

Polarizers: Linear Polarizer

Polarizer: An optical device that only transmits (or reflects) light polarized in a certain way.

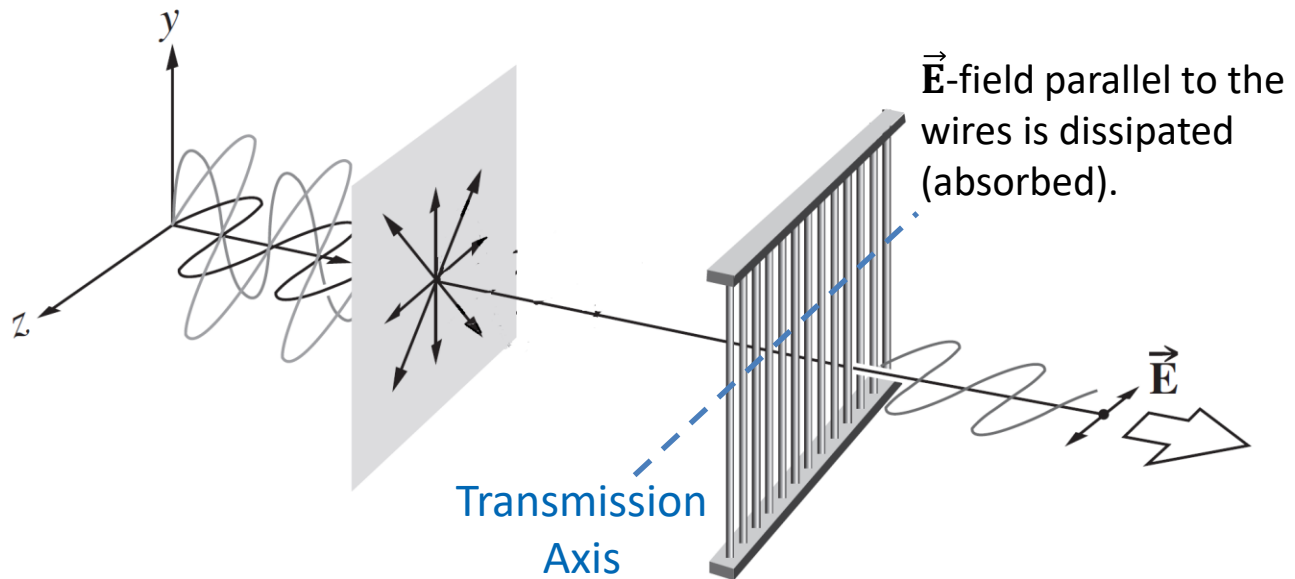
Linear Polarizer: Device designed to linearly polarize incoming light, e.g., only transmits light that is linearly polarized in a certain direction or plane.

Circular or elliptical polarizers can be used to create circularly/elliptical polarized light or alternatively to selectively absorb or pass left and right-handed circularly/elliptically polarized light.

Dichroism: selective absorption of light of certain polarization states

Polarizers: Linear Polarizer (con't)

Wire-Grid Polarizer (linear polarizer for microwaves, $\lambda_0 \approx 10$ cm)



- The metal wires provide high conductivity for \vec{E} -fields *parallel* to the wires. Such fields produce electric currents in the wires, which are then converted to heat because of the small but significant electrical resistance of the wires. This component is *dissipated* in the grid.
- Because of the non-conducting spaces between the wires, no current can flow perpendicular to them. So \vec{E} -fields *perpendicular* to the wires produce virtually no currents and lose little energy, and are hence *transmitted*.
- **Transmission Axis** of the polarizer is *perpendicular* to the wires. (e.g. Transmission axis is along z-axis in the above figure.)

Polarizers: Linear Polarizer (con't)

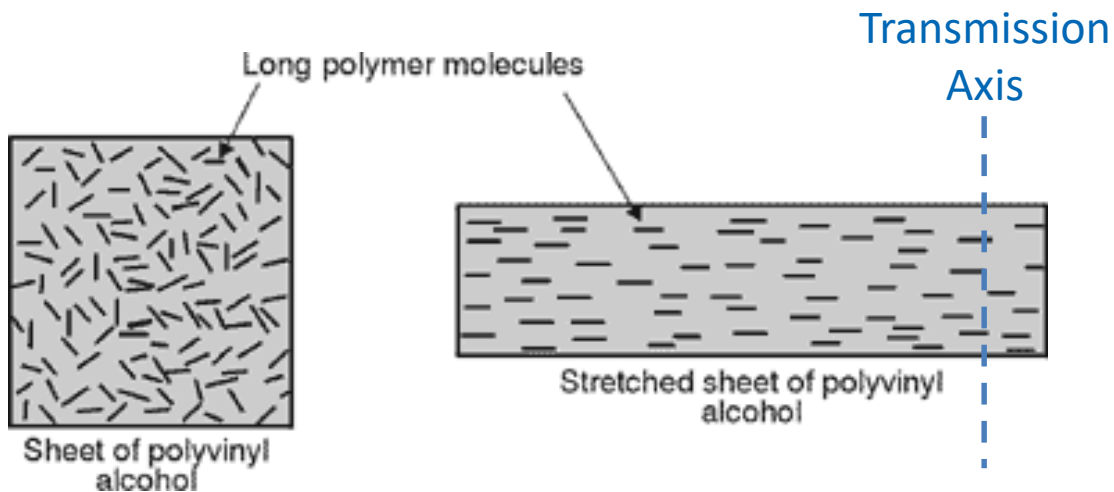


Edwin H. Land
(1909-1991)

H-sheet Polaroid

- The “conventional” wire-grid polarizer is not practical for visible light; the wires have to be on the order of a wavelength (few hundred nm) of light apart.

