anisotropic material!

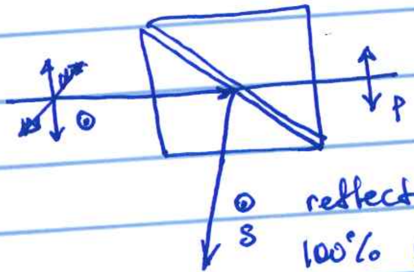
More precise
$$D_x = \varepsilon_0 \varepsilon_x E_x$$
$$D_y = \varepsilon_0 \varepsilon_y E_y$$
$$D_z = \varepsilon_0 \varepsilon_z E_z$$

Most ~~cry~~ anisotropic crystals are <u>uniaxial</u>: two different refractive indices, along the optical axis, and perpendicular to it

If the axis is alone x, then $\varepsilon_y = \varepsilon_z \neq \varepsilon_x$

Majority of high-quality polarization optics utilizes birefringent materials

Polarizers - use selectivity of the total internal reflection



transmitted

reflected (TIR)

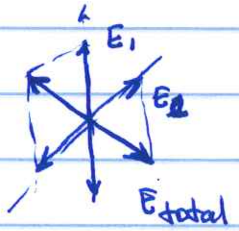
100% reflected, but less pure

(95-98% can be transmitted, with extinction ration down to $5 \cdot 10^{-6}$

How to manipulate the polarization?

Passive controllers: waveplates

Recall – to transform the wave from linearly to circularly polarized we need to delay one half of it with respect of the other, orthogonally polarized, half.



$$\vec{E}_{total} = E_1 \vec{e}_x \cos(kz-\omega t) + E_2 \vec{e}_y \cos(kz-\omega t)$$

inside the material

$$k_x = \frac{2\pi}{\lambda_0} \cdot n_e \qquad k_y = \frac{2\pi}{\lambda_0} n_o$$

Phase difference

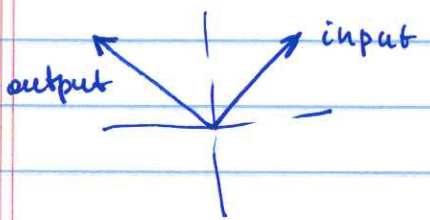
$$\Delta\varphi = k_x d - k_y d = \frac{2\pi}{\lambda_0} \cdot d\,(n_e - n_o)$$

If the phase difference is a quater of a period $\Delta\varphi = \frac{2\pi}{\lambda_0} d(n_e-n_o) = \frac{\pi}{2} \Rightarrow d(n_e-n_o) = \frac{\lambda}{4}$ the linear polarization is transformed in a circular, and such plate is called a quater wave plate.

If the phase difference is a half of the period $\Delta\varphi = \frac{2\pi}{\lambda_0} d(n_e-n_o) = \pi \Rightarrow d(n_e-n_o) = \lambda/2$ the sign of one of the component changes

input $\vec{E} = (E_1\vec{e}_x + E_2\vec{e}_y)\cos(kz-\omega t)$

output $\vec{E} = (E_1\vec{e}_x - E_2\vec{e}_y)\cos(kz-\omega t)$



Polarization is still linear, but is rotated

Half-wave plate.