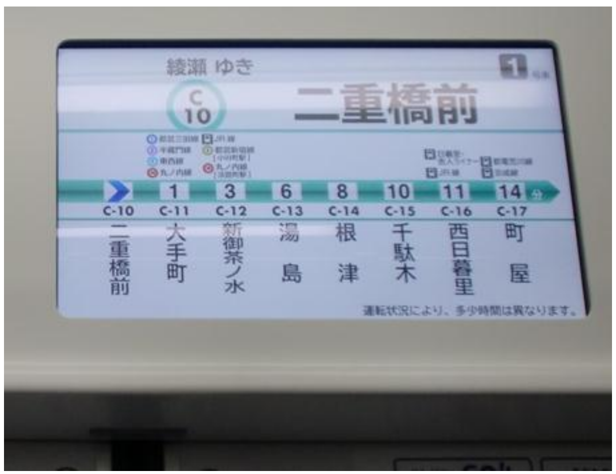
Liquid Crystals in Displays



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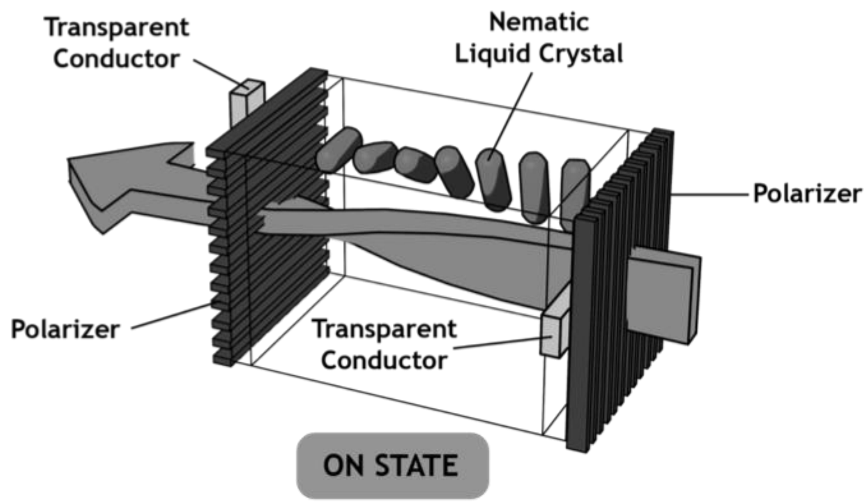
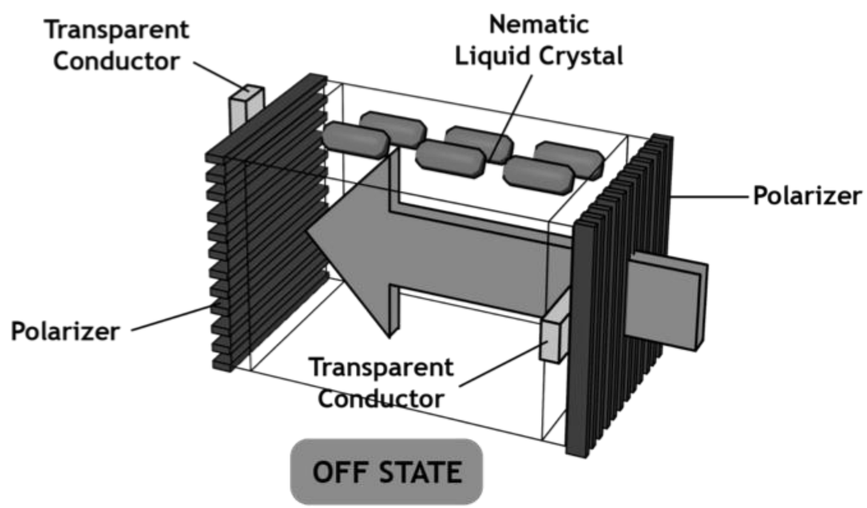
Outline

- Liquid Crystals
- Building a Liquid Crystal Cell
- Liquid Crystal Display Pixel
- Passive/Active Matrix Addressing

Liquid Crystal Displays



$$E = 0$$



$$E \neq 0$$

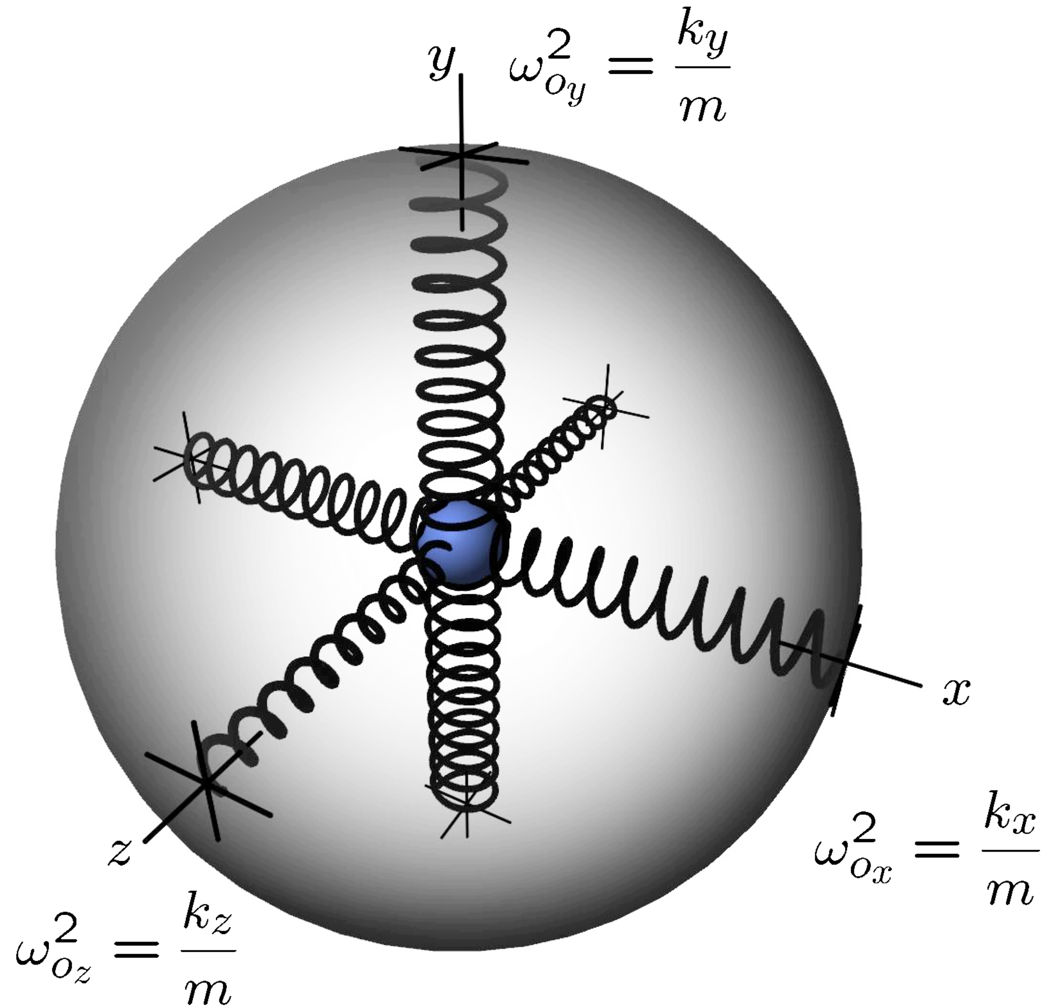
How can a material rotate polarization ?

Figure 2.16 from Hearn and Baker

Anisotropic Material

The molecular "spring constant" can be different for different directions

If $\omega_{o_x} = \omega_{o_z}$, then the material has a single optics axis and is called crystal



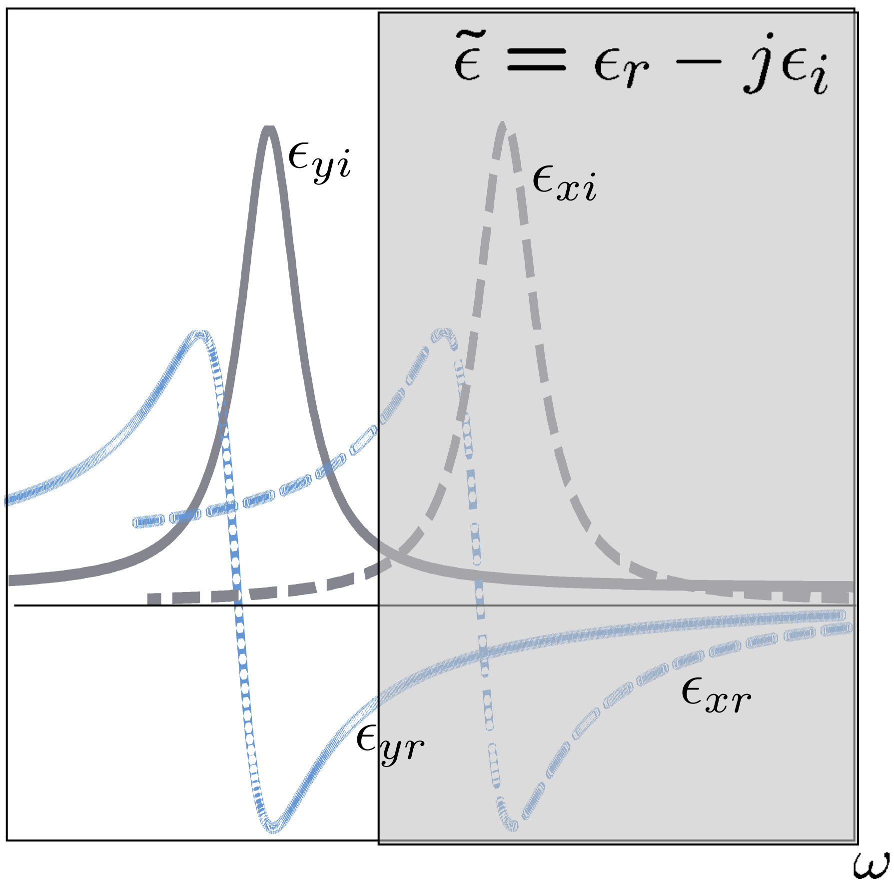
Microscopic Lorentz Oscillator Model

$$P(\omega) = \frac{\epsilon_o \omega_p^2}{\omega_o^2 - \omega^2 + j\omega\gamma} E(\omega) = (\tilde{\epsilon}(\omega) - 1)\epsilon_o E(\omega)$$

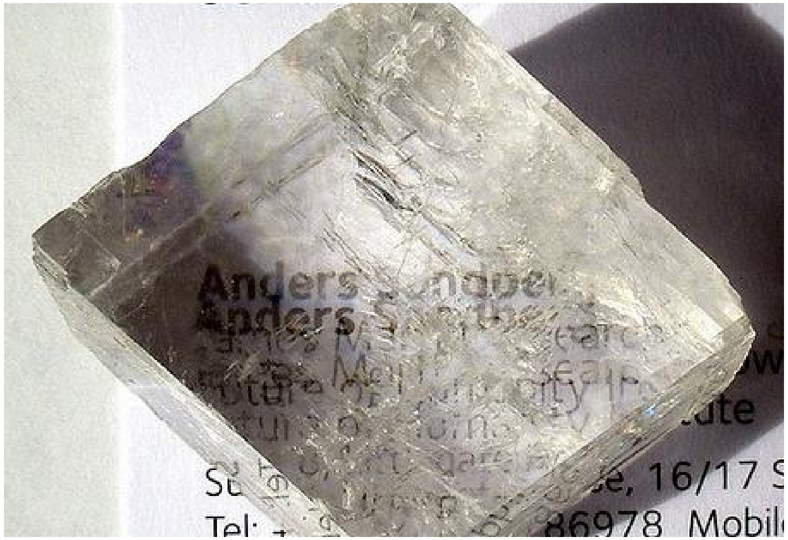
In the transparent regime
$\epsilon_{y_r} >> \epsilon_{y_i}$ ...

