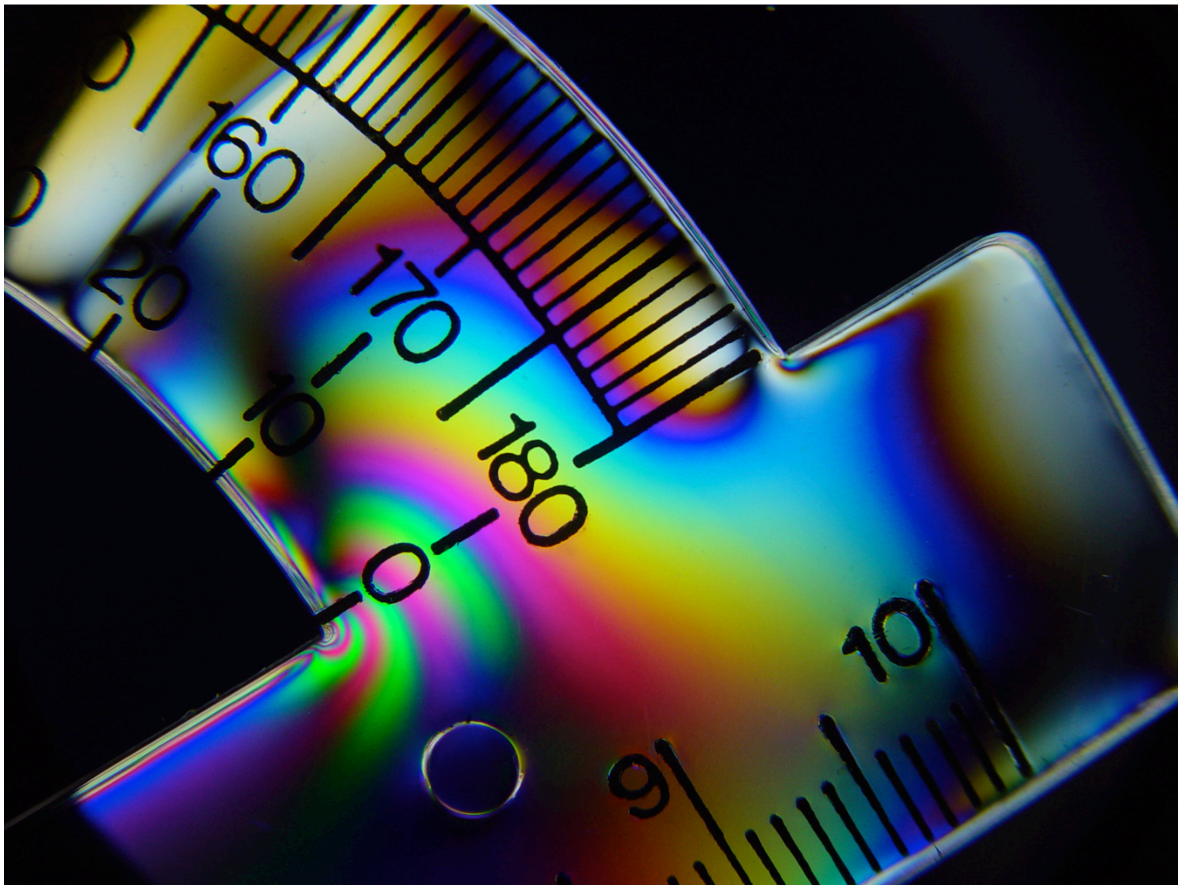
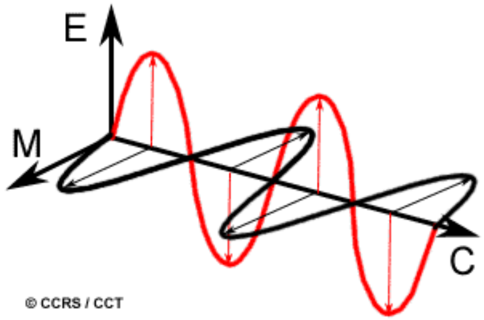
5 – Polarization and Birefringence

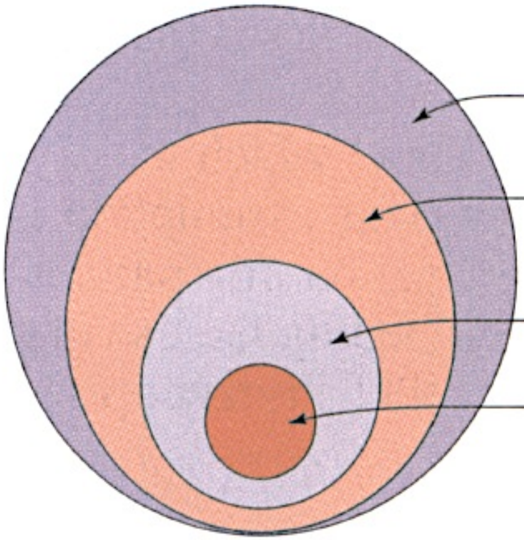


- Long molecules (like polymers, or liquid crystals) exhibit different refractive index dependent on how the polarization of light lines up with them…

Dept. Electrical Engin. & Computing Systems
UNIVERSITY OF Cincinnati

- We need to go down to electromagnetic optics to understand polarization...





Credit: Fund. Photonics – Fig. 1.0-1

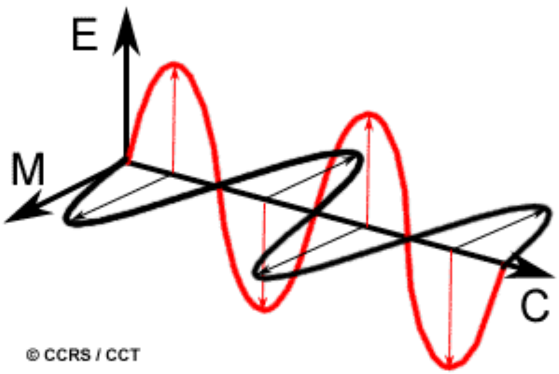
Figures today are mainly from CH6 of Fund. of Photonics or wiki.

- Topics:

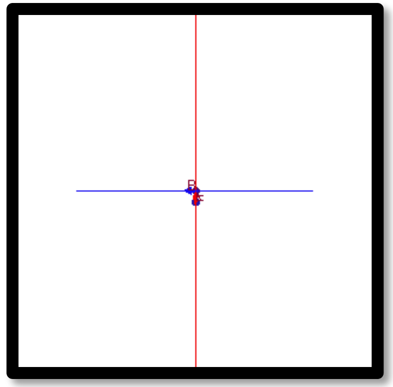
(1) Polarization / Polarizers
(2) Birefringence / Quarter & Half Wave Plates
(3) How to build a 'manual' LCD pixel (we will build a real one later in the course)

- This lecture has several nice animations that can be viewed in the powerpoint version (slide show format).

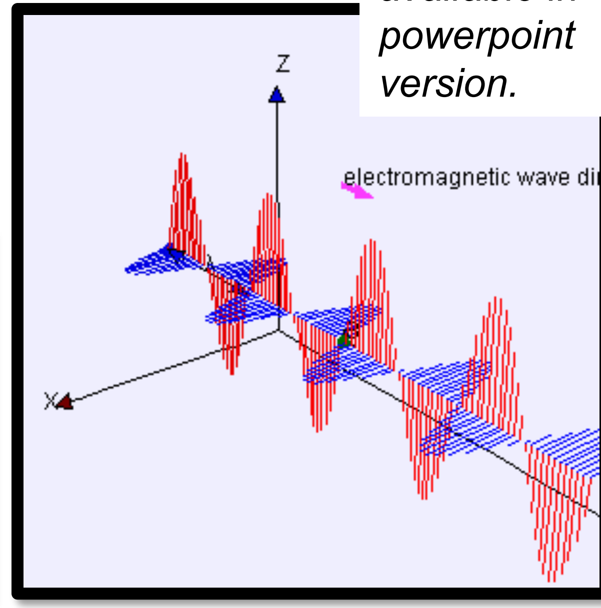
- You could freeze a photon in time (image below) and observe sinusoidal with respect to distance (kx).



- You could also freeze your position and observe sinusoidal with respect to time (wt).



- *Video available in powerpoint version.*



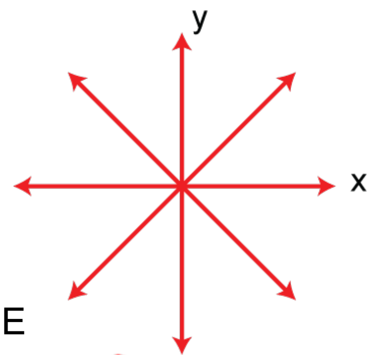
$$E = E_{\max} \sin(wt - kx)$$
$$B = B_{\max} \sin(wt - kx)$$

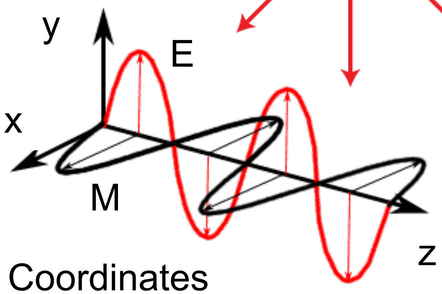
$$w = angular\ \ freq.\ \ (2\pi f, radians / s)$$
$$k = angular\ wave\ number\ (2\pi / \lambda, radians / m)$$

- For polarization, you pick one and track it (conventionally you pick the E-field).

