

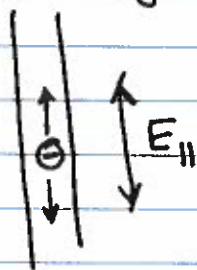
How to make a polarizer

Ideal polarizer : transmits 100% of one polarization and 0 % of the orthogonal
Achieving exact zero is impossible, of course

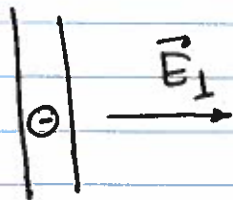
Extinction ratio = $\frac{\text{transmission for "correct" polar}}{\text{transmission for "wrong" polarization}}$

Extinction ratio 1000:1 means that if equal intensity of both polarizations falls onto this polarizer, after it the intensity ratio will be 1000 to 1
The same thing can be written as 10^{-3} extinction

Most common polarizers : dichroic material
Two polarizations are absorbed differently
Physical model - metallic wire grid
Such grid contains free electrons



If electric field of light is parallel to the wire, it will start moving electrons along the wire, so its energy is transferred to electrons and lost $\rightarrow$ high absorption



If electric field is perpendicular, electrons cannot move, so energy stays in the e-m field.

Metal mesh is often used for lower frequency EM radiation (think the microwave oven window).

In optics it is more common to use materials with long hydrocarbon molecules that are all aligned in a particular direction. || $\frac{\text{Extinction ratio} - \text{a few percent}}{\text{Transmission} \sim 70\%}$

Liquid crystal displays contain special material that can with long molecules that can be oriented with externally applied electric field / voltage.

This is the foundation for many computer / phone displays, LCD projectors, etc.

The system consist of two crossed polarizers that block ~~the~~ backlight when no voltage is applied. By applying voltage to each pixel, one can ~~control~~ twist the liquid crystal molecules at this location, ~~and~~ that rotates the polarization and let the light go through.

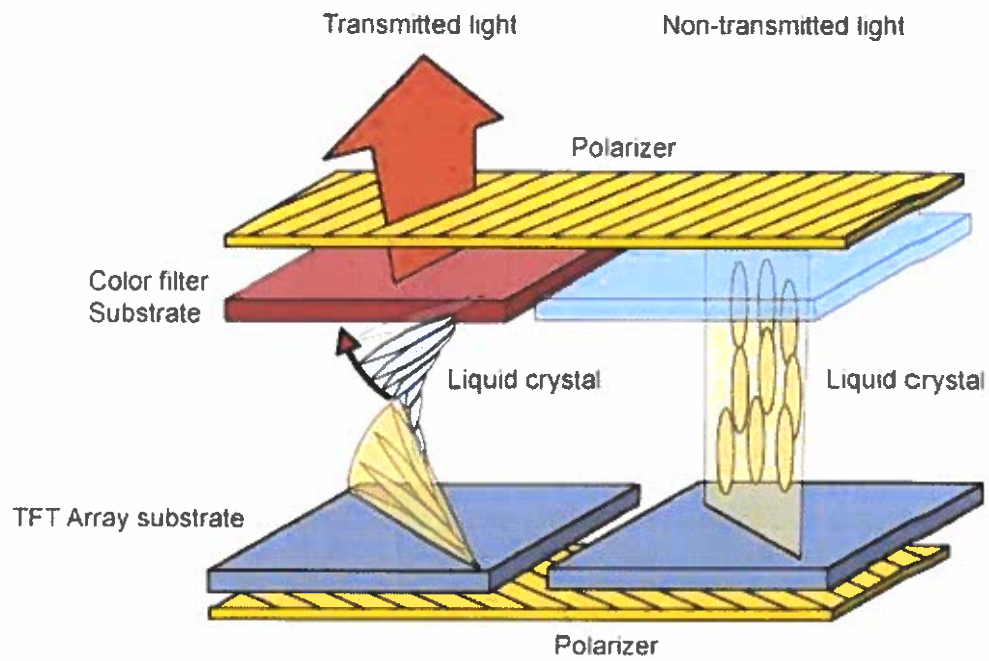


Diagram 2: The Fundamental Photonics of Liquid Crystal (Twisted Nematics)

