Lecture 15
(Polarization and Scattering)

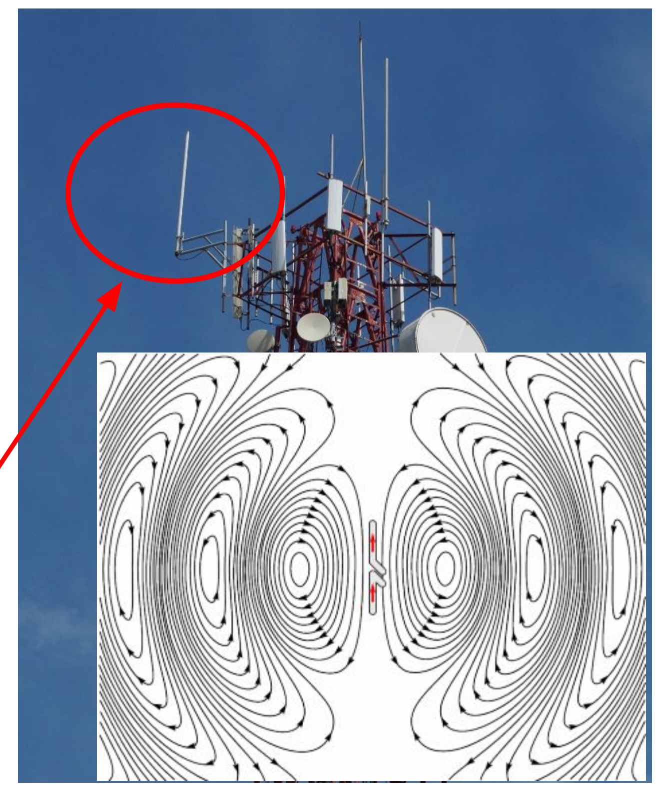
Physics 2310-01 Spring 2020

Douglas Fields

Sources Again

- Let's consider two of the types of sources we talked about previously, thermal emission and antennae.
- Remember that in both cases EM waves are emitted from accelerating charges.
- In the case of the light bulb filament, the high temperature of the material is reflected in the high average kinetic energies of the electrons, and hence when they collide – accelerations.
- But these collisions occur randomly within the material. There is no preferred orientation, and therefore, the direction of the electric field of the EM wave generated will be randomly oriented in space.
- By contrast, the EM waves emitted by the antennae will always have their electric fields oriented vertically.

(b)

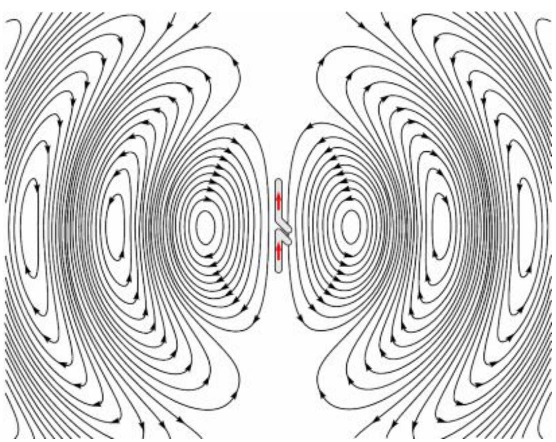


Polarization of an EM Wave

- As we stated back in lecture 11, the direction of the electric field determines the direction of the polarization of the EM wave.
- So, in the case of the light emitted by the filament, we say that the light is ***unpolarized*** (no preferred electric field direction).
- In the case of the (vertically oriented dipole) antennae, the EM waves are ***linearly polarized*** vertically .

Why is the polarization direction interesting/important?