Dept. Electrical Engin. & Computing Systems
UNIVERSITY OF Cincinnati

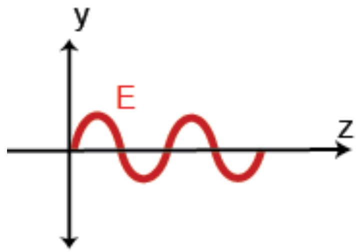
- Unpolarized light

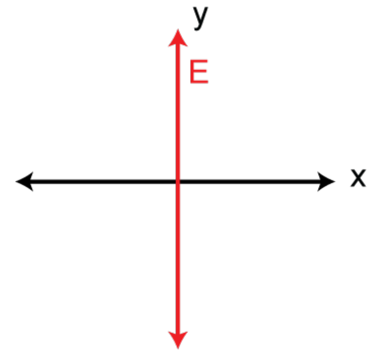




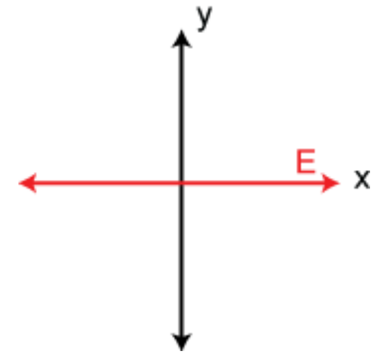
Coordinates

- Linearly polarized light…

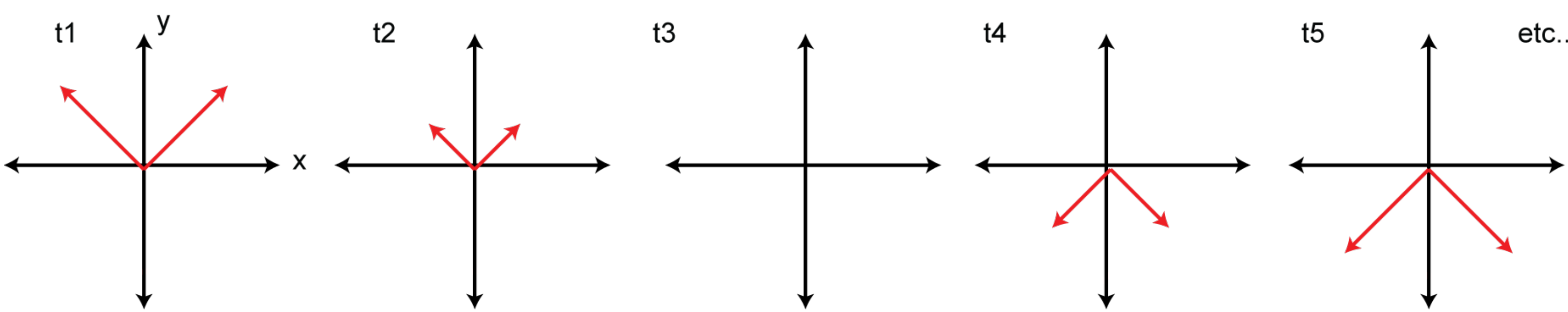




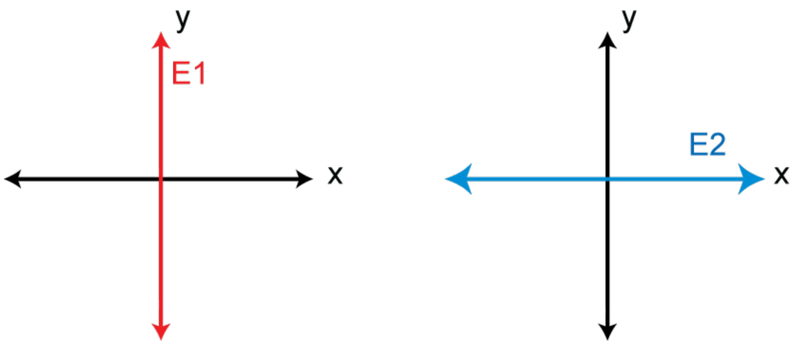
90 deg. rotated…

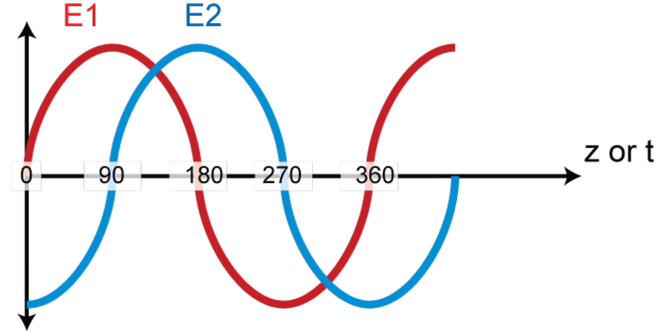


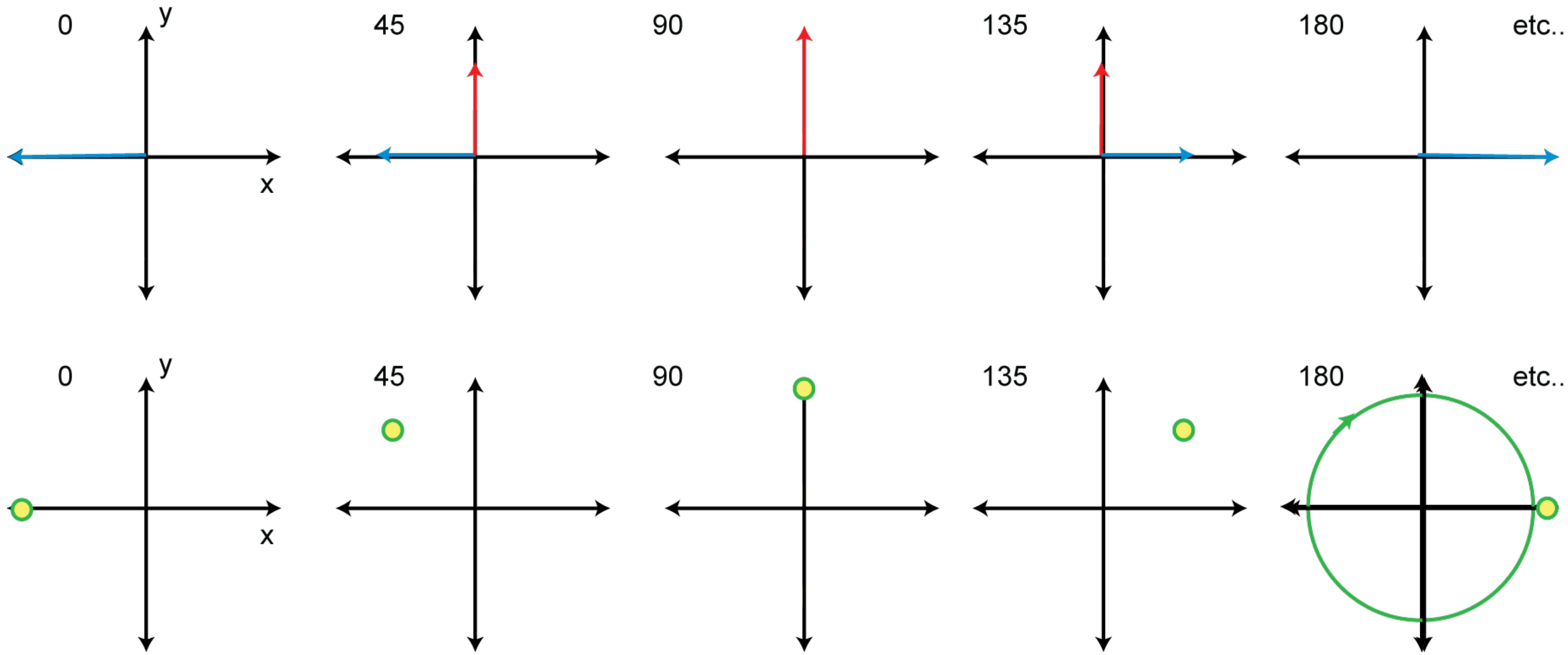
- Also linearly polarized light (think resultant for vectors…)