$$n_y = \sqrt{\frac{\epsilon_{y_r}}{\epsilon_o}}$$

$$n_x = \sqrt{\frac{\epsilon_{y_r}}{\epsilon_o}}$$



Birefringent Materials



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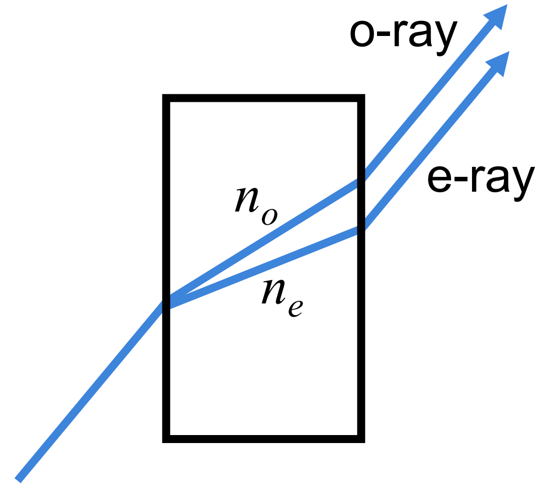


Crystal $\lambda = 583nm$	n_o	n_e
Tourmaline	1.669	1.638
Calcite	1.6584	1.4864
Quartz	1.5443	1.5534
Sodium nitrate	1.5854	1.3369
Ice	1.309	1.313
Rutile (TiO_2)	2.616	2.903

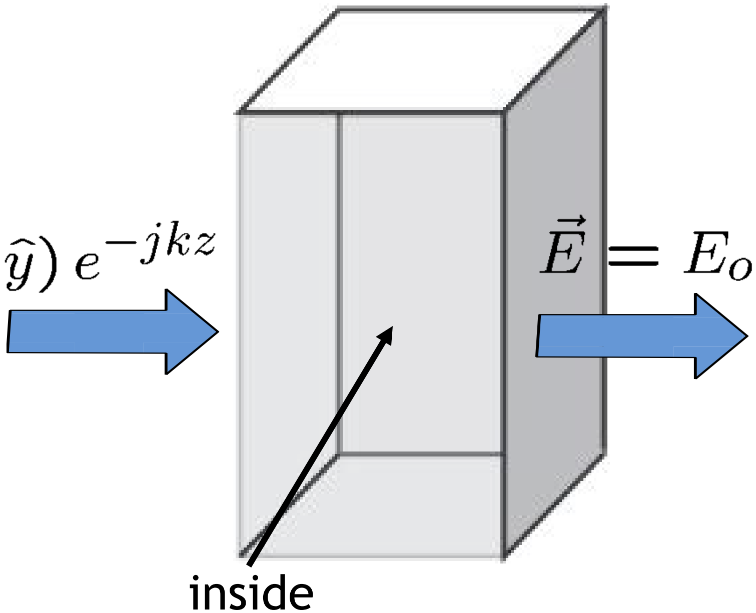
All transparent crystals with non-cubic lattice structure are birefringent.

Polarization Conversion

Linear to Circular

$$\vec{E} = E_o\left(\hat{x} + \hat{y}\right)e^{-jkz}$$

$$\vec{E} = E_o\left(\hat{x}e^{-jk_e d} + \hat{y}e^{-jk_o d}\right)e^{-jkz}$$

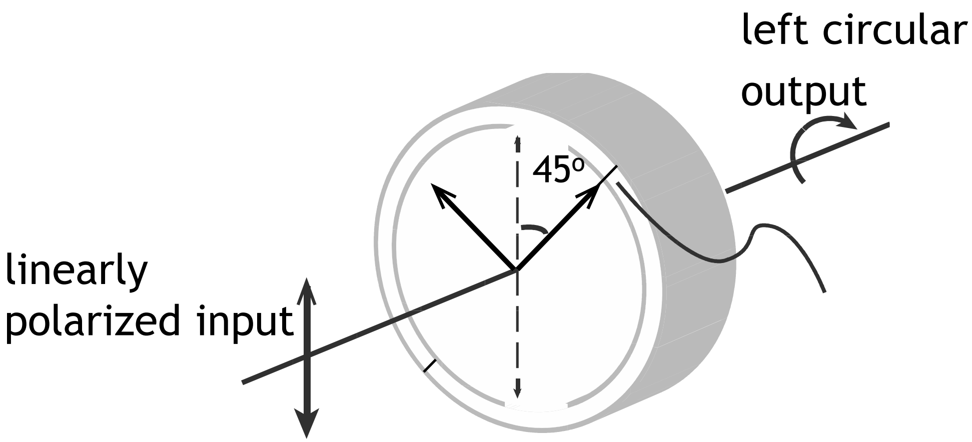


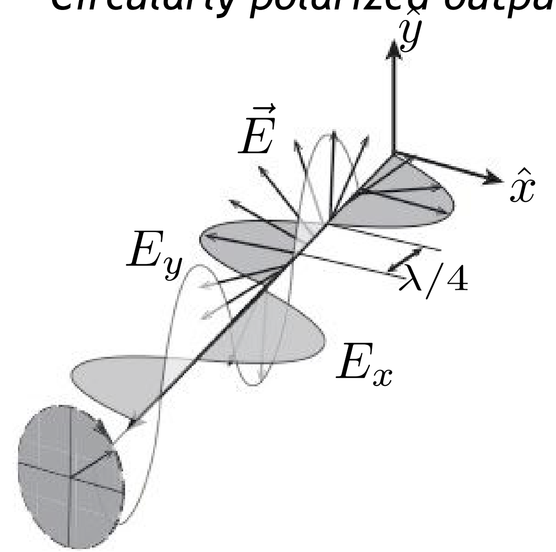
$$\vec{E} = E_o\left(\hat{x}e^{-jk_e z} + \hat{y}e^{-jk_o z}\right)$$

Polarization of output wave is determined by…

$$\frac{E_y}{E_x} = \frac{e^{-jk_e d}}{e^{-jk_o d}} = e^{-j(k_o - k_e)d}$$

Quarter-Wave Plate





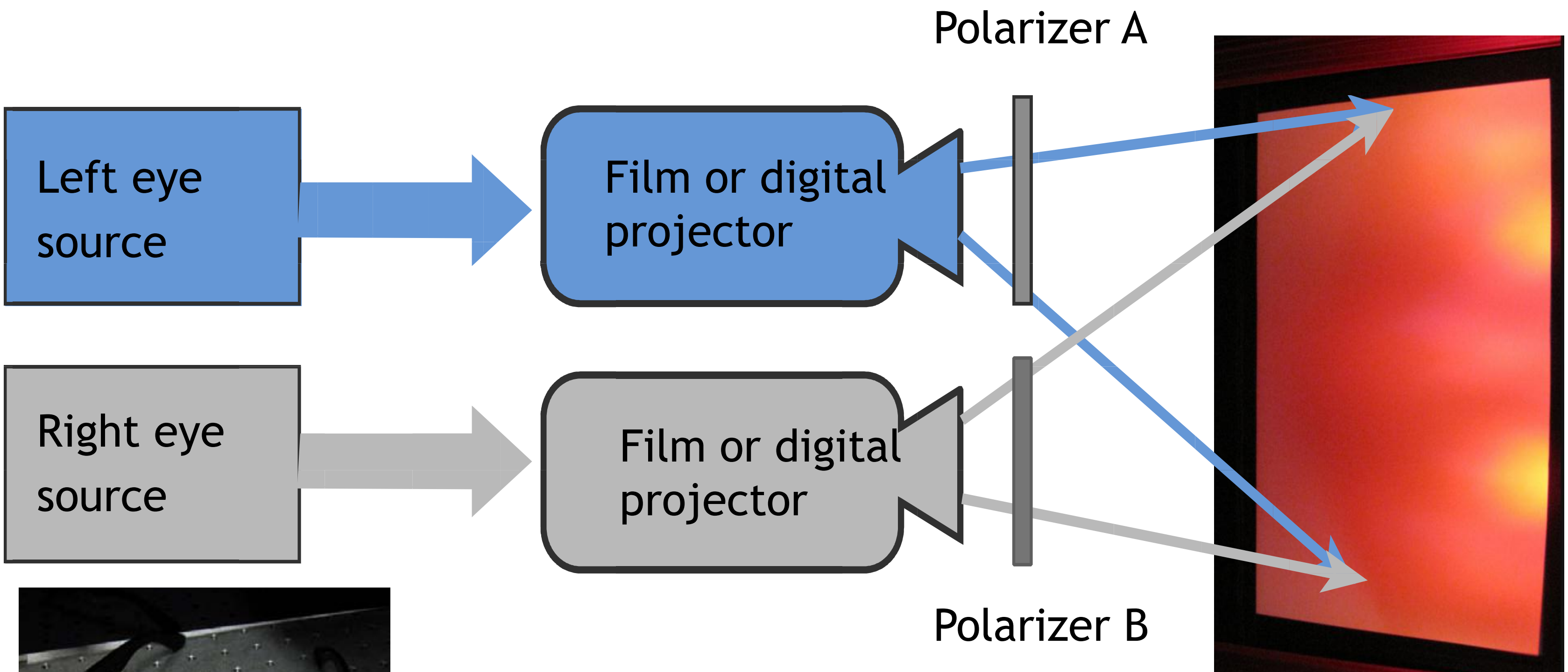
Example:

If we are to make quarter-wave plate using calcite (n_o = 1.6584, n_e = 1.4864), for incident light wavelength of λ = 590 nm, how thick would the plate be ?

$$\frac{2\pi}{\lambda}\left|n_o - n_e\right| d = \frac{\pi}{2} \quad \Rightarrow \quad d = \frac{\lambda}{4\left|n_o - n_e\right|}$$

$$d = 0.857\ \mu\text{m}$$

3D Movies Technology



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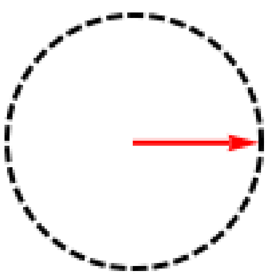
Which approach is better ? Linear or circular polarization ?

A linearly polarized wave can be represented as a sum of two circularly polarized waves

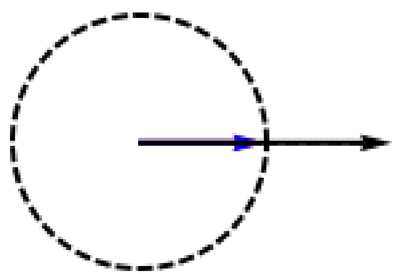
$$E_x(z,t) = \hat{x}\tilde{E}_o sin(\omega t - kz)$$
$$E_y(z,t) = \hat{y}\tilde{E}_o cos(\omega t - kz)$$

$$E_x(z,t) = -\hat{x}\tilde{E}_o sin(\omega t - kz)$$
$$E_y(z,t) = \hat{y}\tilde{E}_o cos(\omega t - kz)$$

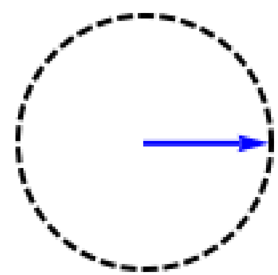
CIRCULAR



LINEAR

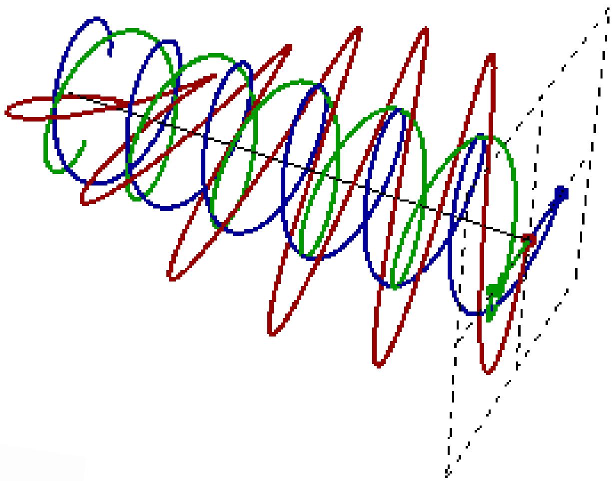


CIRCULAR

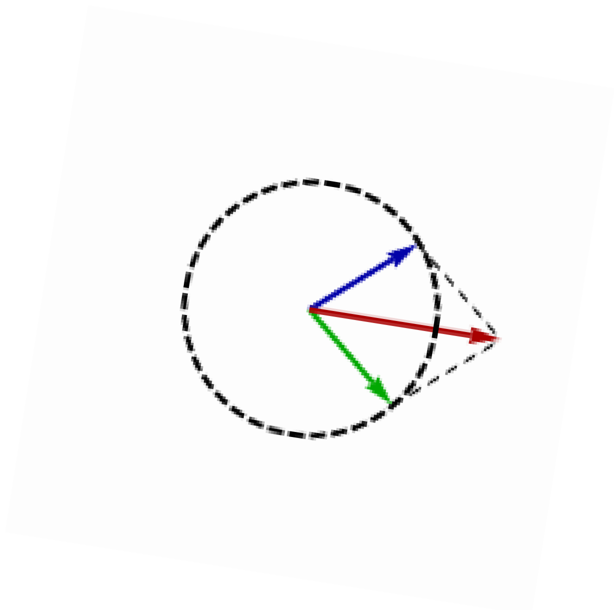


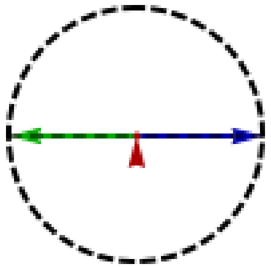
Circular Birefringence

But as the two circular polarizations of light travel through the circular birefringence material at different speeds, they will be phase shifted when they exit the medium