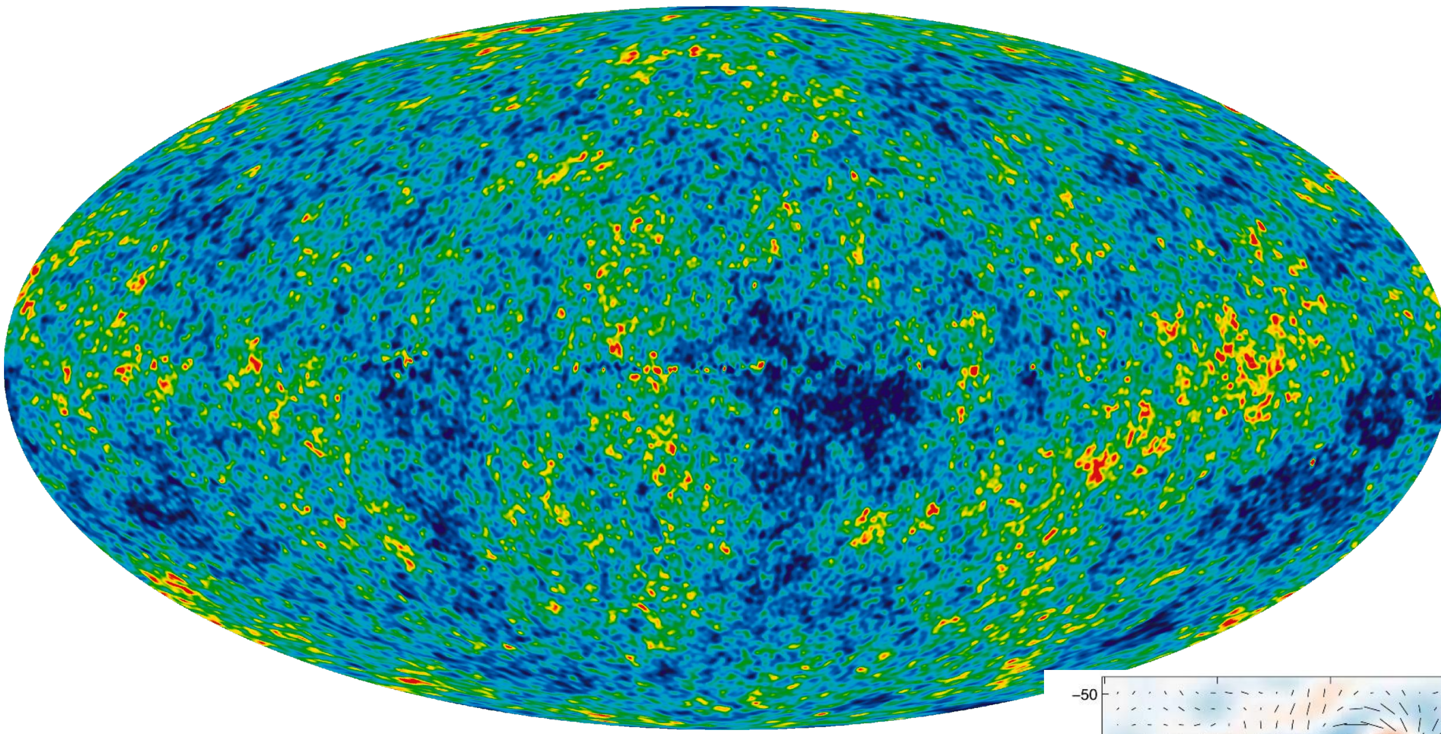
- Because, in general, the way that things interact with EM waves is through the affect of the electric field on charges.
- For instance, if you want to detect the wave that the vertically oriented dipole antenna produced, you would want to use a vertically oriented dipole antenna…

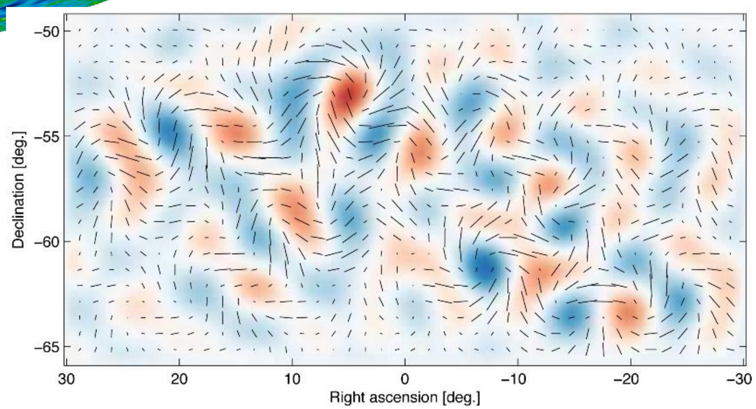


Why is the polarization direction interesting/important?

