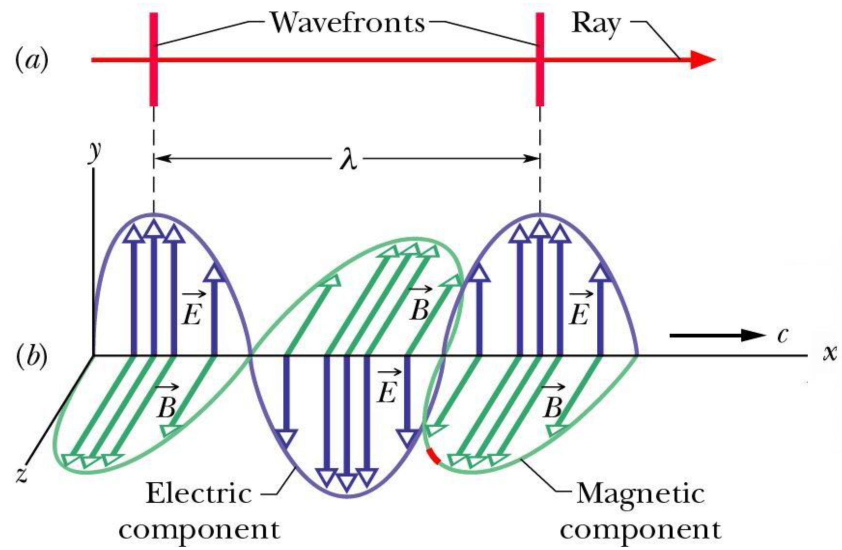

JONIK

Review - EM Waves

- EM Waves
  - Wavelengths of 10^8 to 10^{-16} meters (10-10^{24} Hz)
  - Traveling wave of both *E* and *B* fields
  - *E* field is ⊥ *B* field
  - Wave moves in direction ⊥ to both *E* and *B* fields
  - *E* and *B* vary sinusoidally with same frequency



$$E = E_m \sin(kx - \omega t)$$

$$B = B_m \sin(kx - \omega t)$$

$$v = c = f\lambda = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3\times10^8\,\text{m/s}$$

Review - EM Waves

- Poynting vector, S – rate of energy transported per unit area:

$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$$

- Instantaneous energy flow rate

$$S = \frac{1}{\mu_0}EB = \frac{1}{\mu_0 c}E^2 = \frac{1}{\mu_0 c}E_m{}^2 \sin^2(kx - \omega t)$$

- Peak intensity (when sin=1) given by

$$S_{peak} = \frac{1}{\mu_0 c}E_m{}^2$$

EM Waves: Radiation pressure

- Express in terms of radiation pressure p_r which is force/area

$$p_r = \frac{F}{A}$$

- SI unit is N/m^2 called pascal *Pa*

- Total absorption

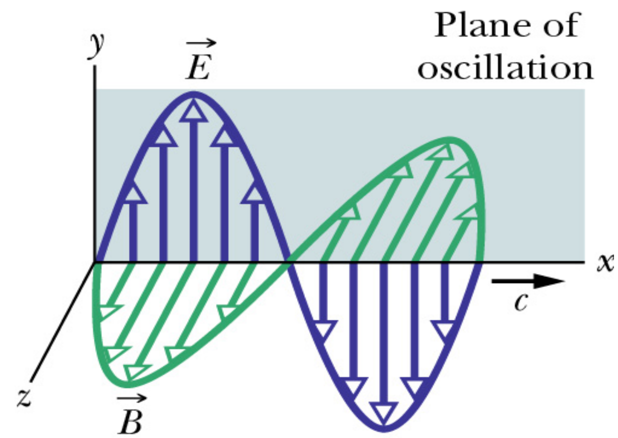
$$p_r = \frac{I}{c}$$

- Total reflection

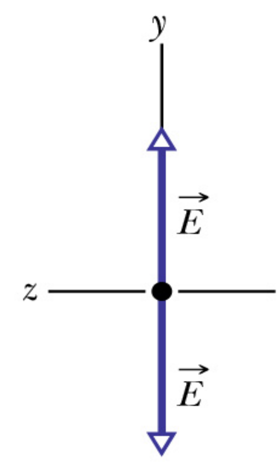
$$p_r = \frac{2I}{c}$$

EM Waves: Polarization

- Source emits EM waves with *E* field always in same plane wave is polarized
- Indicate a wave is polarized by drawing double arrow
- Plane containing the *E* field is called plane of oscillation