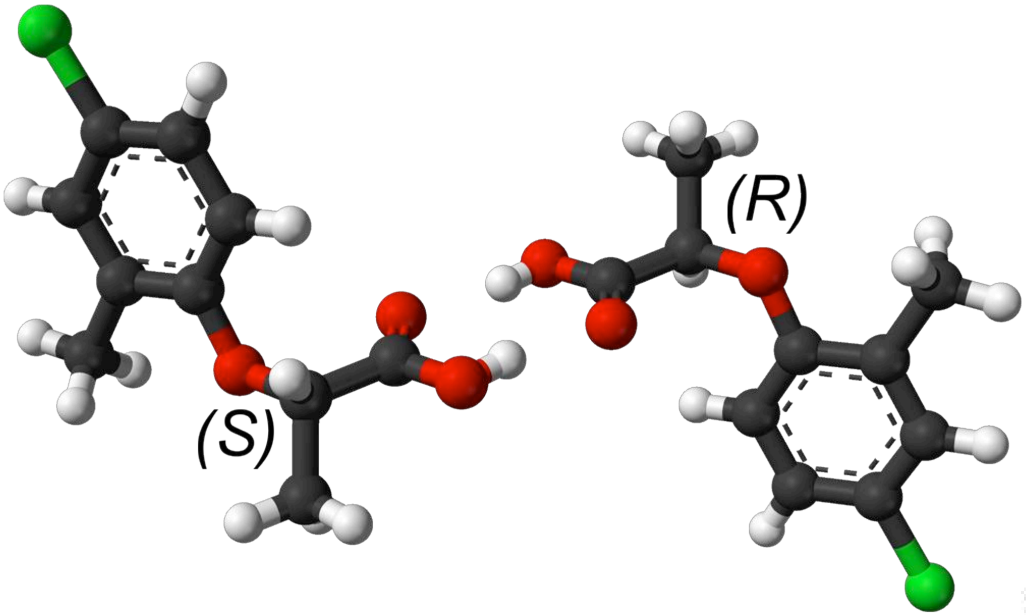


$$n_R \neq n_L$$

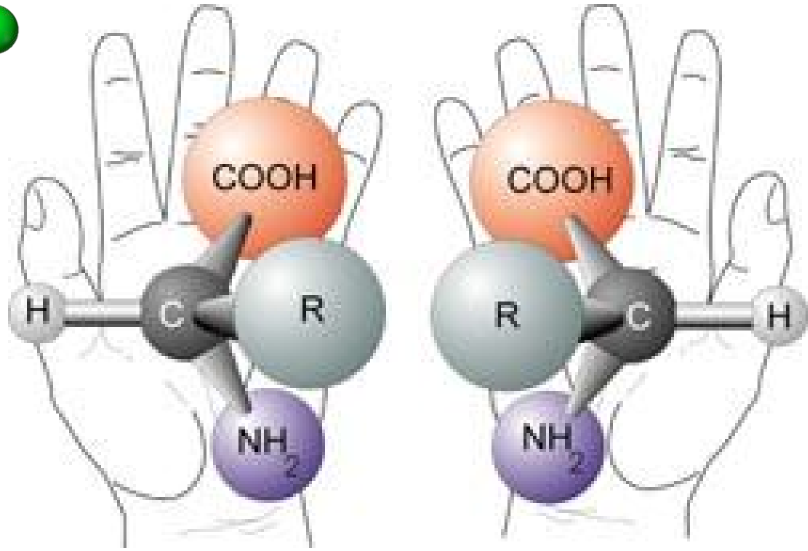




Circular Birefringence



$$n_{left} \neq n_{right}$$



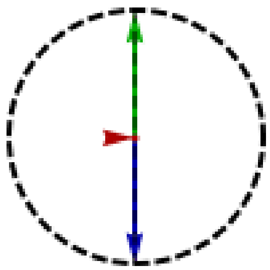
Chiral molecules…
…different interactions with left- and right-circular polarizations

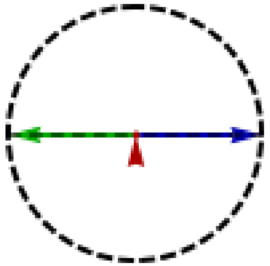
Polarization Rotation with Circular Birefringence

$$\vec{E}_L = E_o \left(\hat{x} + j\hat{y} \right) e^{-jkz}$$

$$\vec{E}_R = E_o \left(\hat{x} - j\hat{y} \right) e^{-jkz}$$

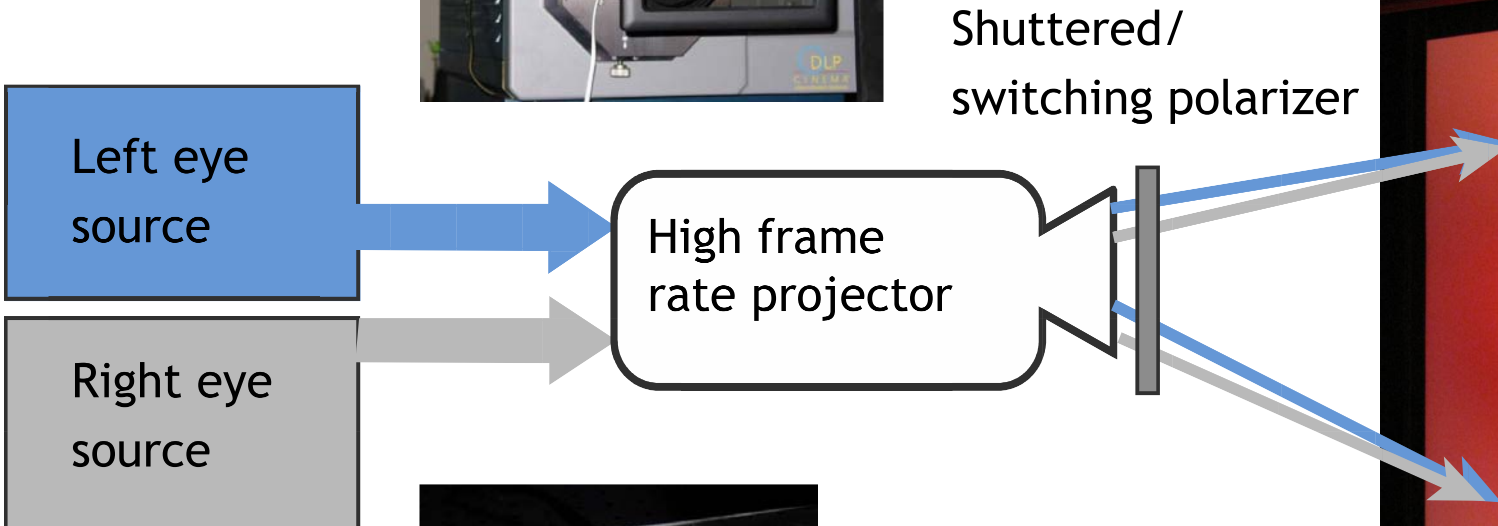
x-polarized $\vec{E} = \vec{E}_L + \vec{E}_R$

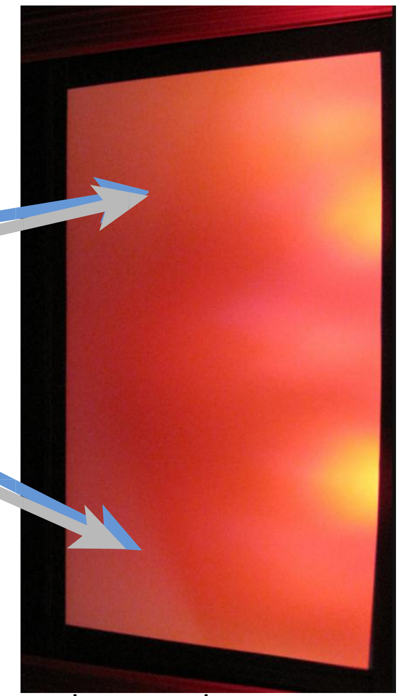




y-polarized $\vec{E} = \vec{E}_L - \vec{E}_R$

Interleaved 3D Movies





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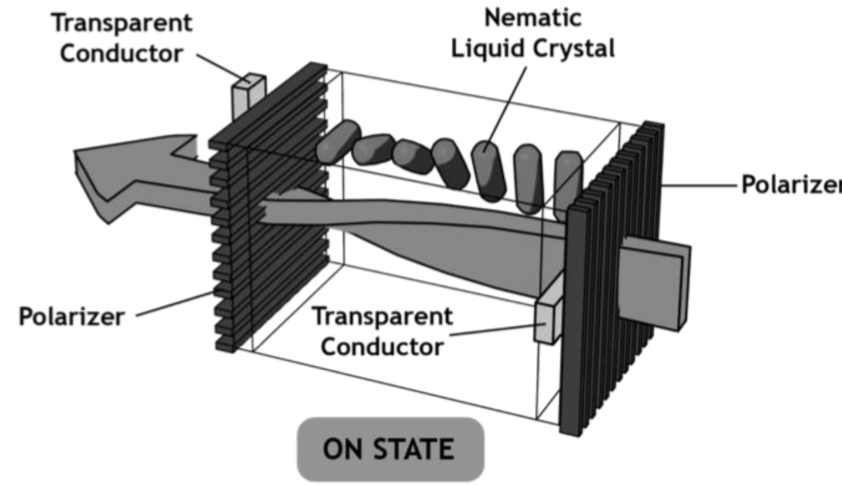
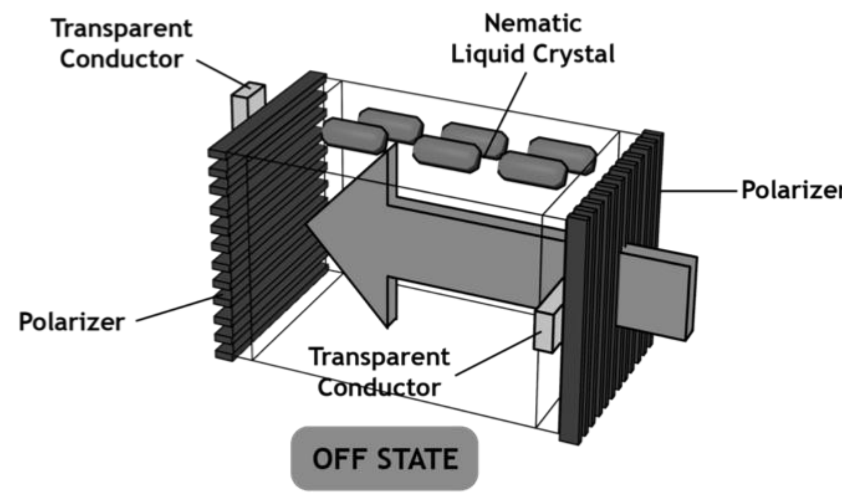
Liquid Crystal Displays