- Some processes (reflection, scattering…) cause unpolarized light to become polarized.
- We can then filter the light to choose the source we want to "see".

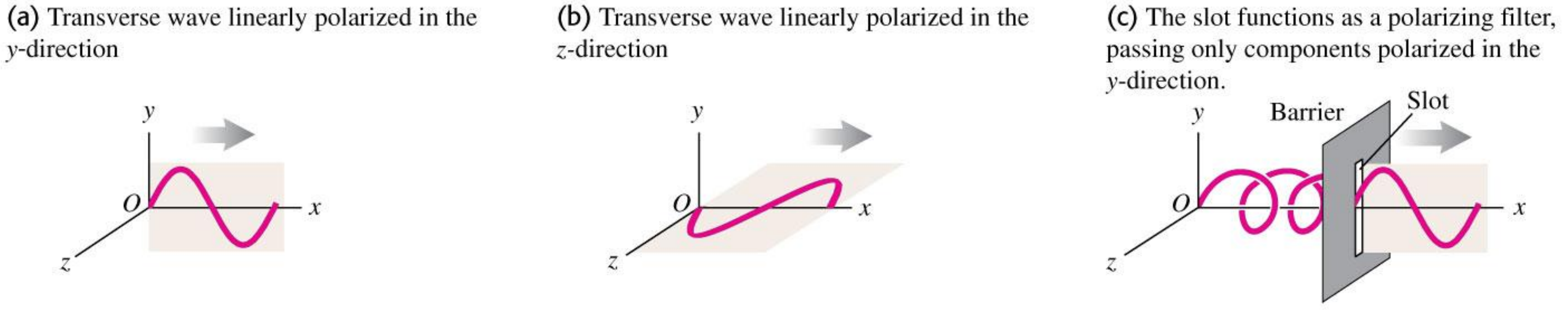
Microwave Background





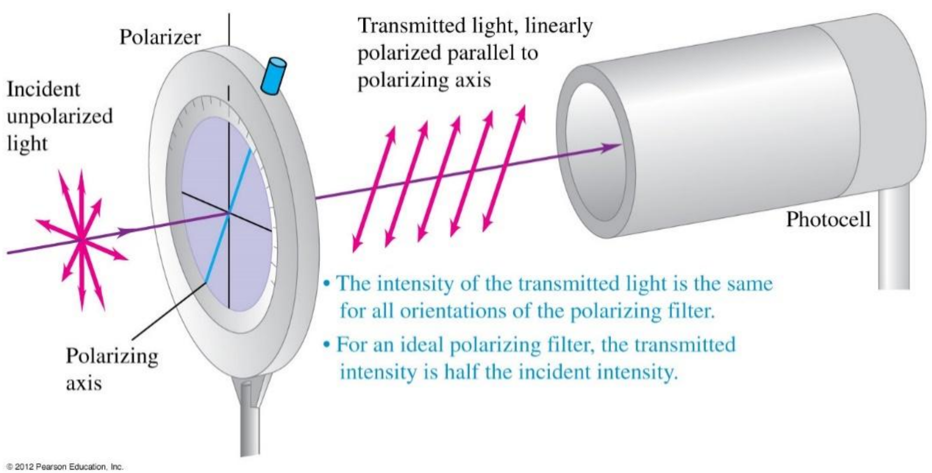
Changing the Polarization

- Consider a transverse mechanical wave.
- I can (by wiggling the string) create a vertically polarized wave, or a horizontally polarized wave, or…
- A circularly polarized wave.
- But if I pass each of these through a filter (a mechanical slit for mechanical waves), I can only let the part of the wave that is in the direction of the slit pass:



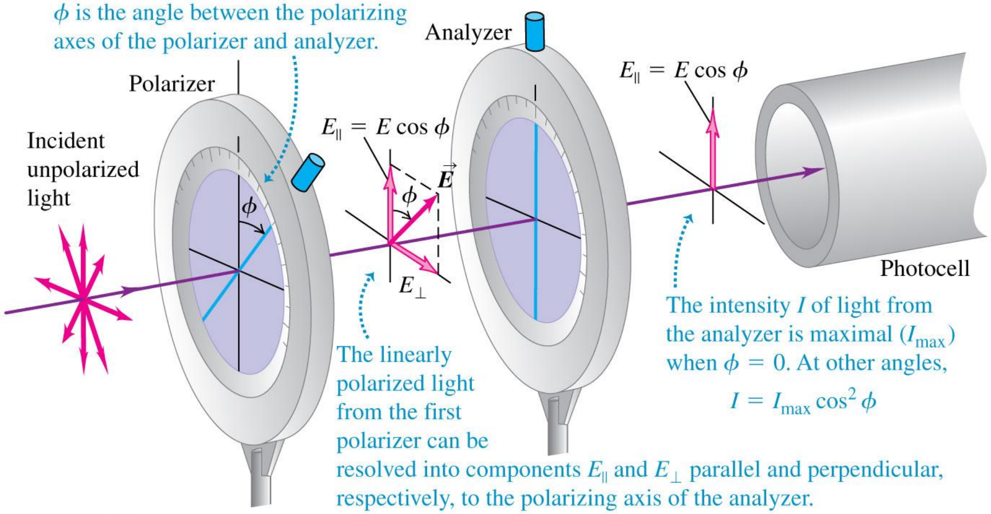
Ideal Polarizers

- The same idea is behind a polarizer for light.
- There is no physical “slit”, but the material absorbs light with all polarizations *except* along the polarizing axis.
- That means that the intensity of light is exactly half of the original light **intensity**.
- With unpolarized light incident on the polarizer, the intensity of light out is independent of the angle of the polarizing axis.



Double Polarizers

- However, if the light incident is already polarized, say, by another polarizer, then the amplitude of the electric field will depend on the angle between the polarizer and the incident polarization of light.



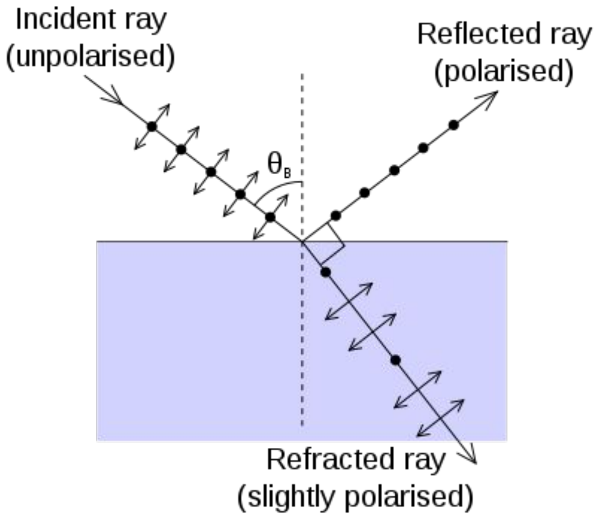
$$E_{out} = E_{in} \cos\phi \Rightarrow$$

$$I = I_{Max} \cos^2 \phi$$

Demonstration of polarizers

Polarization by Reflection

- Another way to polarize light is through reflection.
- Think of an unpolarized light "beam" striking the surface of some refractive medium.
- The molecules of the medium oscillate in the directions of the E-field (polarization direction).
- However, these dipole radiators don't transmit in the direction along their axis.
- So, when the angle of refraction is perpendicular to the angle of reflection, light isn't reflected with polarization in the plane of refraction.
- At that angle then, the reflected light is perfectly polarized.