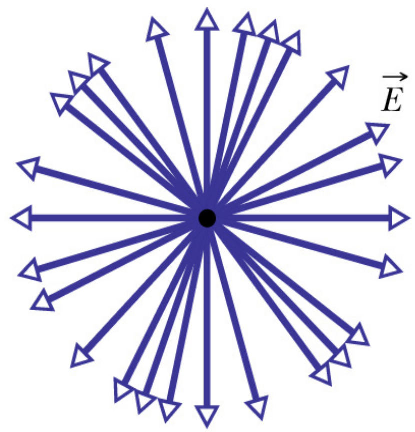
(a)



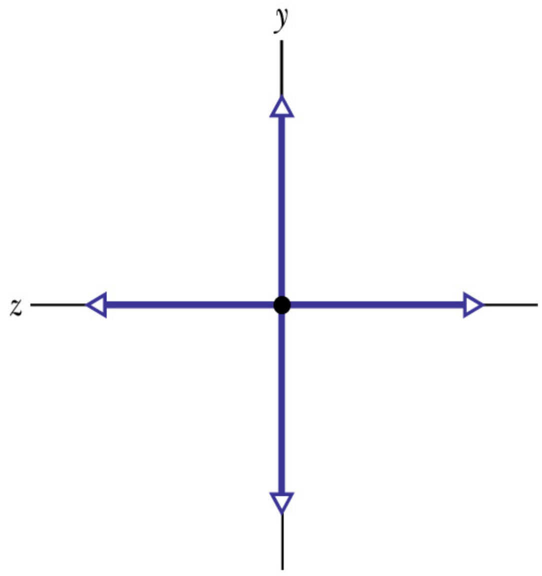
(b)

EM Waves: Polarization

- Source emits EM waves with random planes of oscillation (*E* field changes direction) is unpolarized
  - Example, light bulb or Sun
- Resolve *E* field into components
- Draw unpolarized light as superposition of 2 polarized waves with *E* fields ⊥ to each other



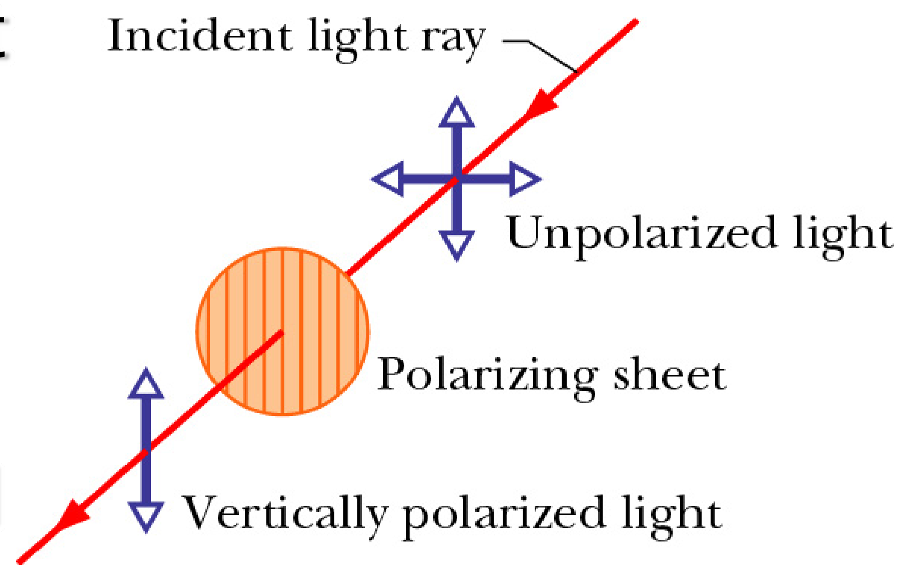
(a)



(b)

EM Waves: Polarization

- Transform unpolarized light into polarized by using a polarizing sheet
- Sheet contains long molecules embedded in plastic which was stretched to align the molecules in rows



- *E* field component || to polarizing direction of sheet is passed (transmitted), but ⊥ component is absorbed
- So after the light goes through the polarizing sheet it is polarized in the same direction as the sheet.