Circular birefringence



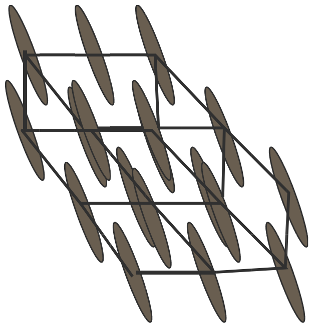
$E = 0$

NO circular birefringence



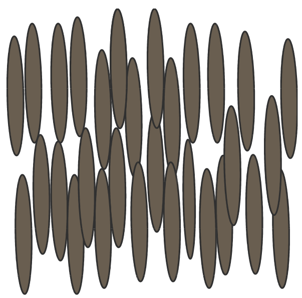
$E \neq 0$

States of Matter



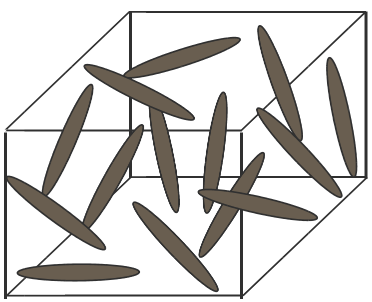
Solid (crystalline):

incompressible, no flow under shear
crystal = periodic in space



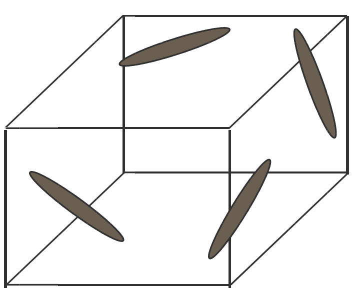
Liquid Crystal:

incompressible, flows under shear
long range order



Liquid:

incompressible, flows under shear
very short range order

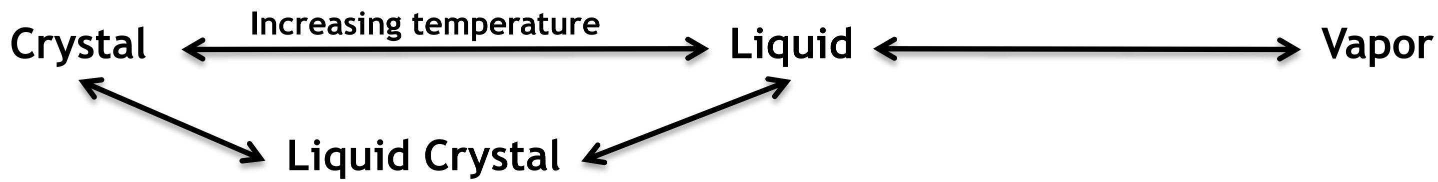


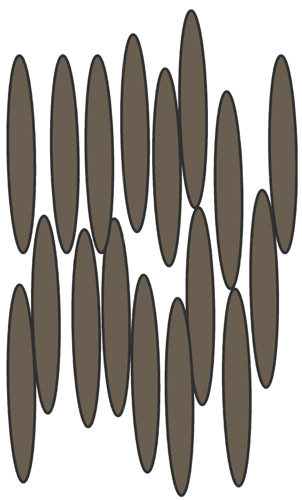
Gas:

compressible

Liquid Crystal Structure

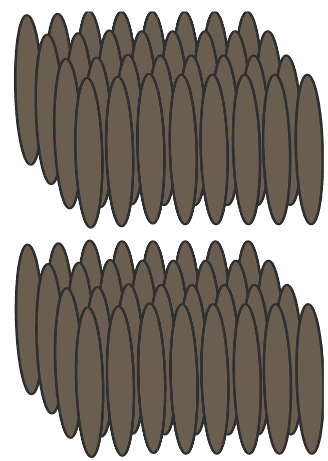
Steemers, SID Seminar Notes 1994.





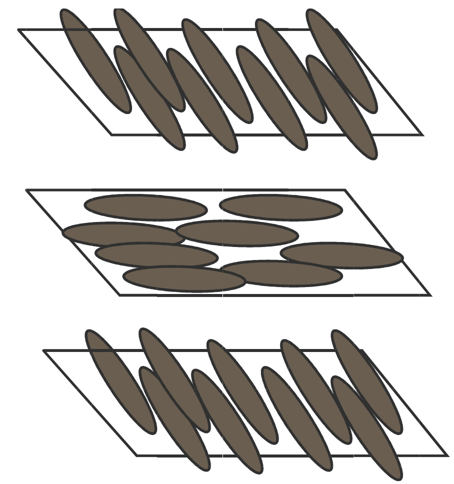
Nematic liquid crystal

- Molecules tend to be parallel but their positions are random
- Long range orientation order



Smetic liquid crystal

- Positional order in 1-D
- Long range orientational order

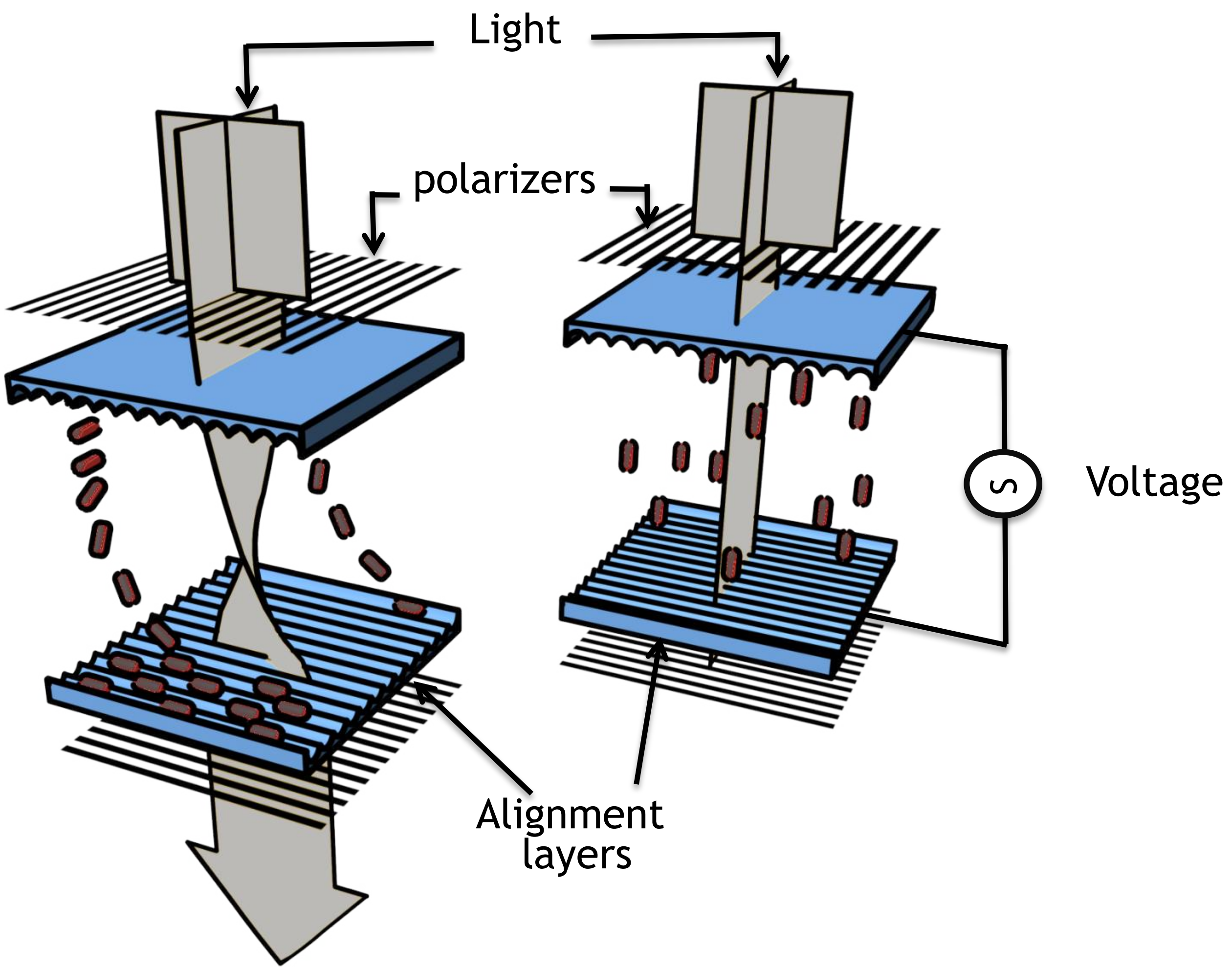


Cholsteric liquid crystal

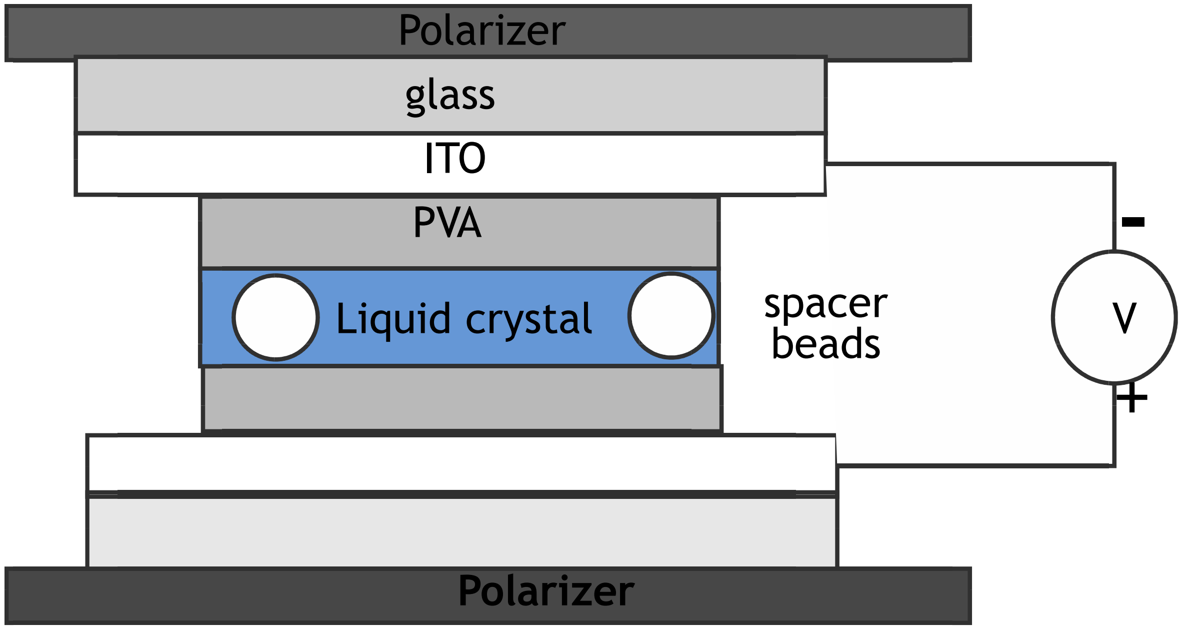
- Distorted form of the nematic phase in which the orientation undergoes helical rotation
- Chiral molecules

Twisting Liquid Crystals

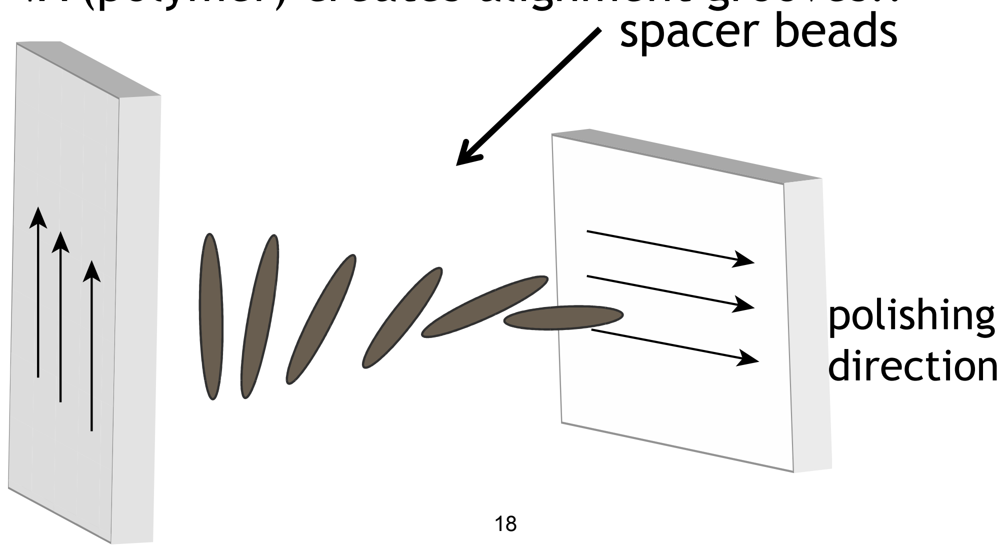
LC ordering is determined by anisotropic boundary conditions (grooves)