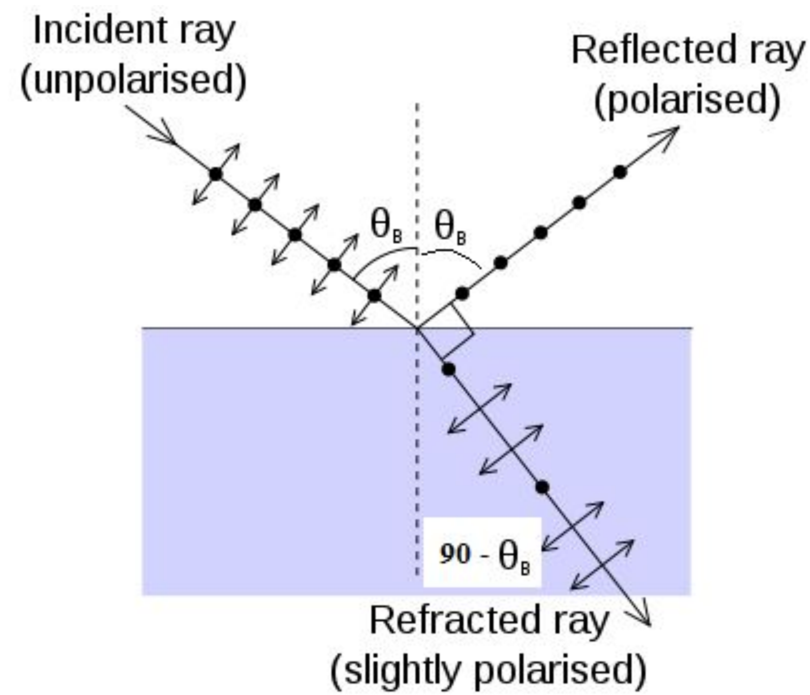


No polarizing filter

With polarizing filter (what orientation?)

Brewster Angle

- From geometry, the laws of reflection and refraction, and some trigonometry, we can find the angle of incidence that gives us completely polarized reflected light:



$$n_a \sin\theta_a = n_b \sin\theta_b$$

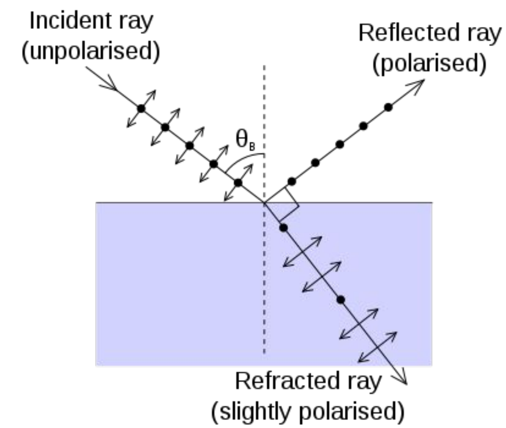
$$n_a \sin\theta_B = n_b \sin\left(90 - \theta_B\right) = n_b \cos\theta_B \Rightarrow$$

$$\frac{n_b}{n_a} = \tan\theta_B$$

$$\theta_B = tan^{-1}\frac{n_b}{n_a}$$

Sunlight reflects off the smooth surface of a swimming pool. (a) For what angle of reflection is the reflected light completely polarized? (b) What is the corresponding angle of refraction? (c) At night, an underwater floodlight is turned on in the pool. Repeat parts (a) and (b) for rays from the floodlight that strike the surface from below.