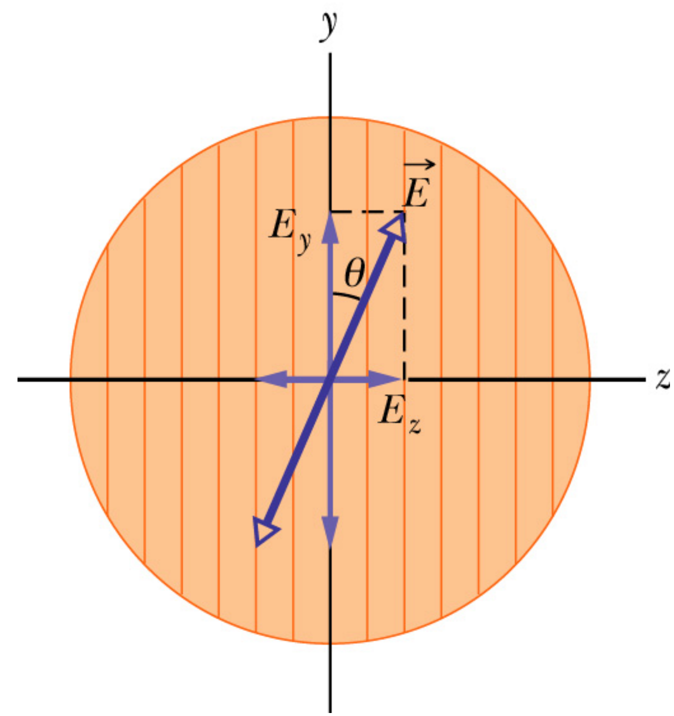
EM Waves: Polarization

- What is the intensity, I of the light transmitted by polarizing sheet?
- For initially polarized light, resolve E into components

$$E_y = E_{||} = E\cos\theta$$

- Transmitted || component is

$$I = \frac{1}{c\mu_0}E_{||}^2 = \frac{1}{c\mu_0}E^2\cos^2\theta = I_0\cos^2\theta$$