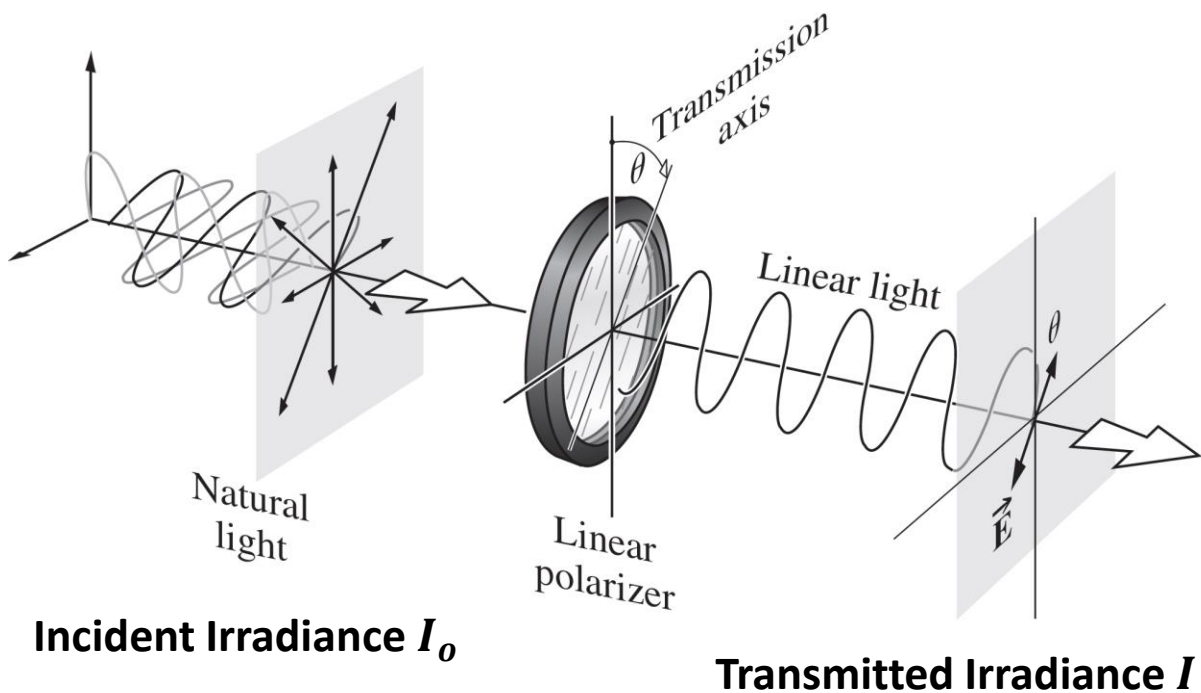
- H-Polaroid sheet invented in 1938 by Edwin H. Land (founder of Polaroid Corporation). Instead of long thin wires, it uses long thin polyvinyl alcohol molecules that contain many iodine atoms.



- These long, straight molecules are aligned almost perfectly parallel to one another and about 3 Å apart. Because of the conductivity provided by the iodine atoms, the \vec{E} -field parallel to the molecules is absorbed. The \vec{E} -field perpendicular to the molecules passes through with little absorption.

- The transmission axis of the polarizer is perpendicular to the direction in which the film was stretched.

(I) *Unpolarized* Light on Linear Polarizer



- If **unpolarized** light is incident on an ideal linear polarizer,

$$I = \frac{1}{2} I_0 \quad (1)$$

Unpolarized (natural) light incident on a linear polarizer.

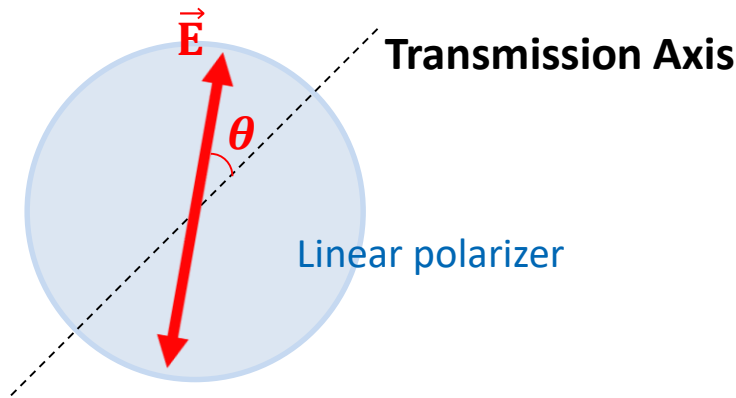
- Only light in a P -state (linearly polarized) is transmitted. i.e., Only the component of \vec{E} parallel to the transmission axis passes through.

e.g. Represent the unpolarized light as two independent orthogonal, linearly polarized waves of equal amplitude where one component is parallel to the polaroid's transmission axis, and the other is perpendicular to it. Only the component parallel to the transmission axis is transmitted, and this component corresponds to "half" of the incoming light.