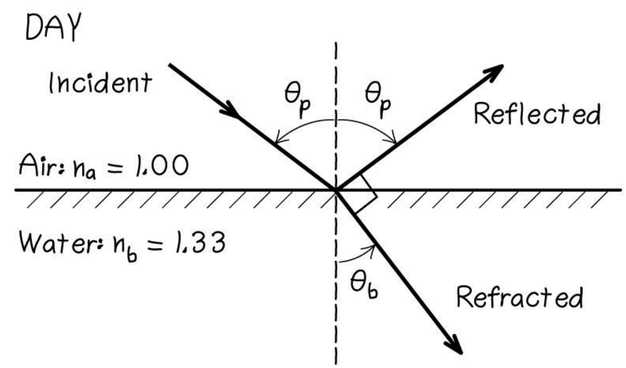
$$a)\ \theta_B = tan^{-1}\frac{n_b}{n_a} = tan^{-1}\frac{1.33}{1} = 53.1°$$



$$b)\ n_a \sin\theta_a = n_b \sin\theta_b$$

$$1\cdot\sin 53.1° = 1.333\sin\theta_b$$

$$\theta_b = \sin^{-1}\left(\frac{\sin 53.1°}{1.333}\right) = 36.9°$$

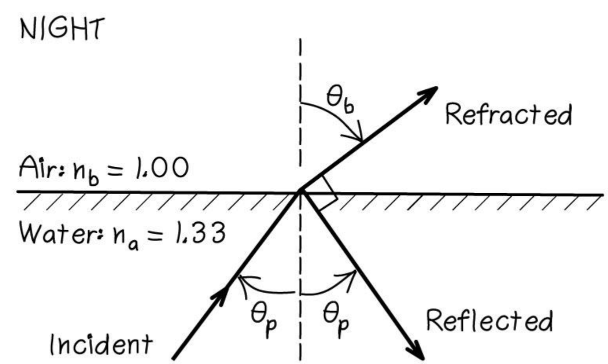


$$c)\ \theta_B = tan^{-1}\frac{n_b}{n_a} = tan^{-1}\frac{1}{1.33} = 36.9°$$

$$d)\ n_a \sin\theta_a = n_b \sin\theta_b$$

$$1.333\cdot\sin 36.9° = 1\cdot\sin\theta_b$$

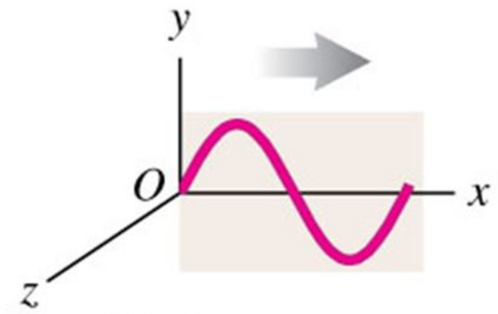
$$\theta_b = \sin^{-1}\left(\frac{1.333\cdot\sin 36.9°}{1}\right) = 53.1°$$

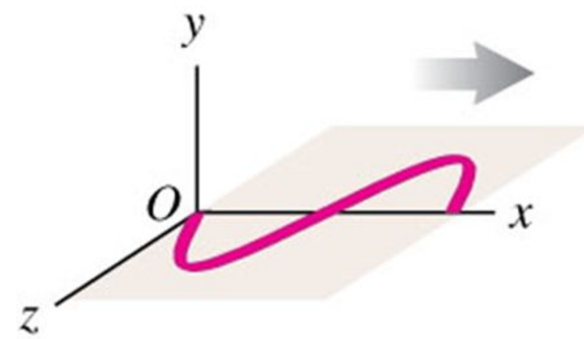


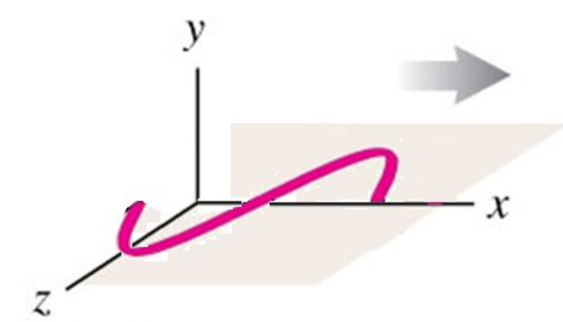
Circular (Elliptical) Polarization

- The polarization direction doesn’t have to stay constant.
- Take, for instance two different waves superimposed:
- Oh, wait, that’s just a constant polarization direction at 45 degrees to the vertical…