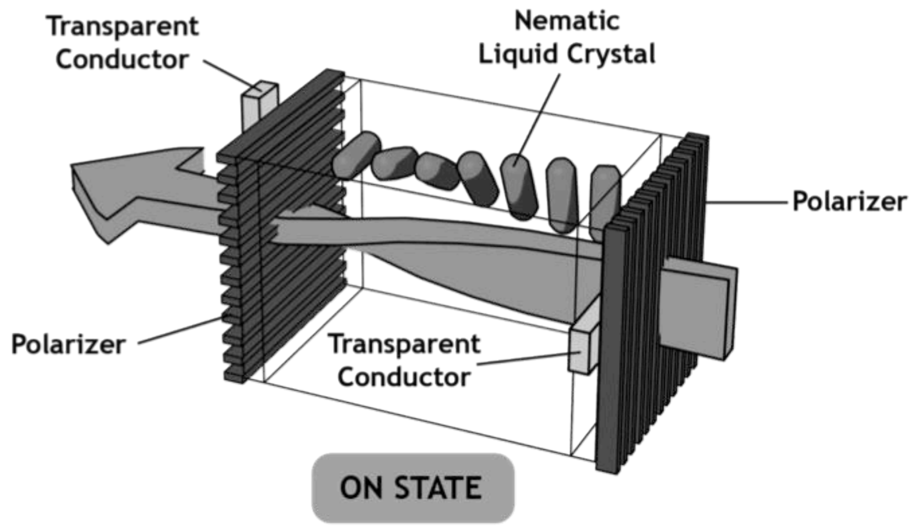
6.007 Lab Pixel



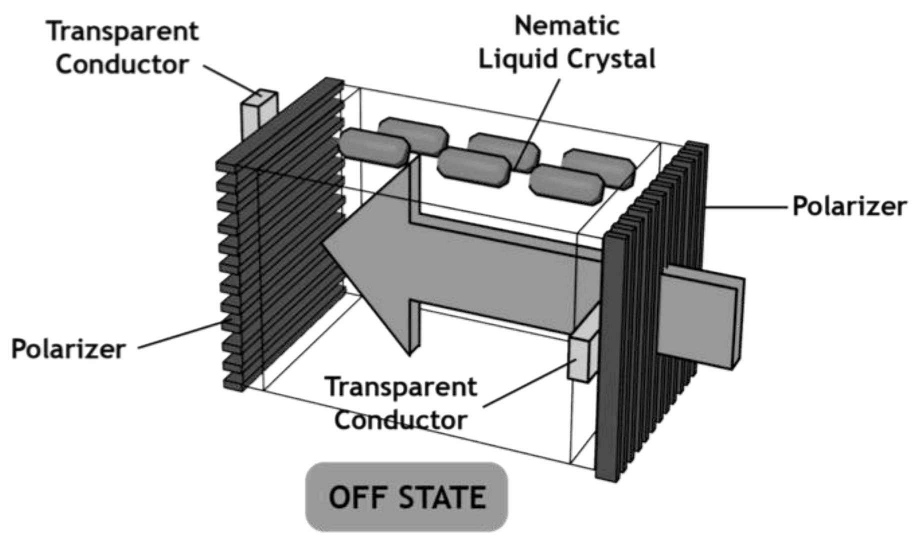
Polishing PVA (polymer) creates alignment grooves..



Liquid Crystal Displays



E = 0



E ≠ 0

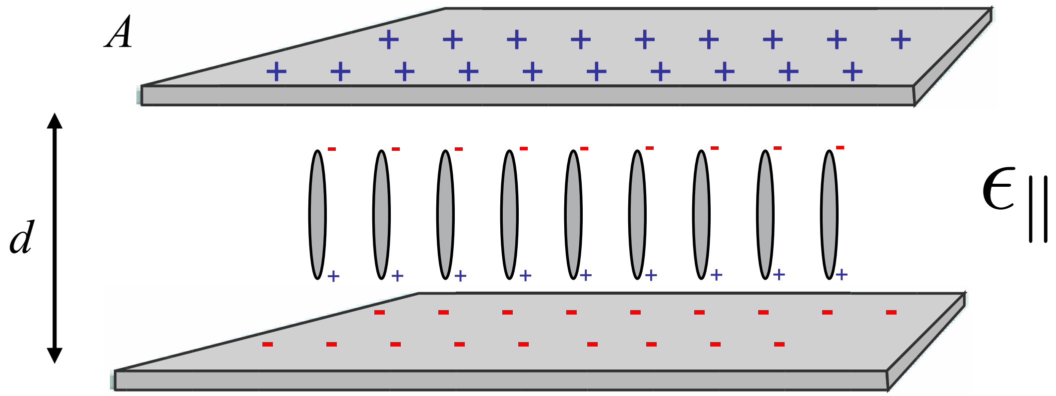
LC dielectric anisotropy allows control of molecular orientation by the external E-field.

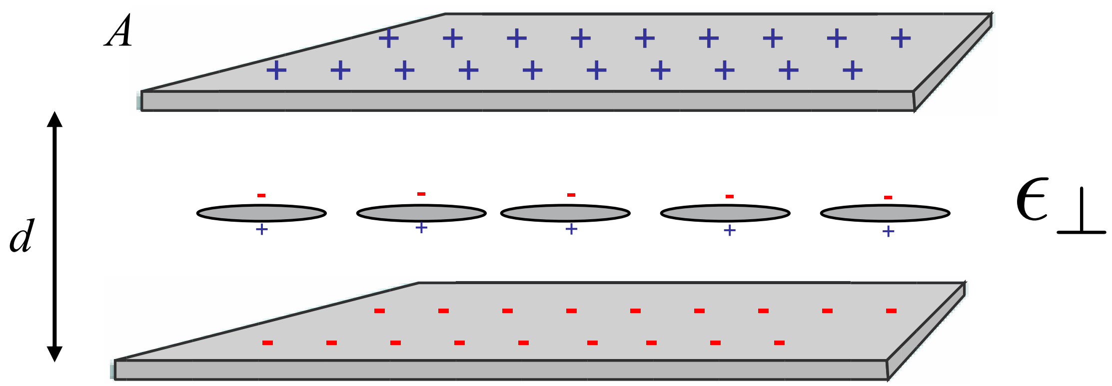
Molecules rotate to minimize stored energy

What is the physical reason for LC rotation ?