- Consider two or more photons…

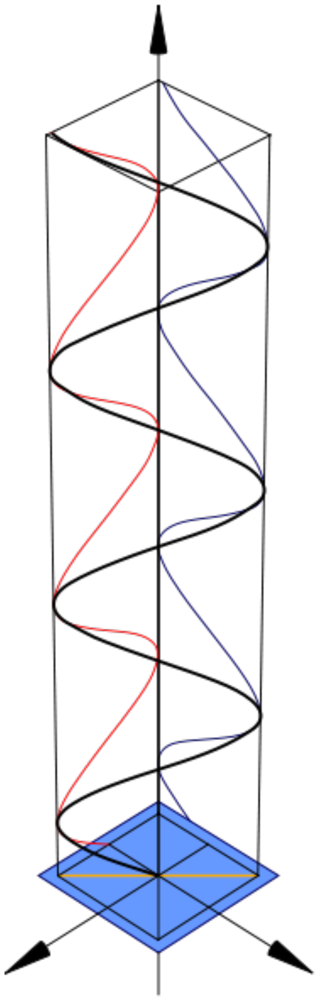




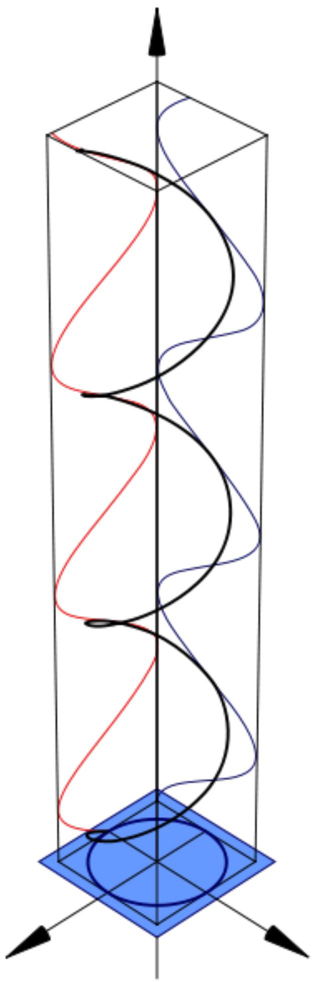


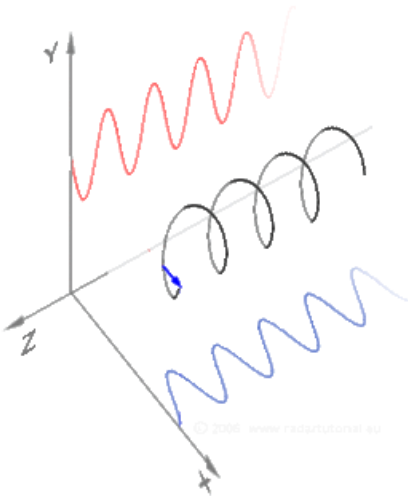
A circularly polarized wave may be resolved into two linearly polarized waves, of equal amplitude, 90 degrees apart, and with their planes of polarization at right angles.

- Linear

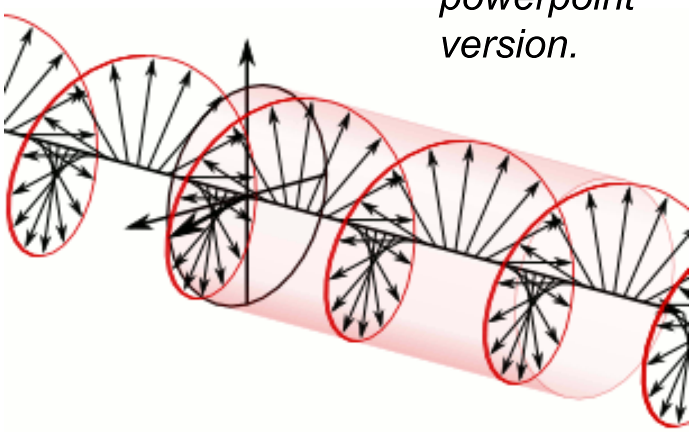


- Circular





- *Video available in powerpoint version.*



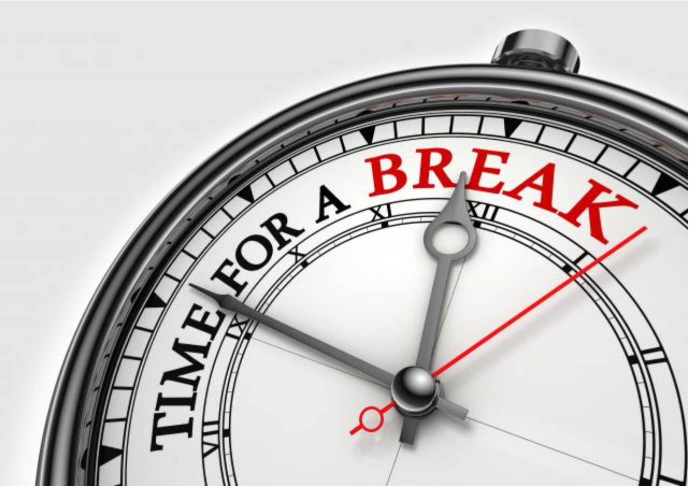
- For circularly polarized light, the two components making up the circularly polarized photon can be interpreted as being:

(a) Out of phase by 90 degrees.
(b) Perpendicular in polarization.
(c) Neither (a) nor (b).
(d) Both (a) and (b).

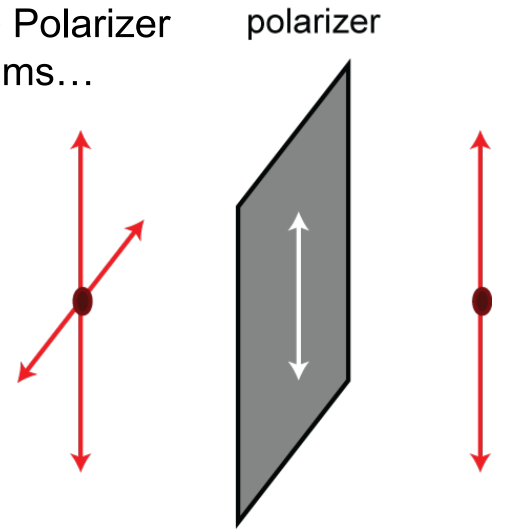
- Why does a metal reflection have more loss (absorption) that glass/air?

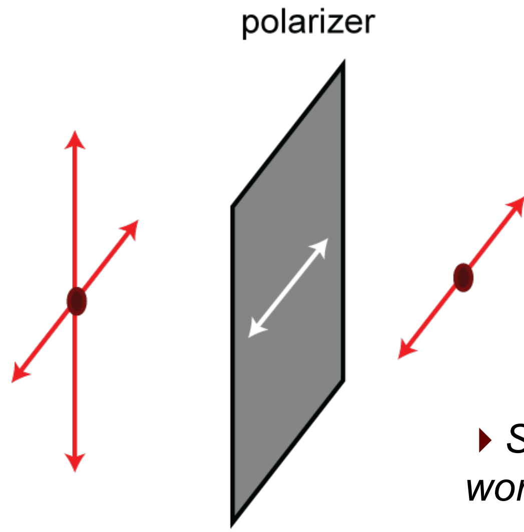
(a) Because metals reflect more strongly.
(b) Because metals have free electrons and ohmic loss.
(c) Because metals have rougher surfaces than glass.
(d) Because metals have lower refractive index than glass.

- Whew! That's enough. Lets take a break!