- But what if the second wave had a different phase…

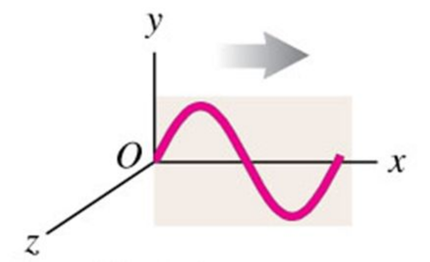


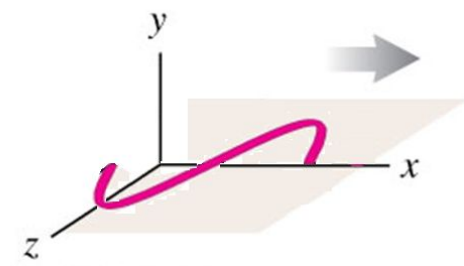


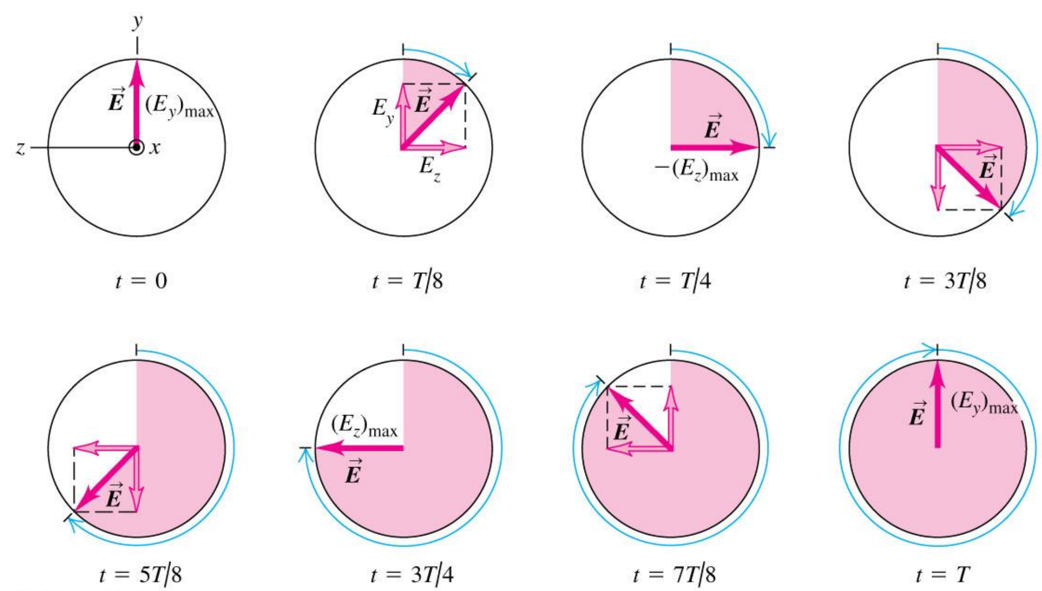


Circular (Elliptical) Polarization

- In that case, the superposition of these two waves has a polarization direction that rotates in time (and in space, along the direction of motion).







Circular polarization: The $\vec{E}$ vector of the wave has constant magnitude and rotates in a circle.

Scattering

- Let's consider our discussion earlier about how you can "sense" an EM wave that was transmitted with a vertical dipole antenna with another vertical dipole antenna.
- Now, take the light from the sun – unpolarized, but as it strikes the earth's atmosphere, there are molecules that *behave* as dipole antennas. Of course they are randomly oriented as well.
- But also remember that dipole antennas don't radiate along their axis.
- So, light scattered down towards the earth has no vertical polarization.
- Also, because of the natural frequency of molecules in the air, blue light scatters more than red…