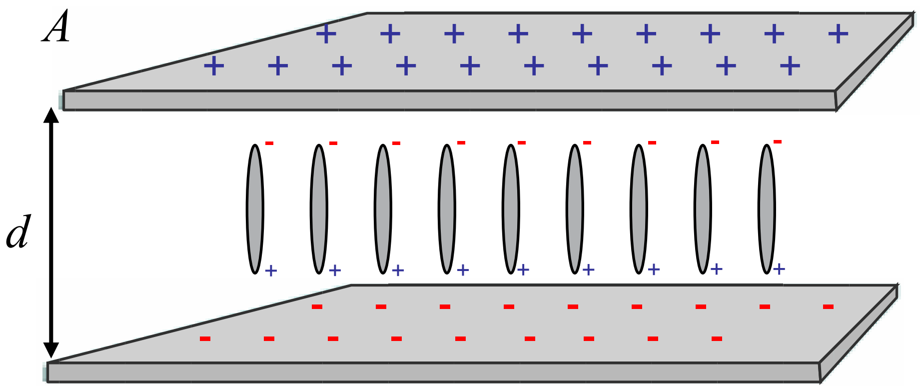
Figure 2.16 from Hearn and Baker

Anisotropic Dielectric Constant





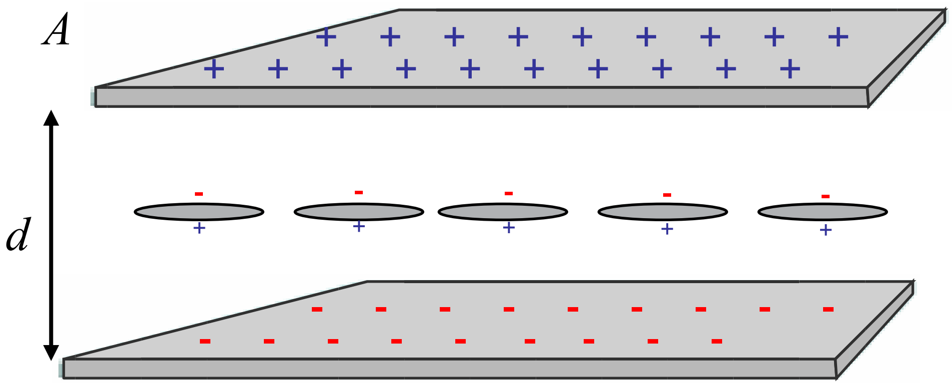
Energy Method for LC



$$\epsilon_{\|} > \epsilon_{\perp}$$

$\epsilon_{\|}$ Stored energy …

$$W_E = \frac{1}{2}\vec{D}\cdot\vec{E} = \frac{1}{2}\frac{Q^2}{C(\theta)}$$

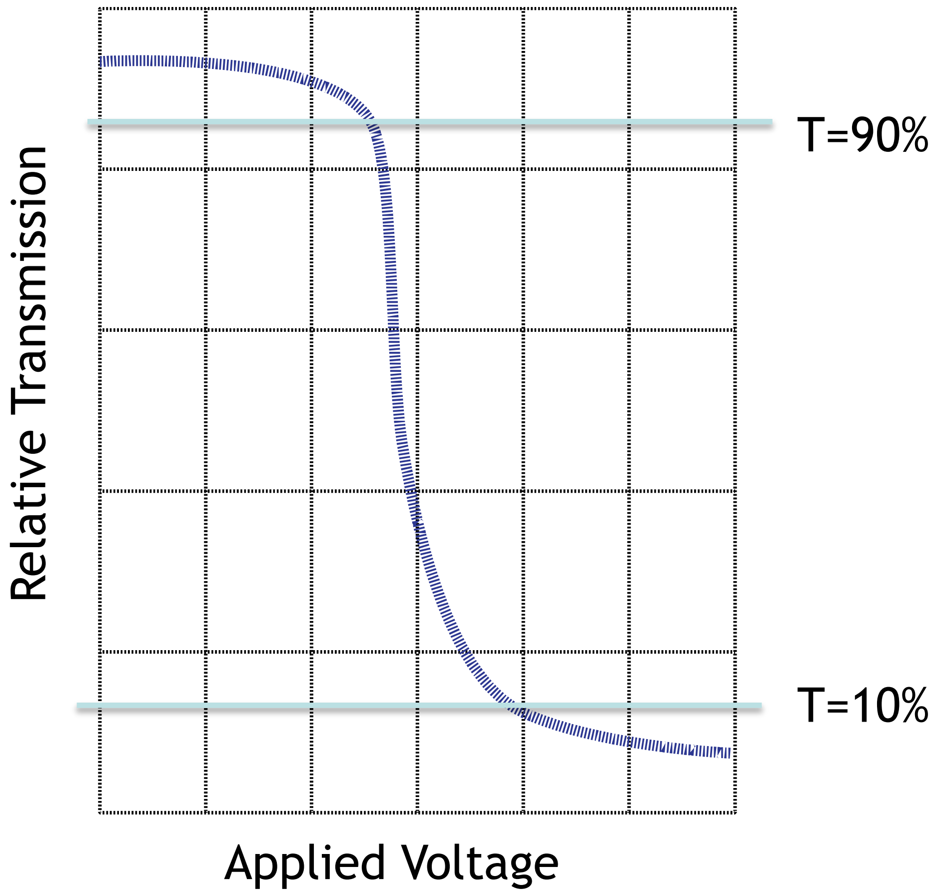


Force acts to increase capacitance …

$\epsilon_{\perp}$ $$f = -\left(\frac{\partial W_E}{\partial \theta}\right)_Q$$

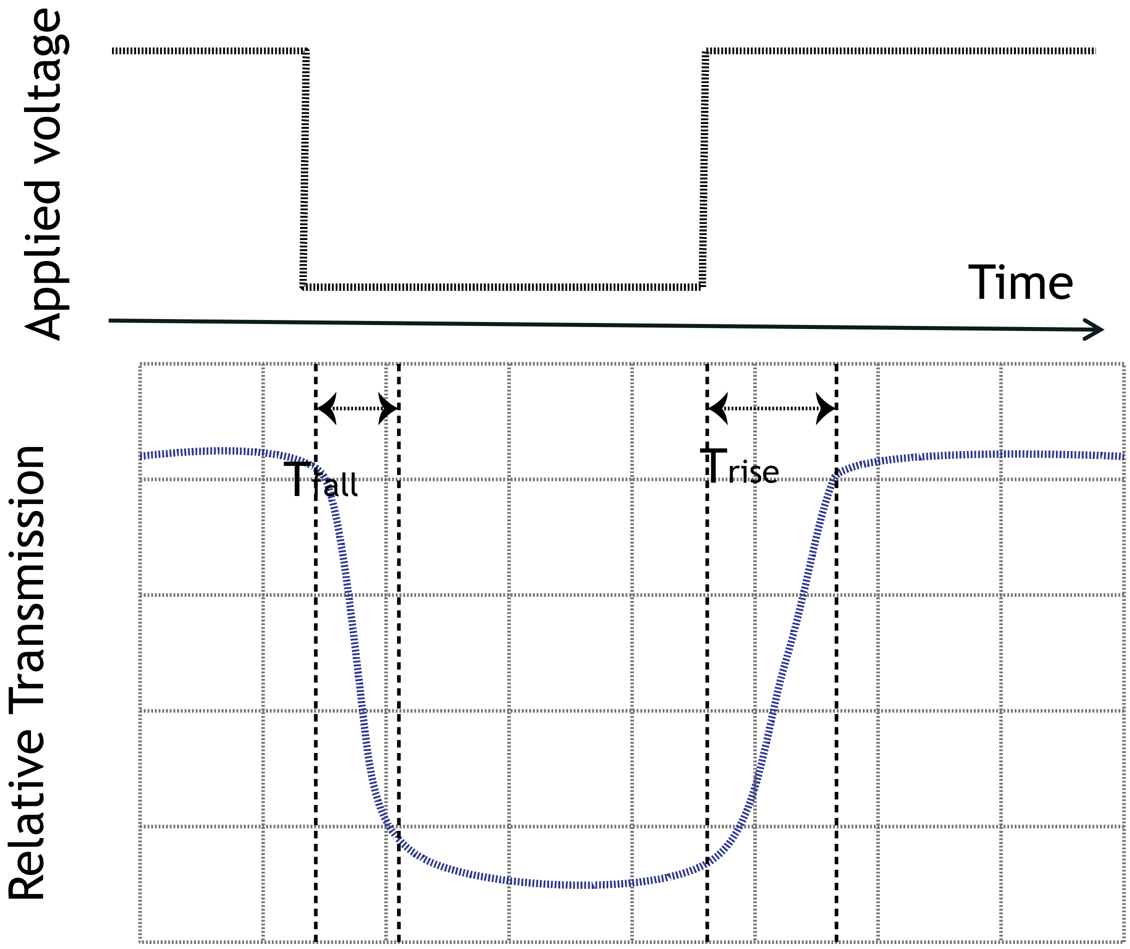
$$D_z = \left(\varepsilon_{\|}\cos^2\theta + \varepsilon_{\perp}\sin^2\theta\right)E$$

Electro-Optic Response of Twisted Nematic Liquid Crystal Cell



LC cell is 5 μm to 10 μm thick
At 3 V applied dc-bias E–field is 3 to 6 kV/cm

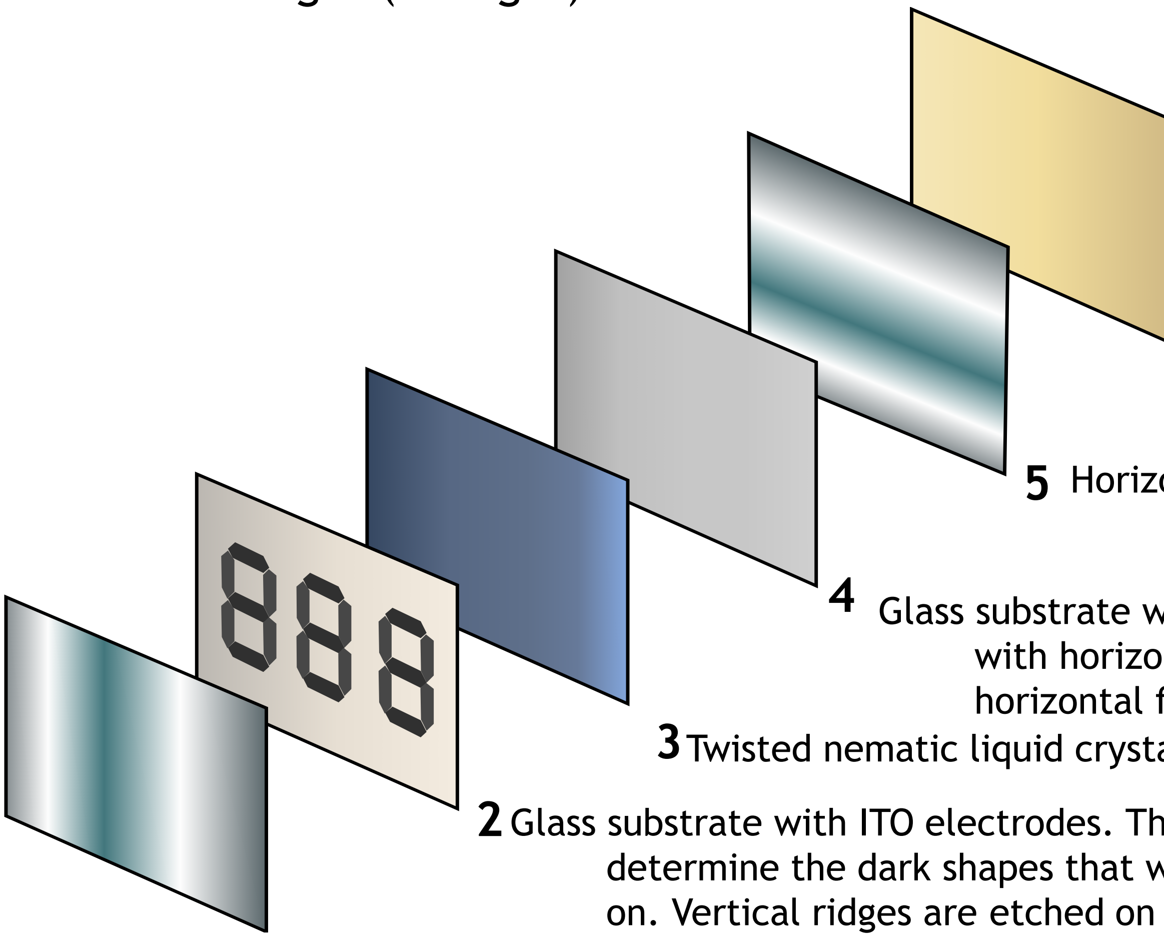
Transient Response of Twisted Nematic Liquid Crystal Cell



The response is not instantaneous. This limits the refresh rate!

Reflective LCD Display

… illuminated by
external light (sunlight)



6 Reflective surface to send light back to viewer.

5 Horizontal filter film to block/allow through light.

4 Glass substrate with common electrode film (ITO) with horizontal ridges to line up with the horizontal filter.

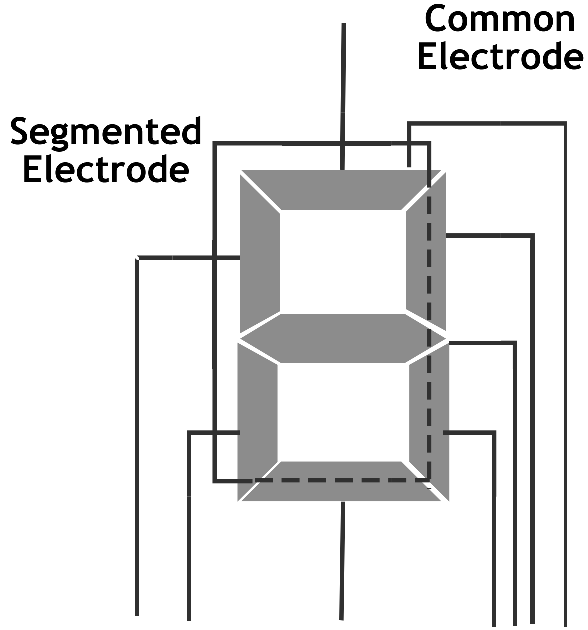
3 Twisted nematic liquid crystals.

2 Glass substrate with ITO electrodes. The shapes of these electrodes will determine the dark shapes that will appear when the LCD is turned on. Vertical ridges are etched on the surface so the liquid crystals are in line with the polarized light.

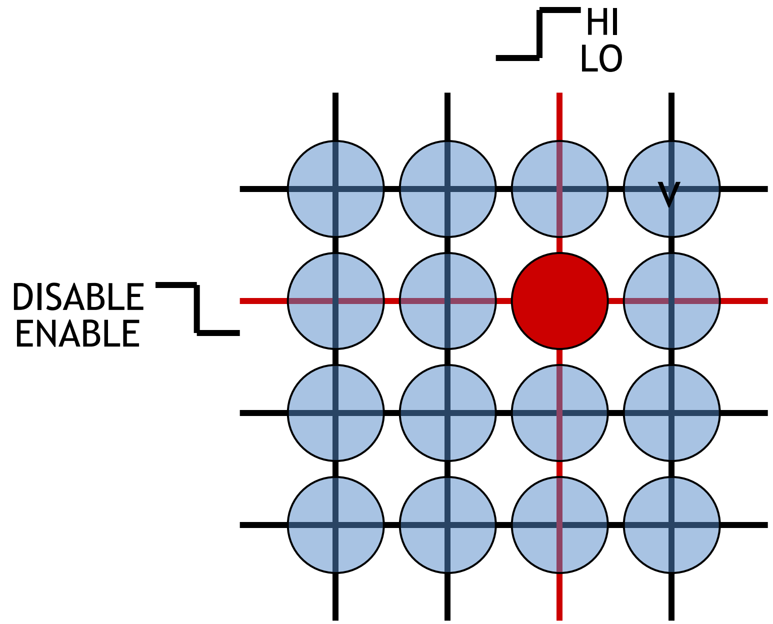
1 Vertical filter film to polarize the light as it enters.