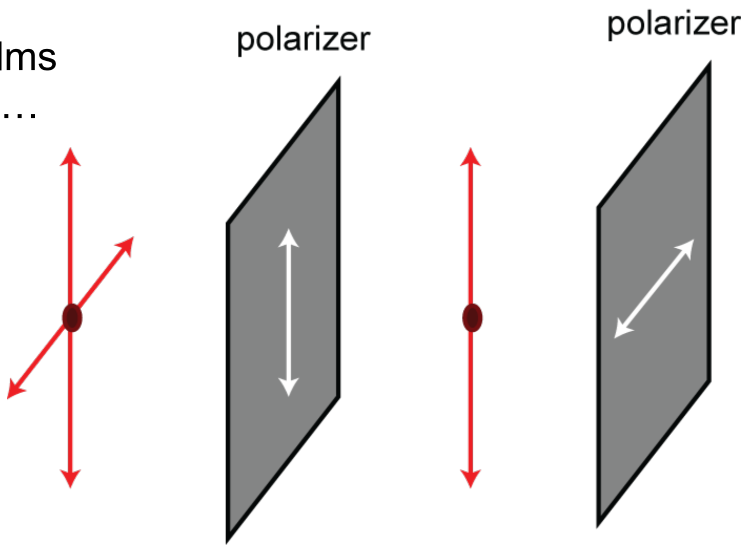
- Polarizer films…





- *So how does this work? Any ideas?*

- Two films in series…

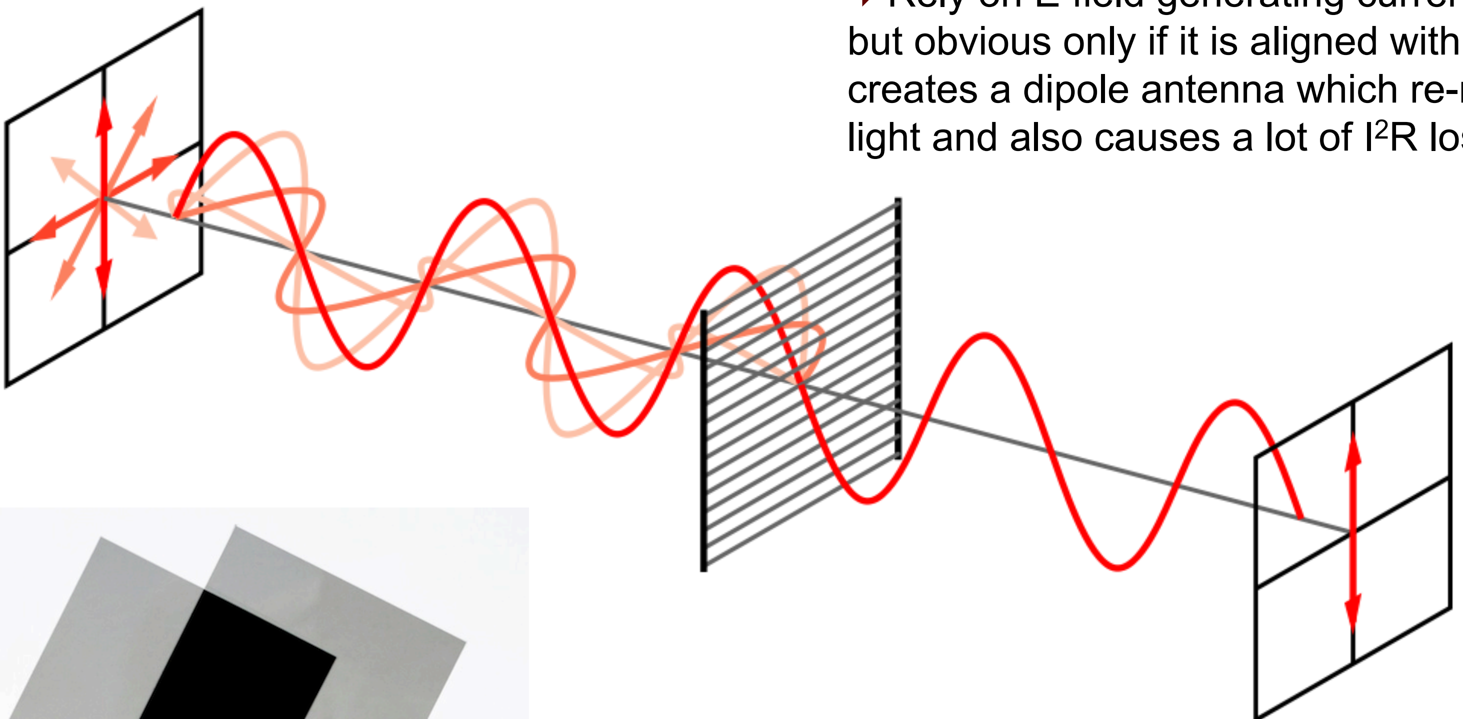


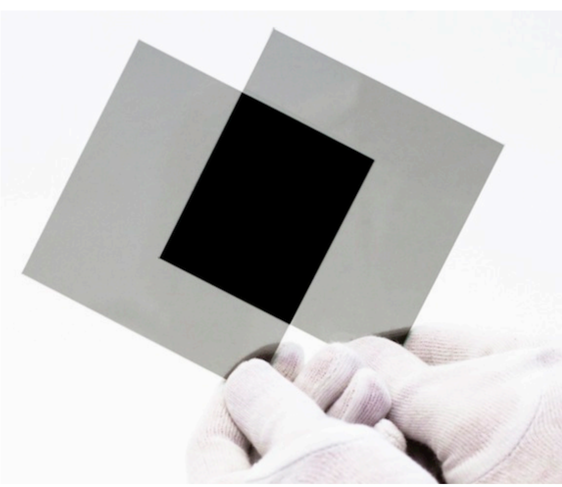
- *Video available in powerpoint version.*

Dept. Electrical Engin. & Computing Systems
UNIVERSITY OF Cincinnati

- Here is a wire grid polarizer (the spacing between wires is less than a wavelength of light to avoid diffraction). How does it work?

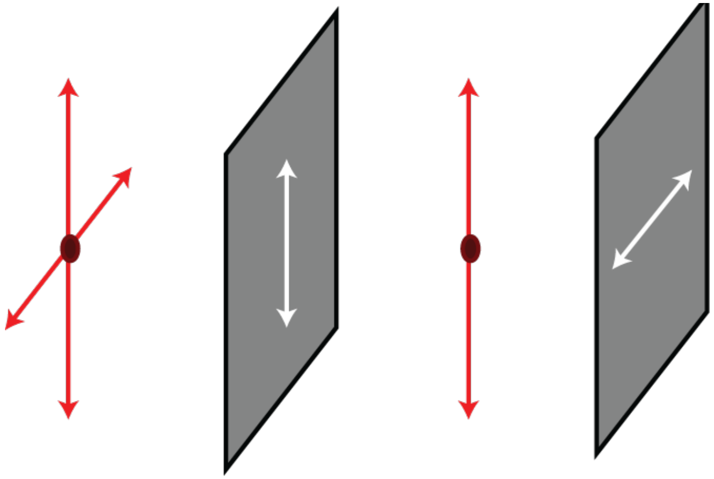
- Rely on E field generating current flow along a wire, but obvious only if it is aligned with the wire! This creates a dipole antenna which re-radiates (reflects) light and also causes a lot of I^2R loss… (absorption)

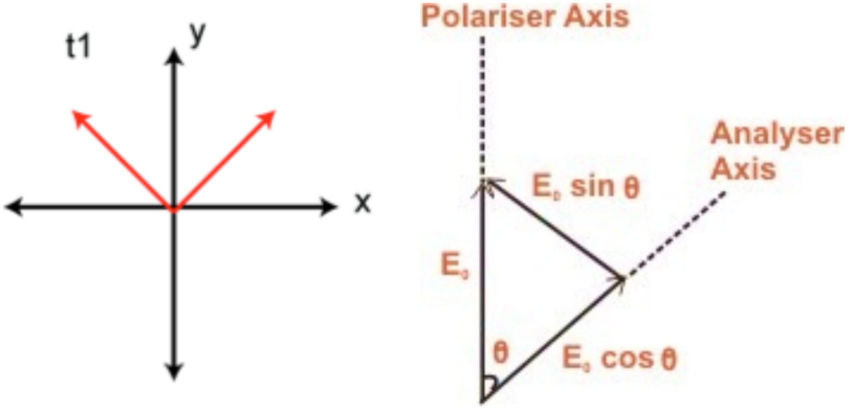




- Most polarizers use lower cost doping of polyvinyl alcohol polymer with iodine (makes the PVC molecules conductive along their long axis). They just melt it, stretch it, then cool it… why?

- Typically ~40% efficient.. and absorptive (not reflective).





- Two components of linear polarized light (sin and cos)…
- 2^{nd} polarizer (analyzer) angle θ with respect to polarization of light…
- Only that light aligned with second polarizer ($E_0\cos\theta$) will transmit…

$$\therefore \quad I \propto (E_0 \cos\theta)^2$$

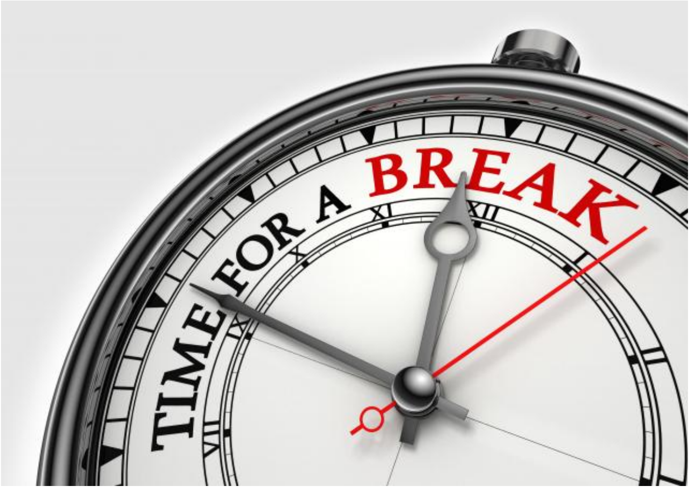
$$\therefore \quad I / I_0 = (E_0 \cos\theta)^2 / E_0^2$$

$$\therefore \quad I = I_0 \cos^2\theta$$

cos 0° =1
cos 90° = 0
cos 180° = -1

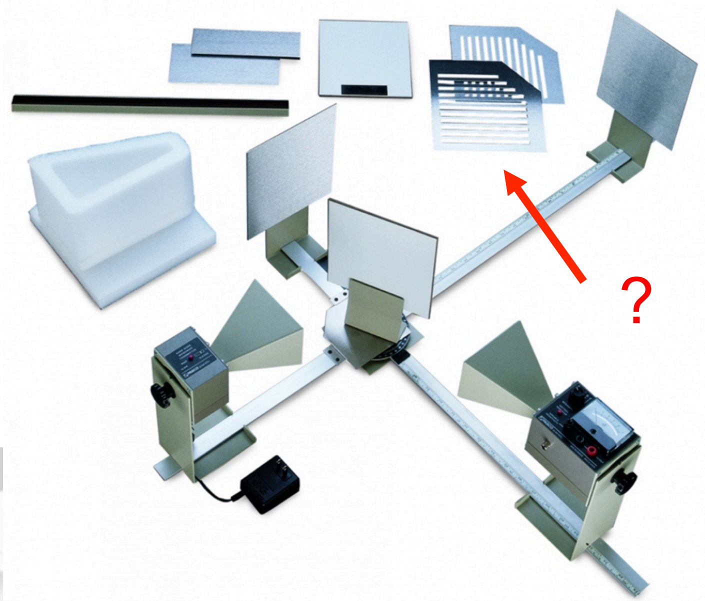
Dept. Electrical Engin. & Computing Systems
UNIVERSITY OF Cincinnati

- Whew! That's enough. Lets take a break!