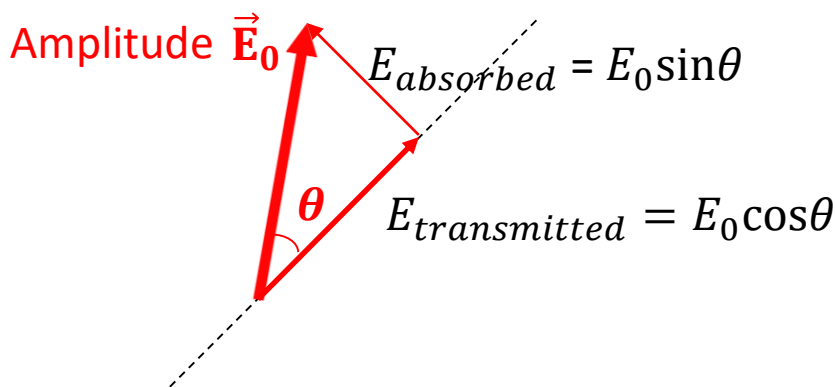
(A single polaroid in natural light appears gray-ish because it absorbs roughly half the incident natural light.)

(II) *Linearly Polarized Light on Linear Polarizer*

- Suppose linearly polarized light is incident on a linear polarizer:



- We can resolve \vec{E} into a component parallel to the *transmission axis* and a component perpendicular to it. The *parallel* component is *transmitted*, but the *perpendicular* component is *absorbed*:



- Recall that irradiance is proportional to the square of the amplitude of the electric field (recall our discussion on Poynting vector):

$$\frac{I(\theta)}{I_o} = \frac{(E_0 \cos\theta)^2}{E_0^2} = (\cos\theta)^2$$

Linearly Polarized Light on Linear Polarizer (con't)

$$I(\theta) = I_0 \cos^2 \theta$$

(2)

Malus's Law

Linearly Polarized light incident on a linear polarizer.

I_0 = irradiance before polarizer

$I(\theta)$ = irradiance after polarizer

θ = angle between $\vec{\mathbf{E}}$ and the transmission axis

Linearly Polarized Light on Linear Polarizer (con't)

Notes:

(1) Malus's Law: $I(\theta) = I_0 \cos^2 \theta$

Hence, $I(0^\circ) = I_0 = \text{maximum}$

and $I(90^\circ) = 0$

If incident light is polarized parallel to the transmission axis, all light is transmitted.

If incident light is polarized perpendicular to the transmission axis, no light is transmitted.

(2) **Extinction Ratio** = $r_e = \frac{T_{90}}{T_0}$

T_{90} = transmittance when incoming light is polarized *perpendicular* to the transmission axis

T_0 = transmittance when incoming light is polarized *parallel* to the transmission axis

$r_e \approx 1/500$ for Polaroid sheet

$\approx 1/10^5$ to $1/10^6$ for birefringent prism polarizer

= 0 for an ideal polarizer

In the optics literature, the extinction ratio is often expressed as "1 / r_e : 1".

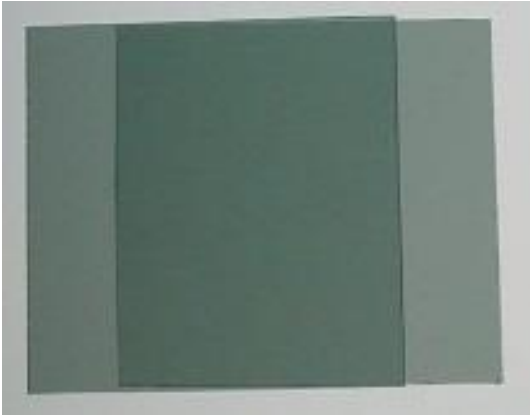
$\approx 500 : 1$ for Polaroid sheet

$\approx 10\,000 : 1$ to $100\,000 : 1$ for birefringent prism polarizer

= $\infty : 1$ for an ideal polarizer

Linearly Polarized Light on Linear Polarizer (con't)

Example: Two polarizers overlapping in the middle



Transmission axes *parallel*



Transmission axes *perpendicular*

(If ideal polarizers are used and their transmission axes are perfectly parallel, the middle part should have been the same darkness as the single polaroid.)

Example: Computer monitors commonly emit light which is polarized (usually vertically, or at 45°).