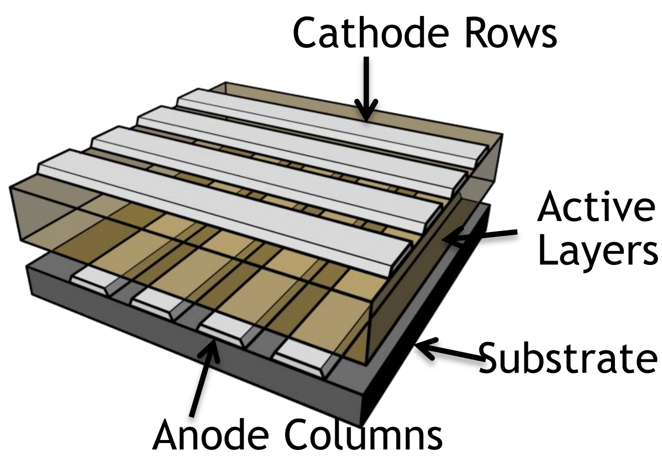
Display Addressing

DIRECTLY ADDRESSED DISPLAY



MATRIX DISPLAY

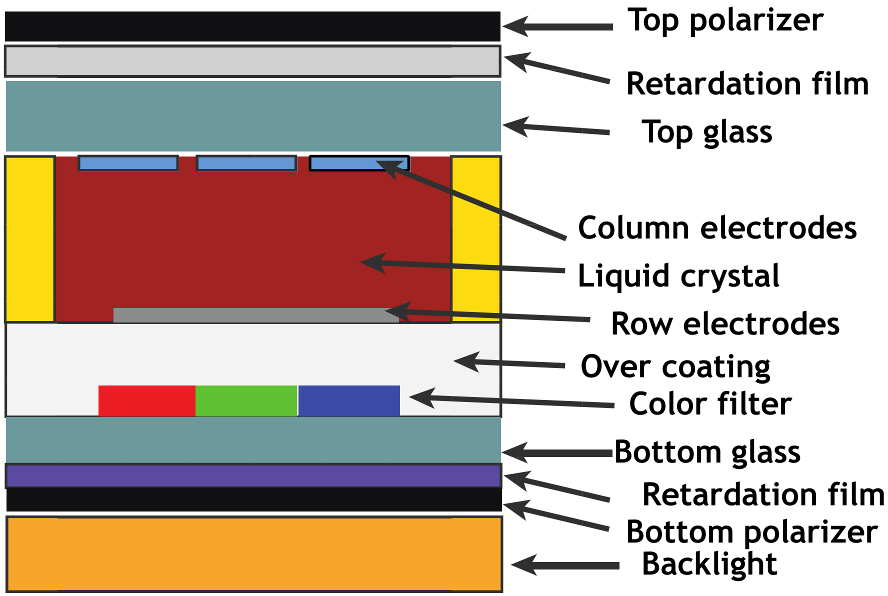


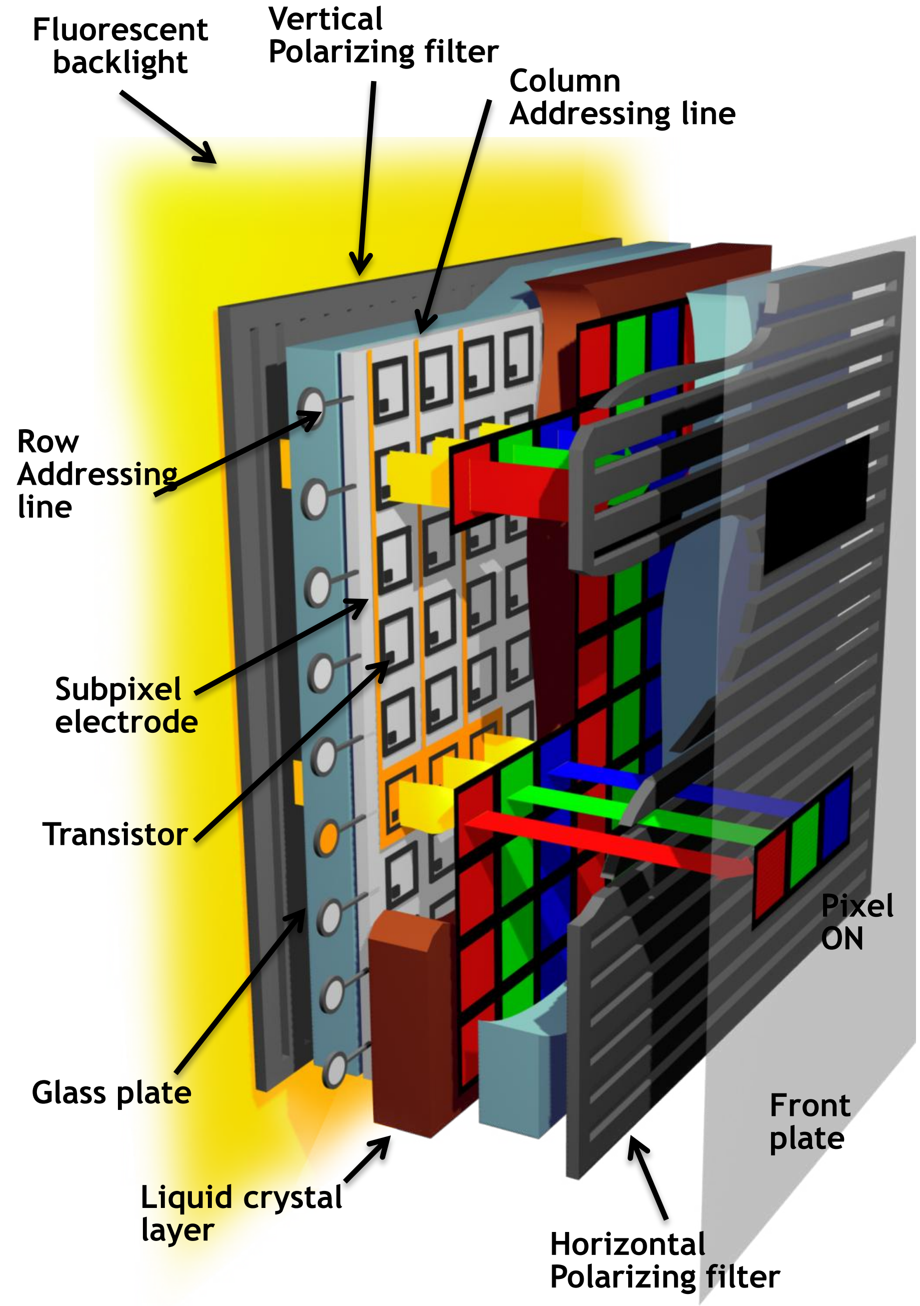


Example:

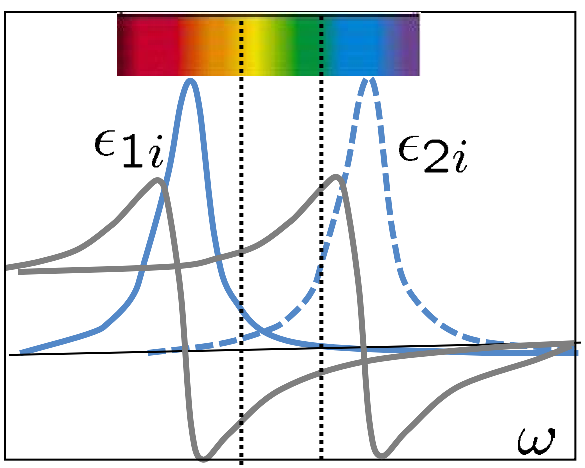
for X=640 x Y480 panel of emissive elements
direct addressing → 2 x 640 x 480 = 614,400 (2*X*Y) wires
matrix addressing → 640 + 480 = 1120 (X+Y) wires

LCD Display Cross-Section





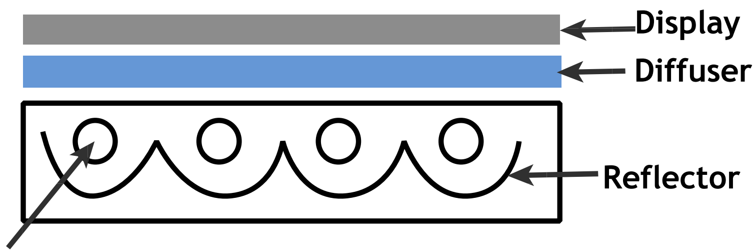
Example of a Color Filter (green)

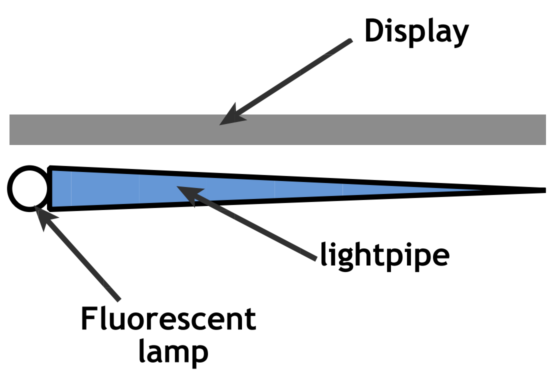


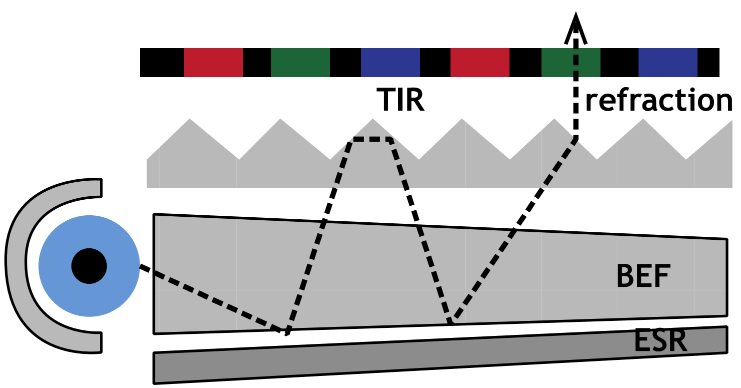
LCD Backlight

- Consists of light source, reflector, and diffuser
- Goals are compactness, high efficiency, uniformity, long life

Fluorescent lamp







What is Color?

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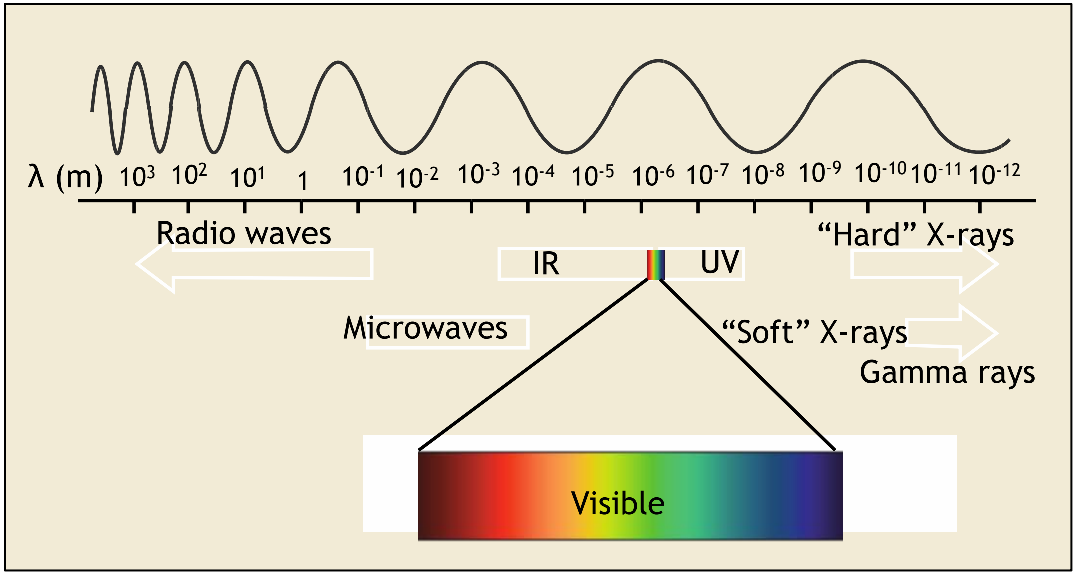
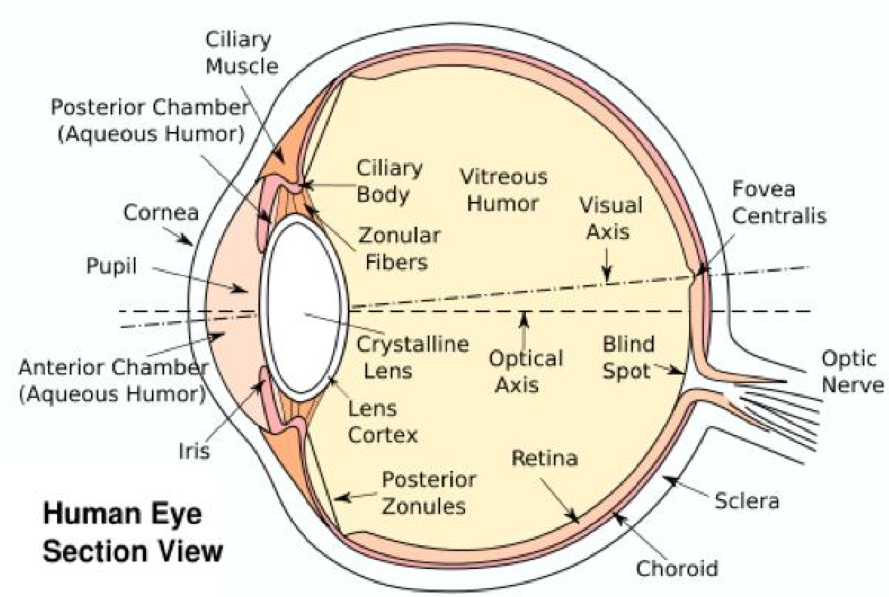


Diagram of the Human Eye



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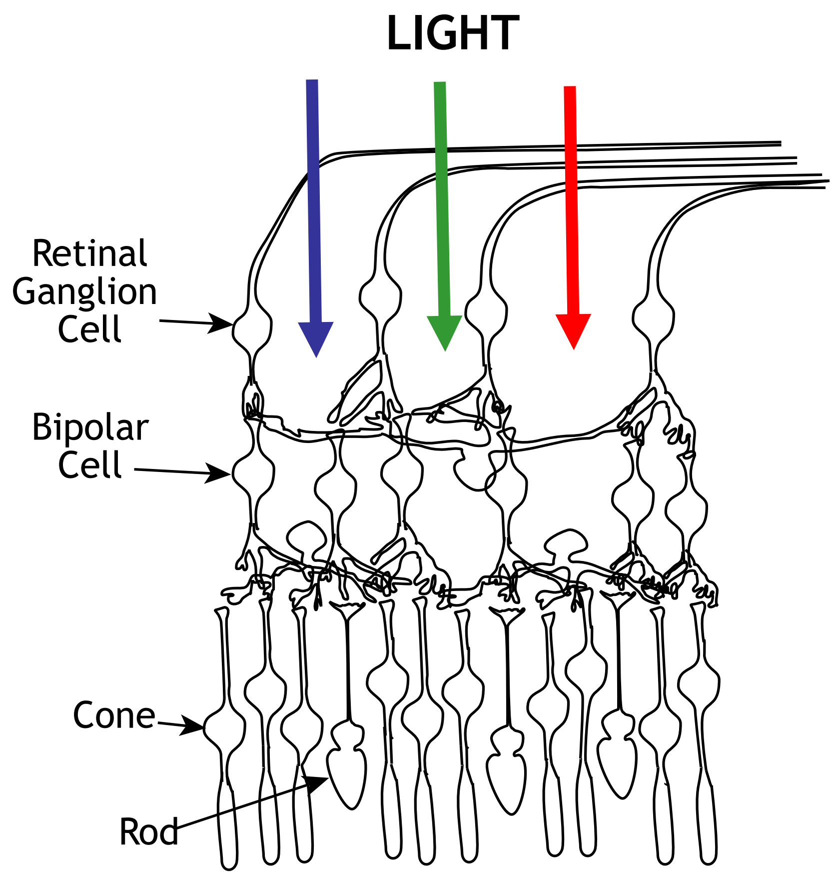