- Cosine-squared rule: Intensity of polarized wave changes as $\cos^2\theta$

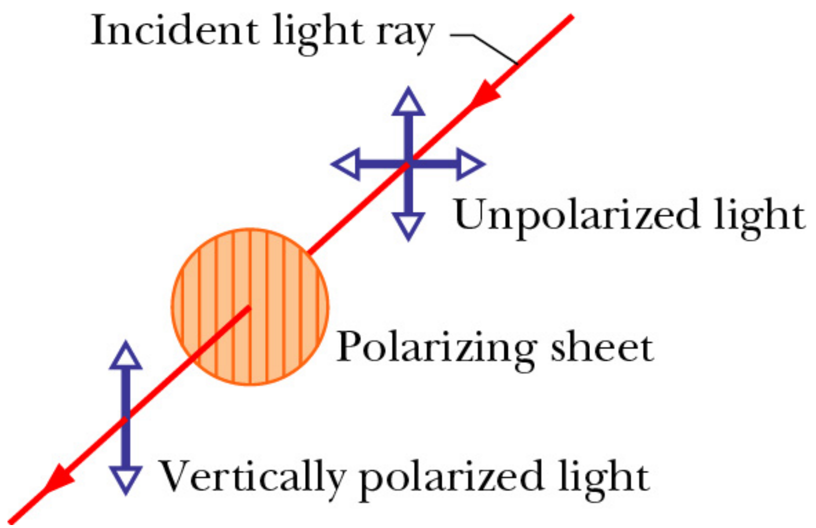
$$I = I_0\cos^2\theta$$

EM Waves: Polarization

- For unpolarized light, average over $\cos^2$

$$I = \frac{1}{2} I_0$$

- Only light || to polarizer is transmitted

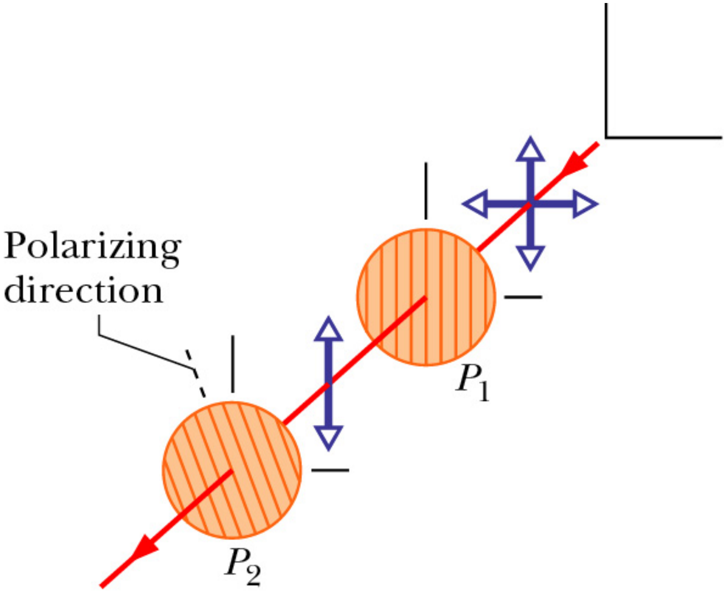


- One-half rule: Intensity of unpolarized wave after a polarizer is half of original

EM Waves: Polarization

- Have 2 polarizing sheets
  - First one called polarizer
  - Second one called analyzer
- Intensity of unpolarized light going through first polarizer is

$$I_1 = \tfrac{1}{2} I_0$$



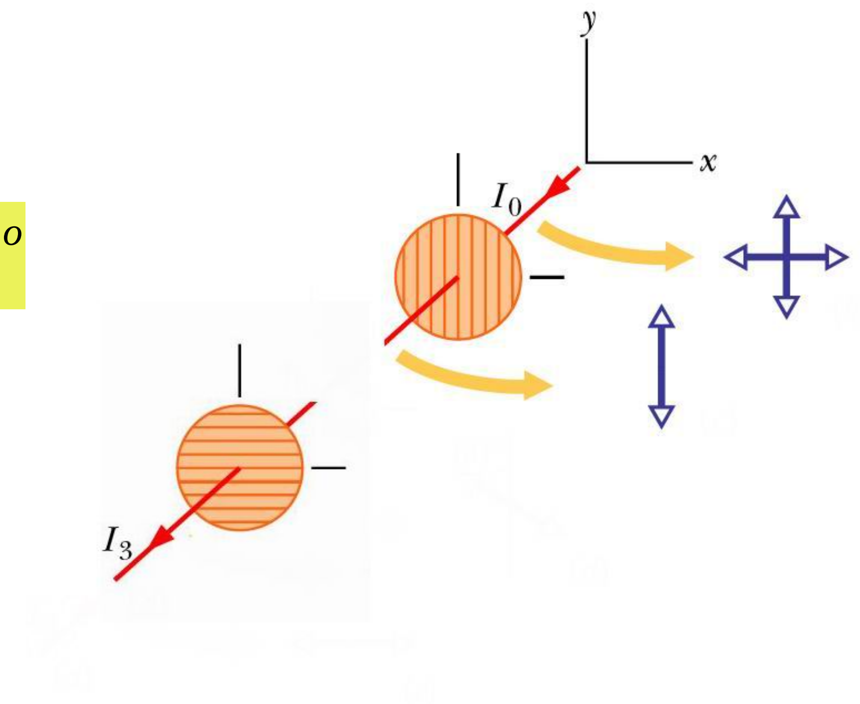
- Light is now polarized and intensity of light after second analyzer is given by

$$I_2 = I_1 \cos^2\theta = \tfrac{1}{2} I_0 \cos^2\theta$$

An interesting demo

- Effect of P_1 and P_3
- Take $\theta_1 = 0^o$ and $\theta_3 = 90^o$
- After P_1 $I_1 = \frac{1}{2} I_0$
- After P_3