- The element shown in the experimental learning kit at right (with arrow pointed toward it) is most likely a:

(a) Wire grid polarizer for microwave wavelengths.
(b) Quarter wave plate for microwave wavelengths.
(c) Wire grid polarizer for visible wavelengths.
(d) Quarter wave plate for visible wavelengths.



Dept. Electrical Engin. & Computing Systems
UNIVERSITY OF Cincinnati

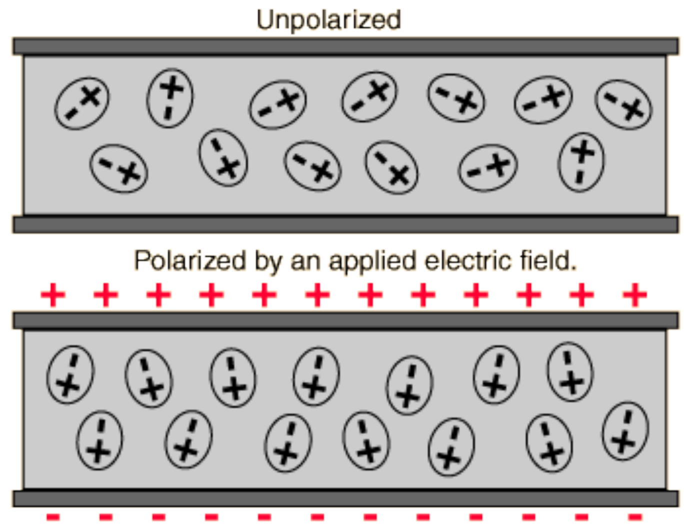
- In vacuum, E & M fields only interact with each other…

- In a medium composed of atoms/molecules, the E & M fields induce a time-varying response in charged particles (e.g. electrons)…

- Most of the 'motion' for these charged particles is 'highly elastic' and energy temporarily transferred to the particles is returned… but this 'exchange' takes time!

- The more charged particles per unit volume, or the more they can 'move' in response to E & M, the slower the light travels in the medium!

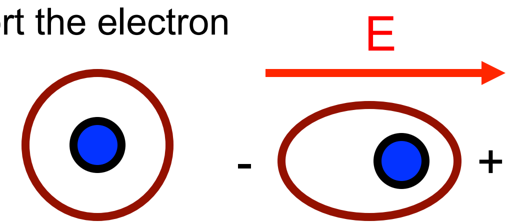
- So higher permeability (ε) = higher refractive index!



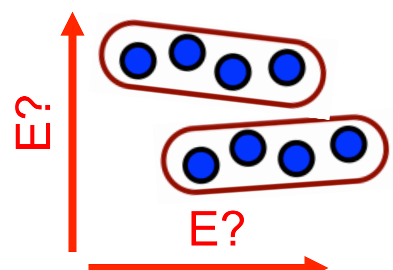
- Speed of light in a medium is slowed by the mediums refractive index!

$$v = \frac{c\,(m/s)}{n} \qquad n = \sqrt{\varepsilon_r \mu_r}$$

- In most materials.. You don't actually rotate the molecules, you just distort the electron cloud…



- So… long molecules (like polymers) have electron cloud too… which way would E field distort the most?

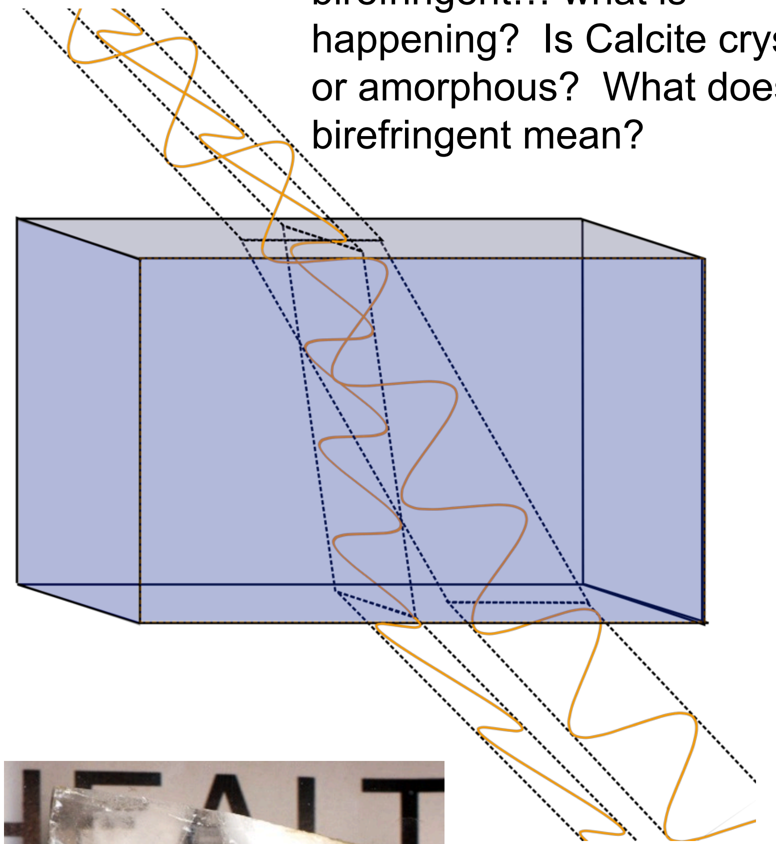


- Strongest interaction of E with molecule (highest n) when E is aligned with the molecule!

- Could refractive index be dependent on polarization of photons then? How?

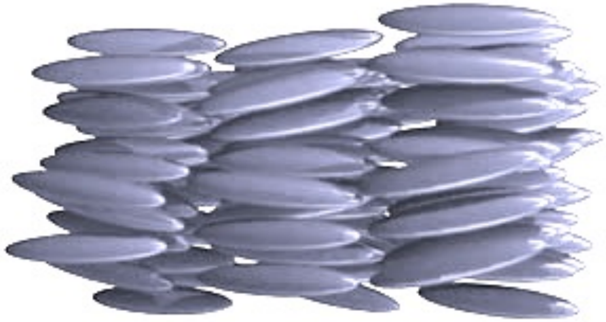
Dept. Electrical Engin. & Computing Systems
UNIVERSITY OF Cincinnati

- This Calcite material is birefringent… what is happening? Is Calcite crystal or amorphous? What does birefringent mean?

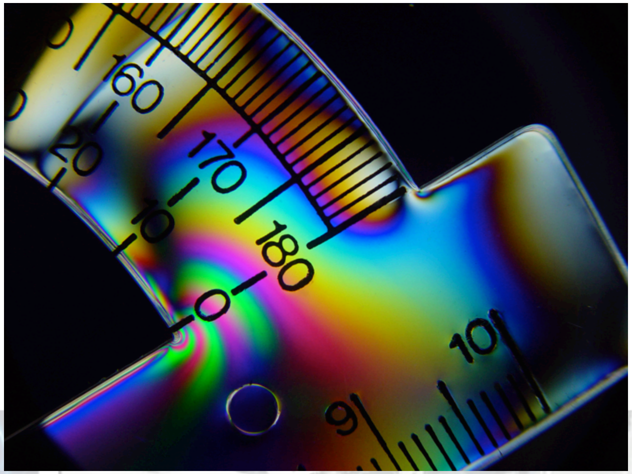


- Most stretched or extruded polymers (like scotch tape) will exhibit birefringence… why?