Separation of Light Waves by a Birefringent Crystal

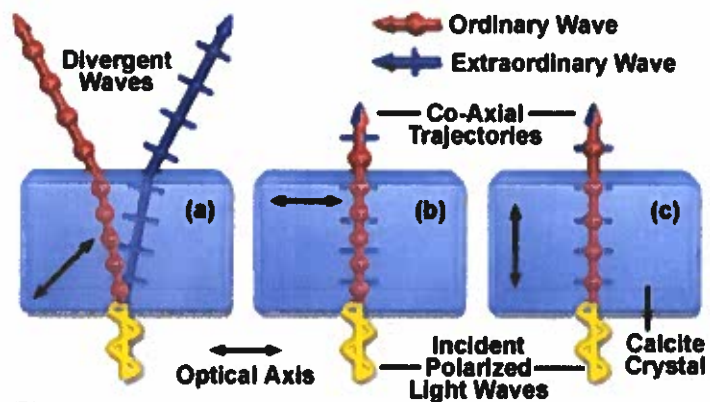
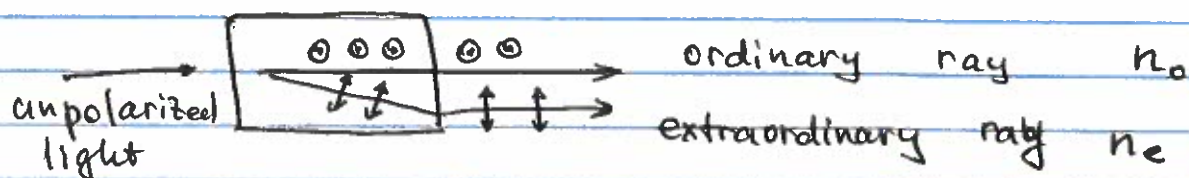


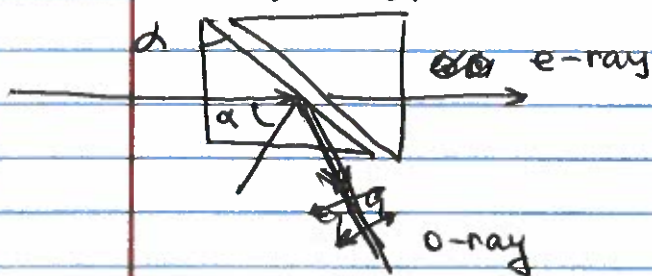
Figure 4

Birefringent materials : transparent for both polarizations, but have two different refractive indices. These are anisotropic crystals that ~~have~~ have ~~different~~ non-symmetric internal structure. The optical axes are dictated by the structure of the crystal



Such materials are very handy for polarization manipulations

High-quality polarizers exploit the refractive index difference to separate polarization by total internal reflection



calcite crystal

$$n_o = 1.658$$

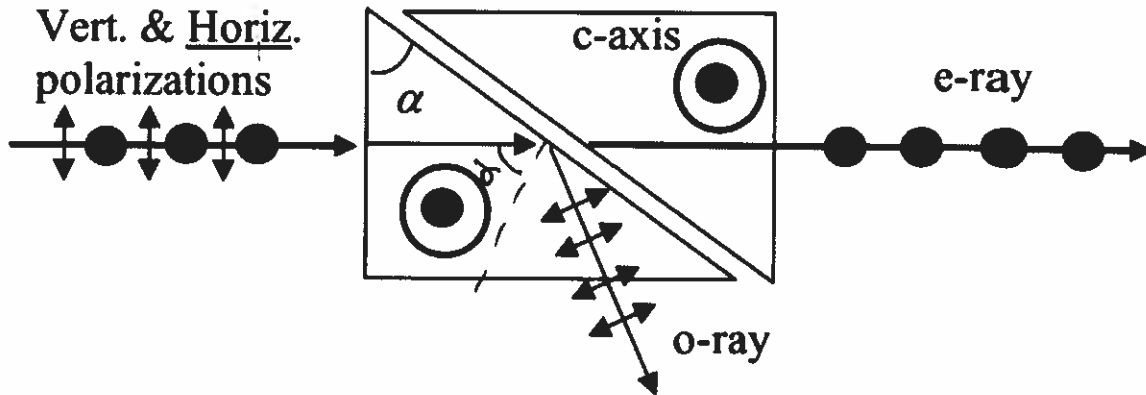
$$n_e = 1.486$$

$$\theta_{cr}^{(o)} = \sin^{-1}\left(\frac{1}{n_o}\right) = 37^\circ$$

$$\theta_{cr}^{(e)} = \sin^{-1}\left(\frac{1}{n_e}\right) = 42^\circ$$

if $\theta_{cr}^{(o)} < d < \theta_{cr}^{(e)}$ then
e-ray is transmitted, but o-ray is 100% reflected.

5. Refraction in anisotropic crystals can be utilized to produce polarized light in composite prisms. Consider a light beam incident on a plane boundary from the inside of a calcite crystal ($n_o = 1.658$, $n_e = 1.486$). Suppose that the c-axis (optic axis or z-axis) of the crystal is normal to the page as shown in the diagram below.



(a) Find the range of the internal angle of incidence such that the ordinary wave is totally reflected and the transmitted wave is thus completely polarized.