$$I_3 = I_1 \cos^2(90^o) = 0$$



An interesting demo

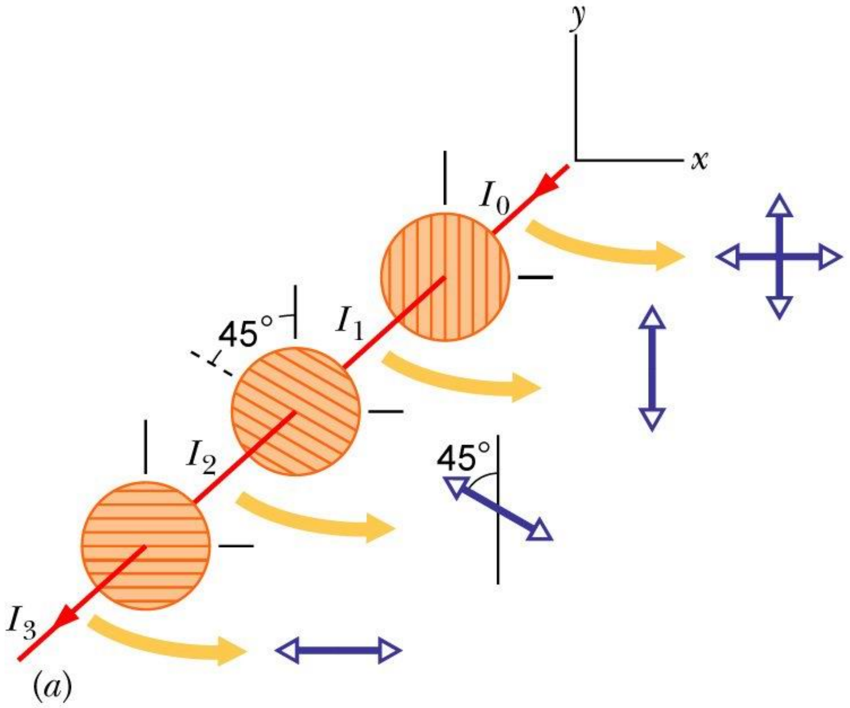
- Keep $\theta_1 = 0^o$ $\theta_3 = 90^o$

- Now insert P_2 in between P_1 and P_3 with $\theta_2 = 45^o$

- After P_1 $I_1 = \frac{1}{2} I_0$

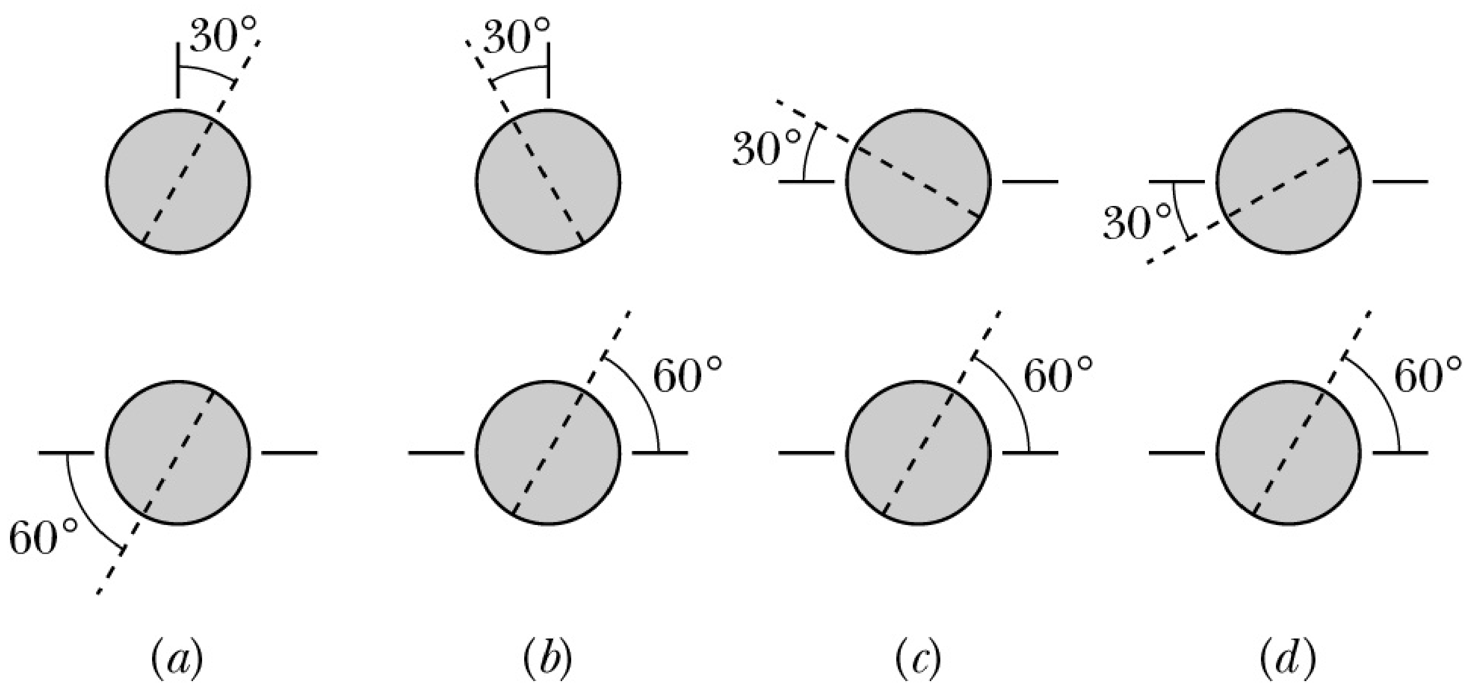
- After P_2 $I_2 = I_1 \cos^2(45^o) = \frac{1}{4} I_0$