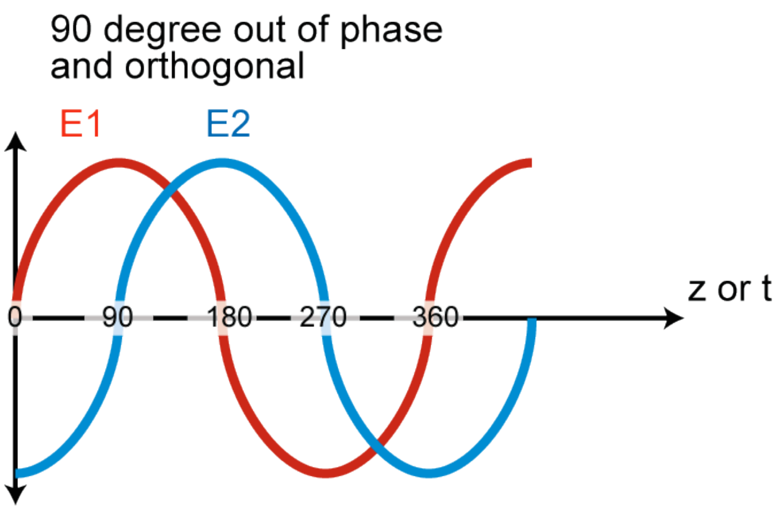
Image below is for aligned liquid crystals, also birefringent…

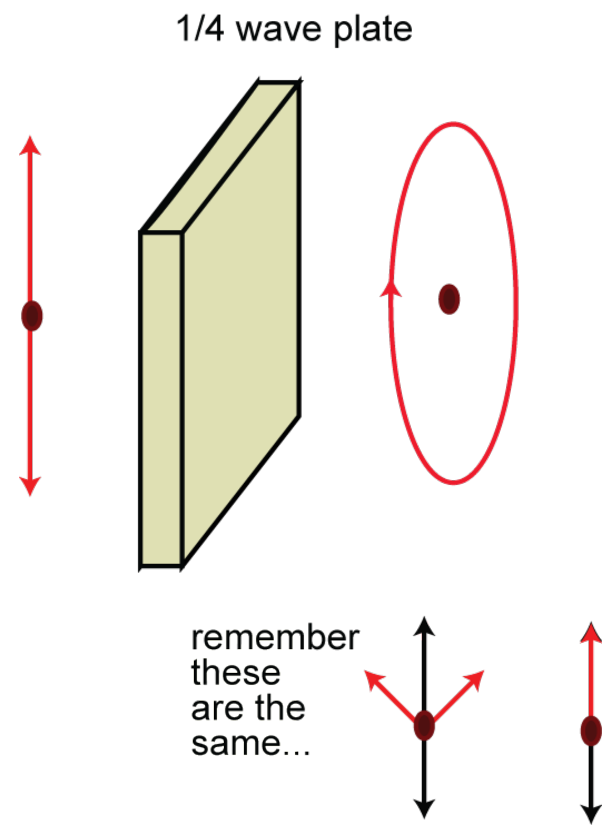


- This protractor was not stretched but was injection molded…

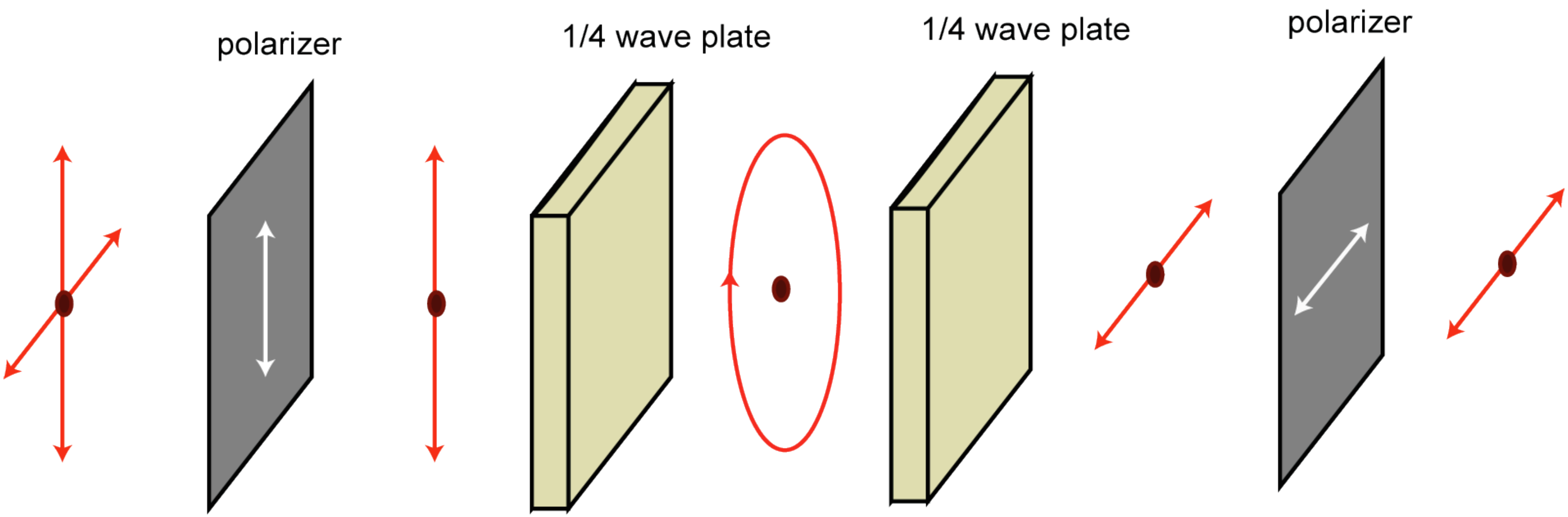


- So what does this have to do with polarization ?
- Consider a birefringent material that is thick enough such that it delays the one of the two sub-components of a polarized photon by 90 degrees compared to the other subcomponent…
- Called a 1/4 wave plate, why?



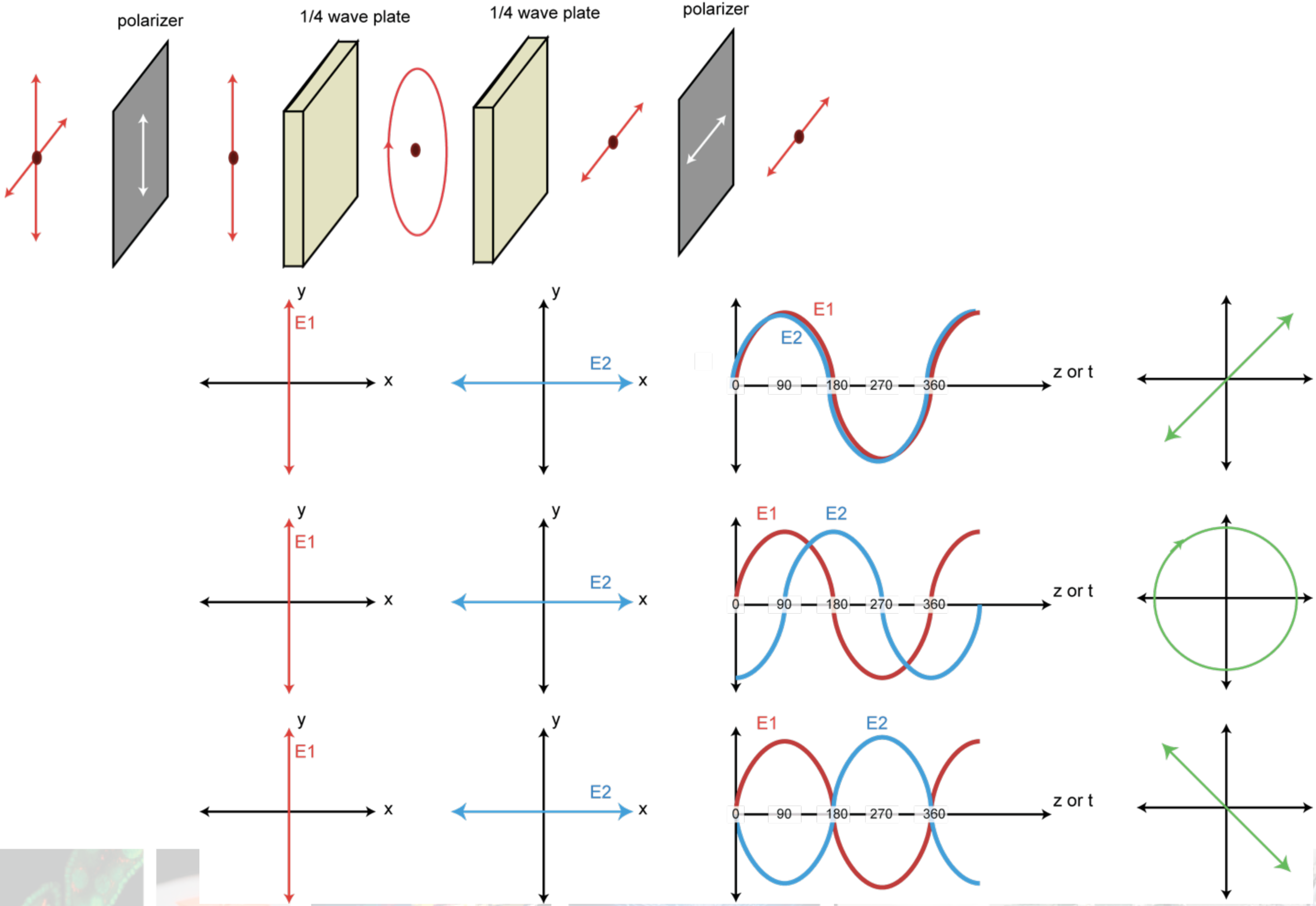


- Two 1/4 wave plates add together to make a 1/2 wave plate (180 degrees, see next slide)