(b) Glan prism design: Use the approach of part (a) to design a calcite Glan prism with the structure shown in the accompanying diagram (i.e. find the allowable range of apex angle α over which the prism will work).

$$\theta_{cr}^{(o)} = \sin^{-1} \left(\frac{1}{n_o} \right) = 37^\circ$$

$$\theta_{cr}^{(e)} = \sin^{-1} \left(\frac{1}{n_e} \right) = 42^\circ$$

$$\theta_{cr}^{(o)} < \alpha < \theta_{cr}^{(e)}$$

Extinction ratio
 $5 \cdot 10^{-6}$

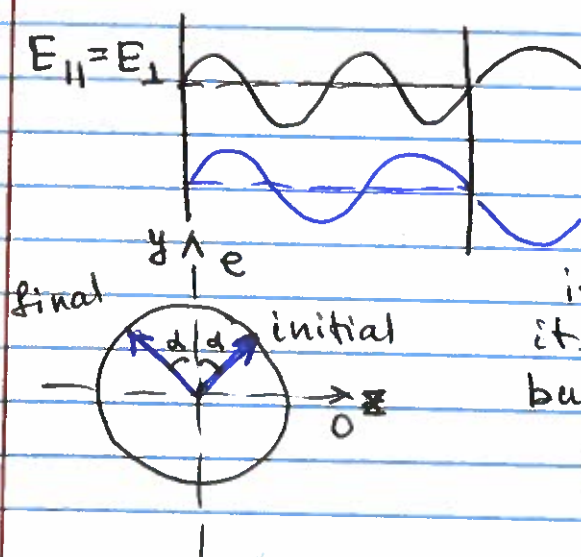
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The other polarization-related application of ~~to~~ birefringent materials - waveplate

Speed of light in the material: $\frac{c}{n}$

So e-wave and o-wave move inside the crystal w/ different speeds

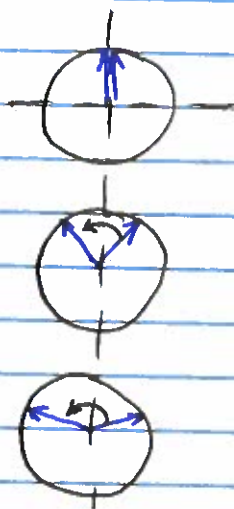
Half wave plate - one polarization gains extra half-wave: rotates linear polarization



if a wave polarized along e or its polarization stays the same but if

$$\vec{E} = \underbrace{\frac{1}{\sqrt{2}} E_0 \hat{x}}_{\text{along } o} + \underbrace{\frac{1}{\sqrt{2}} E_0 \hat{y}}_{\text{along } e}$$

after the waveplate $E_o \rightarrow E_o$
 $E_e \rightarrow -E_o$



By changing the angle of the waveplate axis w/respect to optical polarization by α , we can rotate the direction of polarization by 2α

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Quarter wave plate: one polarization gains $\pi/2$
With correct orientation transforms
linear polarization to circular (and vice versa)
ordinary extraordinary

Before: $E(x,t) = \frac{1}{\sqrt{2}} E_0 \hat{z} \cos(kx - \omega t) + \frac{1}{\sqrt{2}} E_0 \hat{y} \sin(kx - \omega t)$
linearly polarized at 45° to the waveplate axis
Shift by $\pi/2$ transforms $\cos$ to $\sin$
for (let's say) extraordinary wave

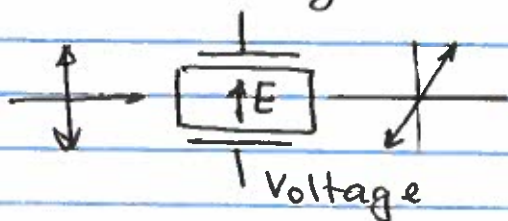
After: $E(x,t) = \frac{1}{\sqrt{2}} E_0 \hat{z} \cos(kx - \omega t) + \frac{1}{\sqrt{2}} E_0 \hat{y} \sin(kx - \omega t)$

Circularly polarized light

Many materials can rotate polarization.
Since the amount of rotation depends
on wavelength, that helps creating
colorful images.

Active control of light polarization

a) Kerr effect: linear birefringence induced by electric field



induced refractive index difference

$$n_e - n_o = \lambda_0 K E^2$$

λ_0 - wavelength in vacuum

K - Kerr constant

Kerr effect is very fast, so the polarization of light can be changed in tens of picoseconds (10^{-10} s) at ~ 10 GHz rate. This control enabled current speed in data transmission and communication in optical fiber networks, optical routers, etc.

b) There is also similar Pockels effect that is linear with applied electric field, so it requires lower voltages (but less common among materials)

c) Zeeman effect: circular birefringence induced by ~~the~~ longitudinal magnetic field ~~across~~

$$\varphi = V B l$$

l - length of the crystal, B - magn. field
 V - Verdet constant

Interestingly, magnetic field rotates light in the same direction independently of its propagation direction