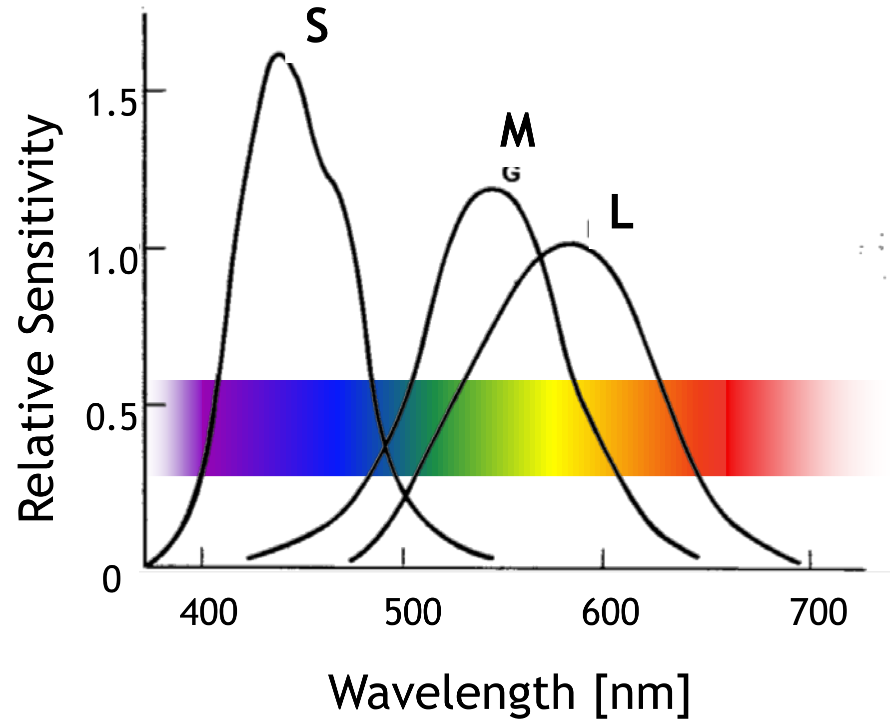
The Neural Structure of the Retina

Retina has FOUR types of Receptors:

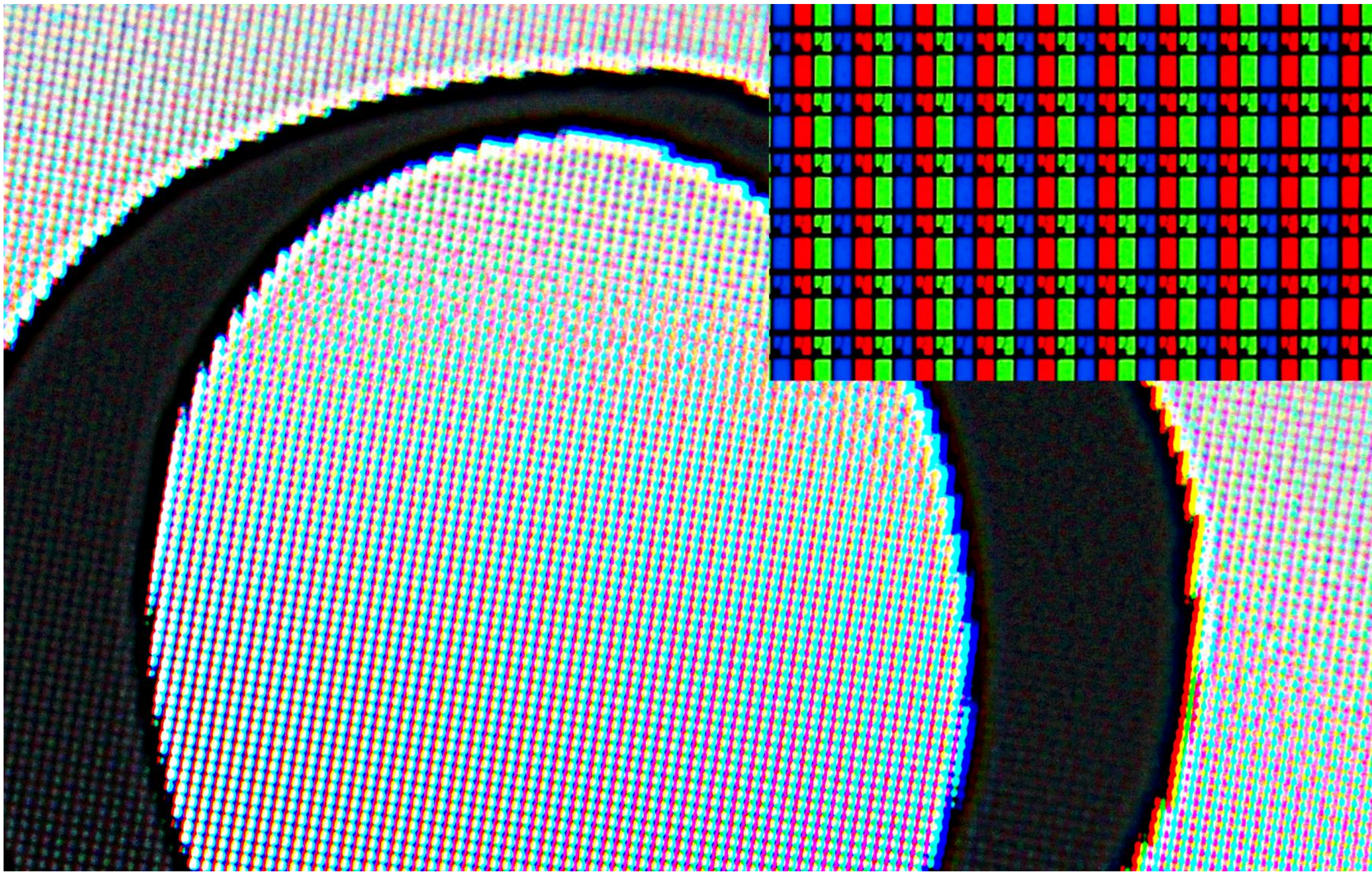
120 million Rods - brightness
6 million Cones - color
B 5-10% ("S-cones")
G ~30% ("M-cones")
R ~60% ("L-cones")

Spectral Sensitivity of Cones

- L-cones have peak absorption at λ~560 nm
- M-cones have peak absorption at λ~530 nm
- S-cones have peak absorption at λ~430 nm
- The three cones have broad sensitivity curves with a lot of overlap
  - Light at 550 nm will evoke response from L- and M-cones but much weaker response from S-cones



LCD under a Magnifier



Polymer Dispersed LCDs – Privacy Glass

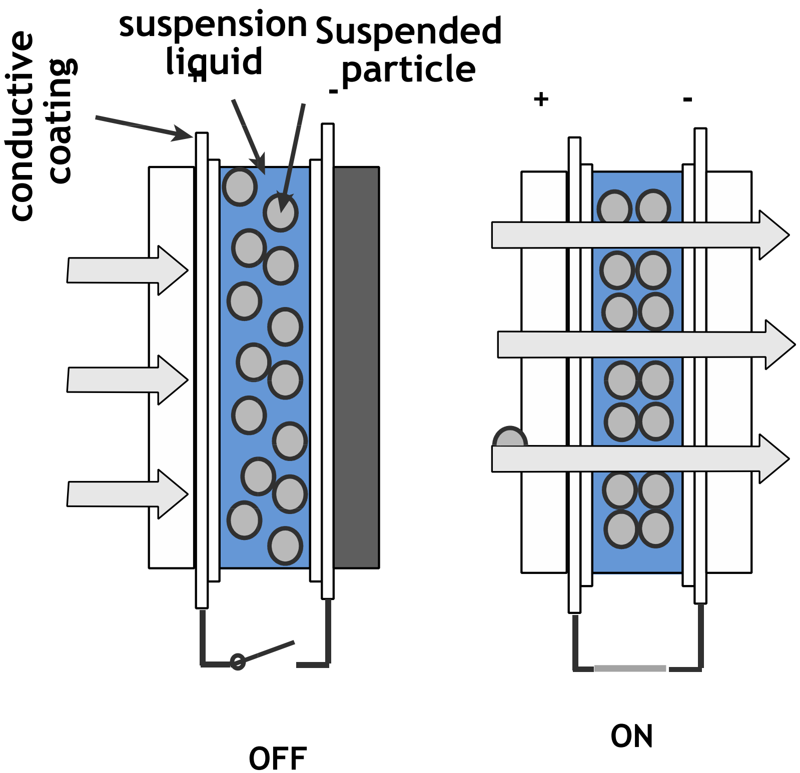


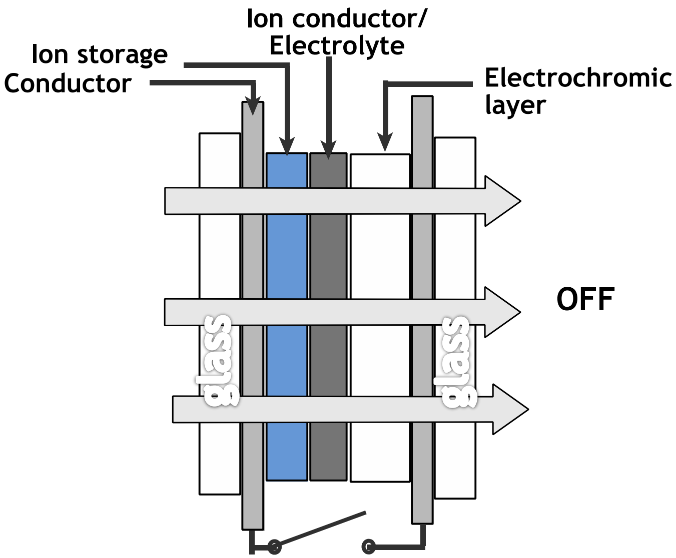
Image by University of Michigan MSIS http://www.flickr.com/photos/umich-msis/6443313259/ on flickr

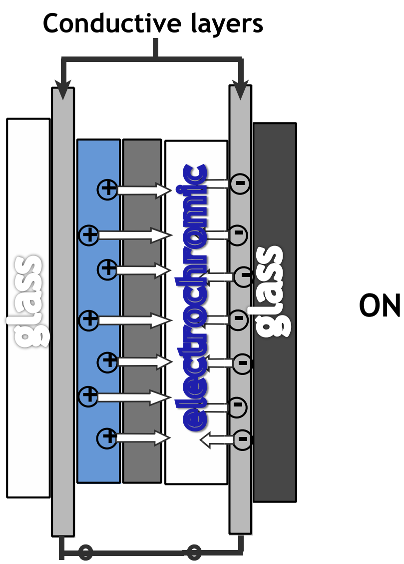
- A standard meeting room with some privacy protection
- Polymer dispersed LCDs allow for changeable transparency

Electrochromic Windows

- Shift of the Lorentz Oscillator

- change Optical Absorption





When switched "OFF" and electrochromic window remains transparent.
When switched "ON" voltage drives the ions from the ion storage layer, through the ion conducting layer and into the electrochromic layer. O**xidation reaction** -- a reaction in which molecules in a compound lose an electron changes the dielectric properties of the electrochromic layer, which now absorbs the incident light, are what allow it to change from opaque to transparent. It's these ions that allow it to absorb light. By shutting off the voltage, the ions are driven out of the electrochromic layers and into the ion storage layer. When the ions leave the electrochromic layer, the window regains its transparency.

Image by Bitboy http://www.flickr.com/photos/bitboy/2388546266// on flickr

A rear view mirror with an electrochromic layer for dimming during night time use