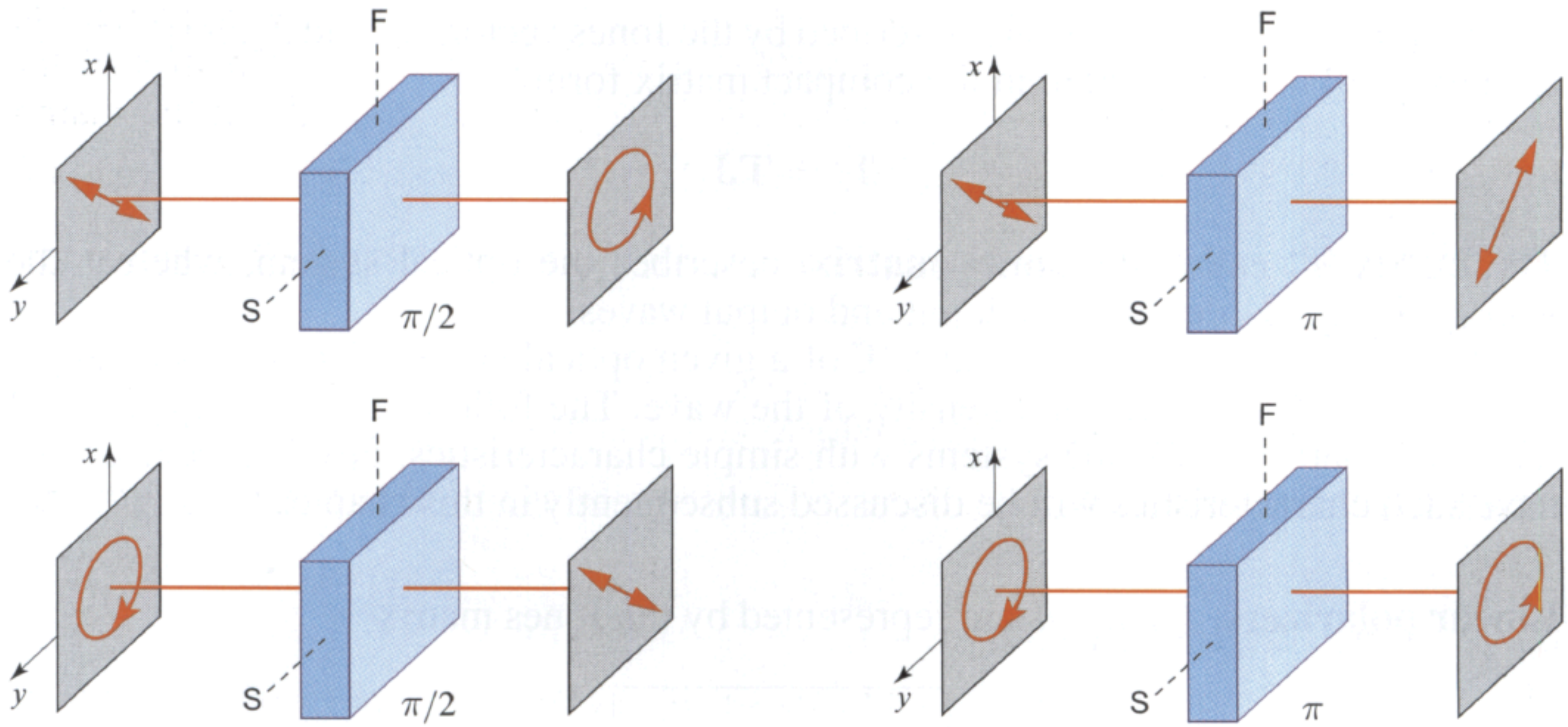


- *What if we could make this electrically switchable? What would you have? Knowing what you know about birefringence, how might you make it switchable?*

Dept. Electrical Engin. &
Computing Systems
UNIVERSITY OF Cincinnati



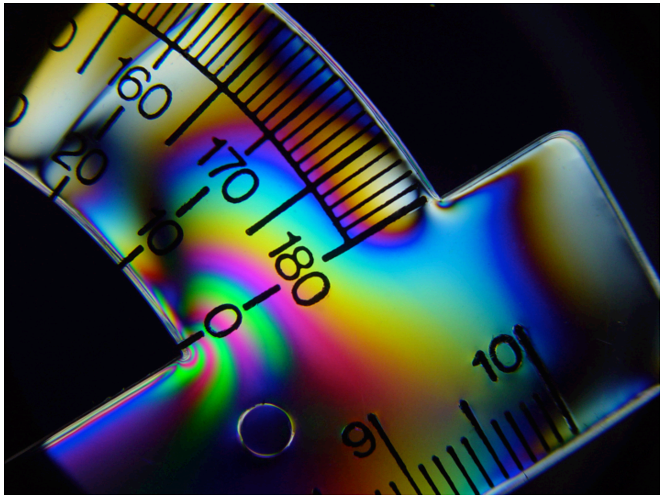
- From Fund. of Photonics (CH 6)



(*a*) Quarter-wave retarder (*b*) Half-wave retarder

- The piece of plastic shown at right:

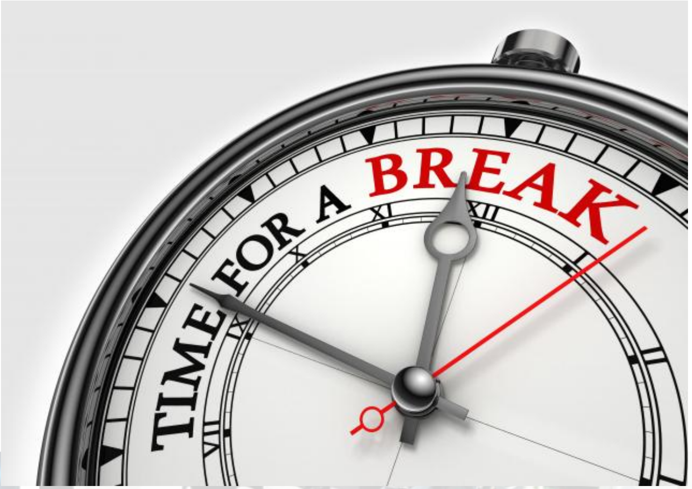
(a) Is causing phase delays for certain polarizations of light.
(b) Is made with the plastic molecules aligned.
(c) Is birefringent.
(d) All the above.



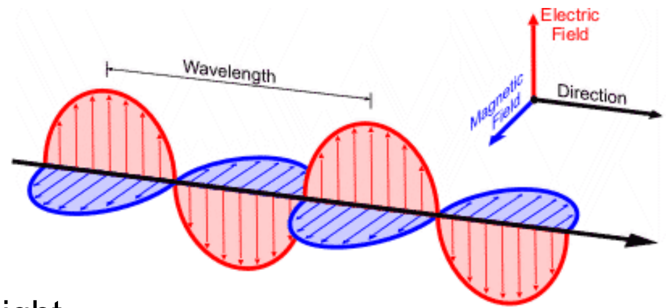
- Two quarter wave plates rotate the polarization of light by:

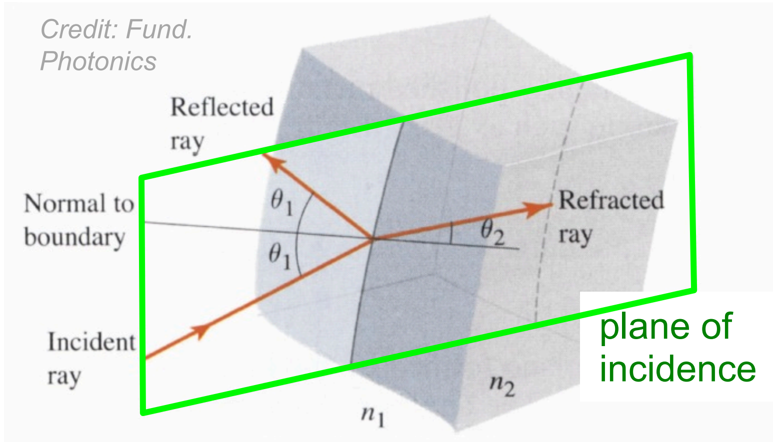
(a) 180 deg. (two quarters = half of a full 360 rotation).
(b) 90 deg.
(c) 25 deg.
(d) Magic.