- After P_3 $I_3 = I_2 \cos^2(45^o) = \frac{1}{8} I_0$



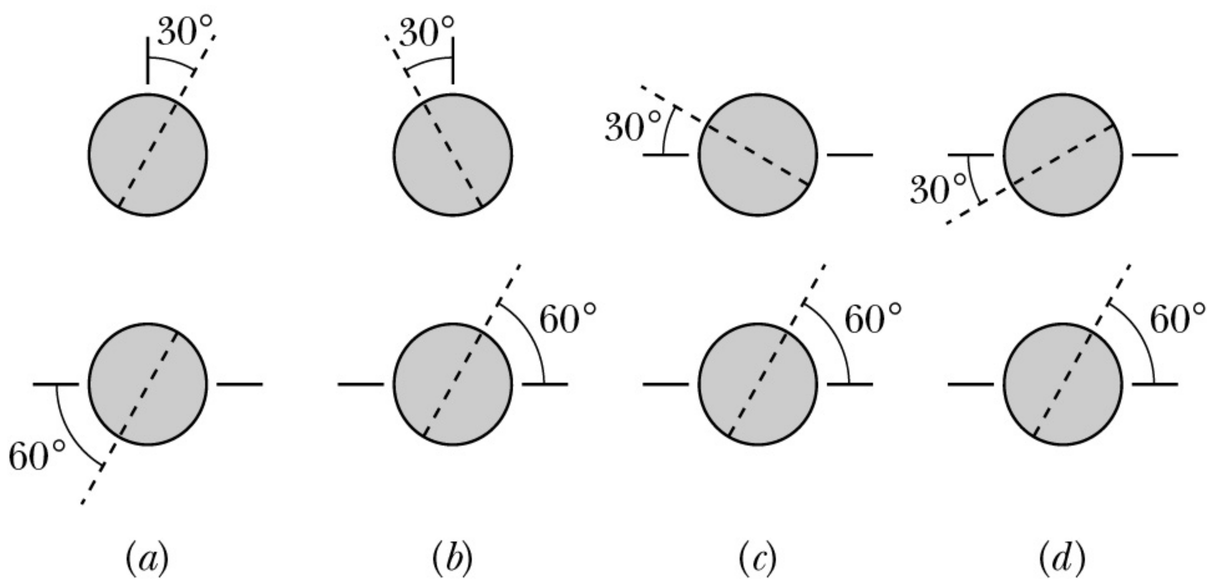
Exercise

- Unpolarized light hits a polarizer and then an analyzer. The polarizing direction of each sheet is indicated by dashed line. Rank pairs according to fraction of initial intensity which is passed, greatest first.



Exercise

- Look at relative orientation of polarization direction between the 2 sheets.
- What is the intensity if the sheets are...
  - Polarized || – all light passes
  - Polarized ⊥ to each other – no light passes
  - For angles in between – get more light if closer to ||



a,d,b,c

Optical activity

- Certain materials rotate the plane of polarization
- The rotation angle may depends on the frequency (color)
- This is due to molecular asymmetry - e.g. molecules with spiral shapes
- Karo syrup