- Whew! That's enough. Lets take a break!



- For non-zero incidence angles…



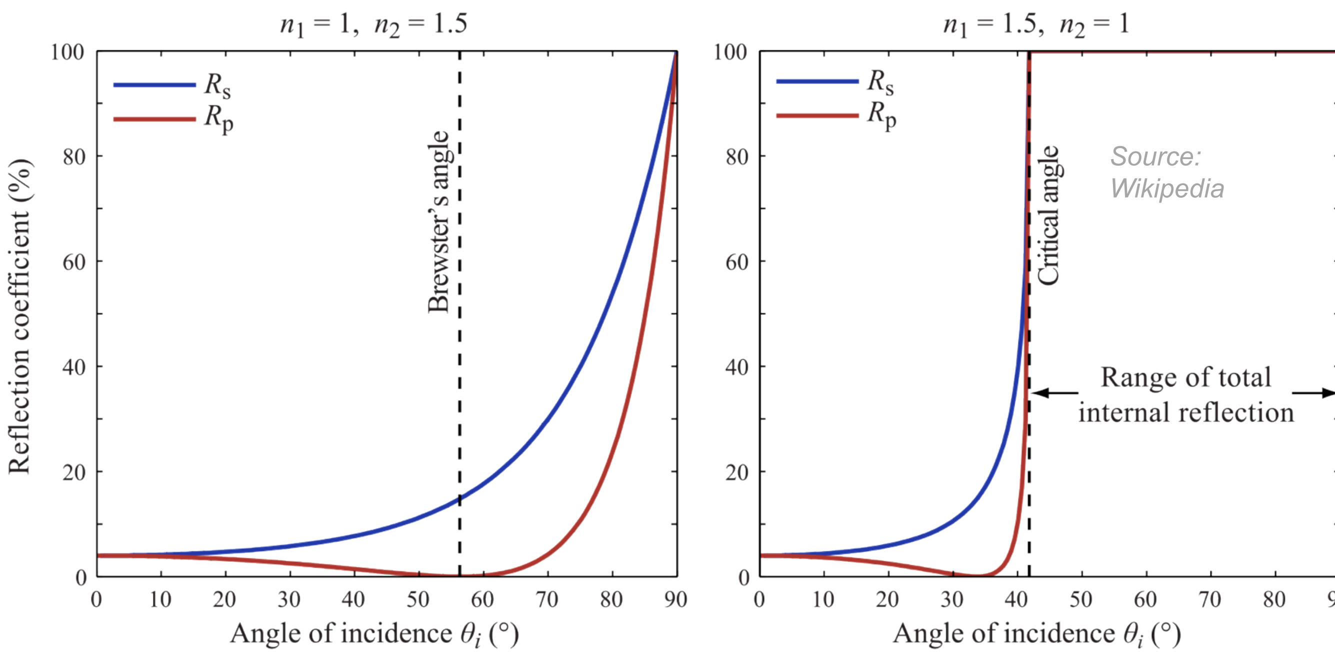


(1) For s-polarized light magnetic field is parallel to the plane of incidence

$$\%R_S = \left(\frac{n_1 \cos\theta_1 - n_2 \cos\theta_2}{n_1 \cos\theta_1 + n_2 \cos\theta_2} \right)^2$$

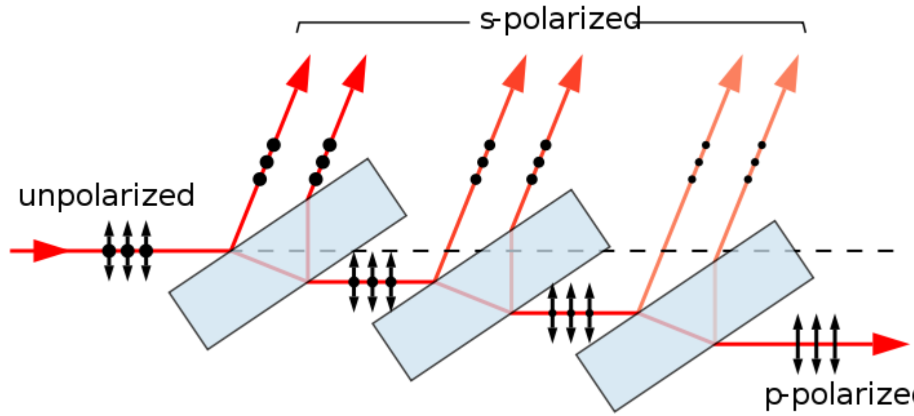
(2) For p-polarized light electric field is parallel to the plane of incidence

$$\%R_P = \left(\frac{n_1 \cos\theta_2 - n_2 \cos\theta_1}{n_1 \cos\theta_2 + n_2 \cos\theta_1} \right)^2$$



Note, the s and p convention varies and so do alternate names such at TE and TM. Be careful!

- You can use Brewster angle to make a simple polarizer…



- What do polarized sunglasses do?


Without Polarized Lense


With Polarized Lense

- Other applications include polarized microscopes… what do they do?

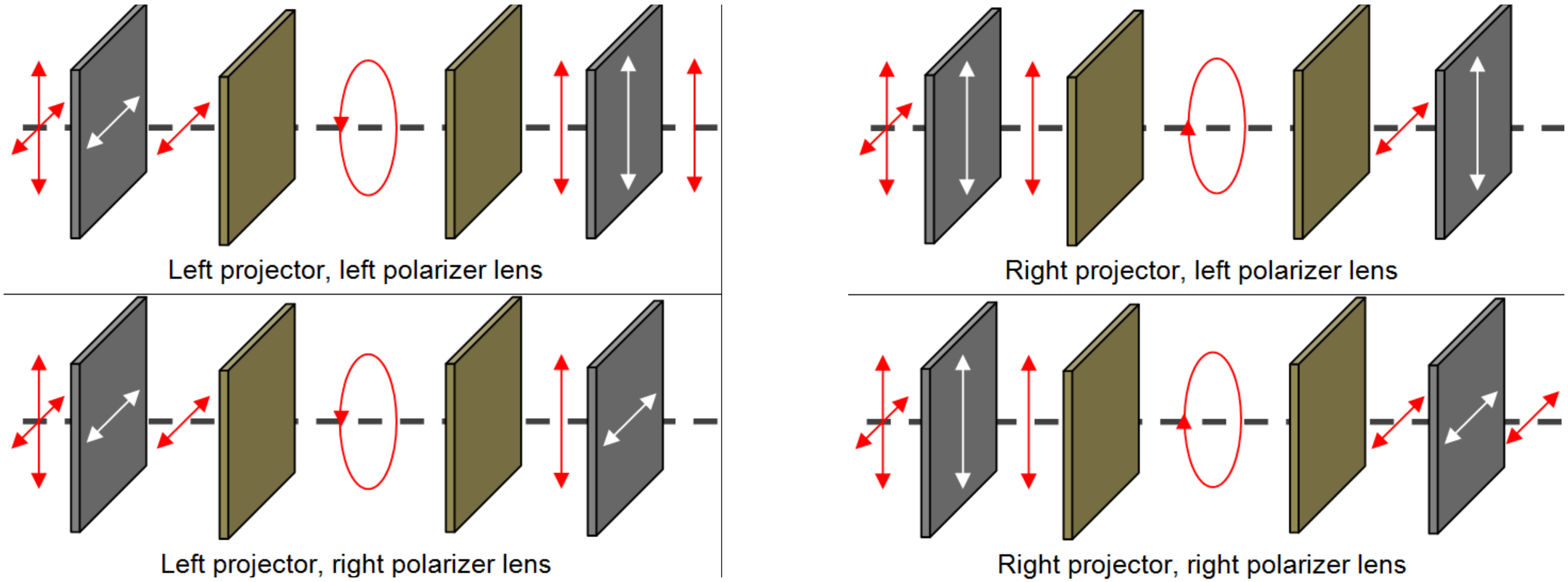
- And LCDs! Wait a few weeks :)

- You are lost in the desert and dying of thirst… is this water? What is it?

Dept. Electrical Engin. & Computing Systems
UNIVERSITY OF Cincinnati

- *Video available in powerpoint version.*

- Projector and glasses each have a ‘circular’ polarizing film for left and right channel!



- Q1: Why note just use polarizers alone? Think tilting head, etc…
- Q2: Will a perfectly diffuse (Lambertian) screen work?

- At the Brewster angle, one of the polarizations of light is:

(a) Perfectly reflected.
(b) Perfectly transmitted.
(c) Both of the above..
(d) Neither of the above.

- Sunglasses with polarizers can be used for:

(a) 3D movies.
(b) Eliminating a lot of the Fresnel reflection (glare) on a sunny day.
(c) Neither of the above.
(d) Both of the above.

- Lastly a microwave oven has a mesh on the front (see picture) which is for:

(a) Absorbing/reflecting all polarizations of microwave radiation.
(b) Letting visible light through of all polarizations.
(c) Neither of the above.
(d) Both of the above.

- Whew! Finished!