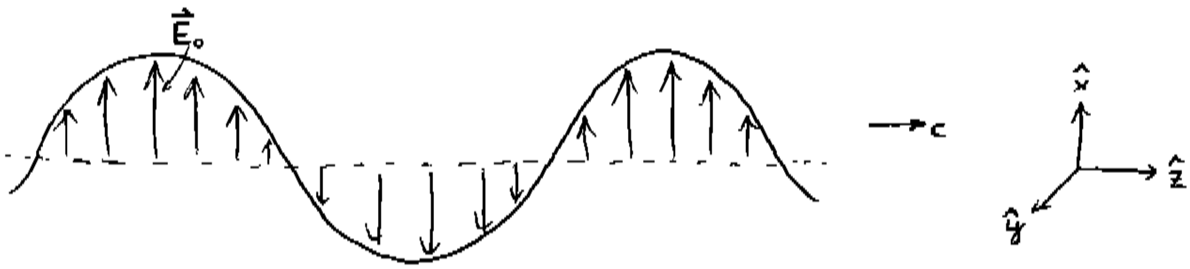
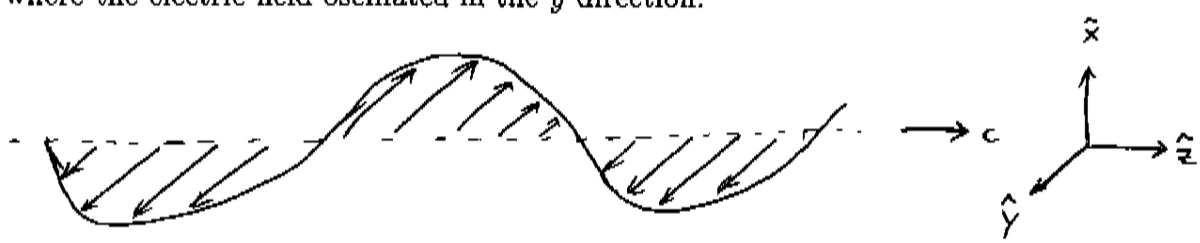
Polarization



Pictured above is a snapshot of the electric field along the direction of motion in a monochromatic electromagnetic wave. The electric field at every point is perpendicular to the direction of motion of the wave; this is required by Maxwell's equations. In this picture, the direction of motion is the $\hat{z}$ direction, and the electric field points in the $\hat{x}$ direction. In particular, if we were able to look at the electric field as a function of time at some particular point, we would see it simply oscillating in the $\hat{x}$ direction,

$$\vec{E} = \hat{x}E_0 cos(\omega t + \phi) \ . \tag{1}$$

Now, there is nothing special about the $\hat{x}$ direction. We could also have a wave with exactly the same amplitude, frequency, direction, and phase, but where the electric field oscillated in the $\hat{y}$ direction.

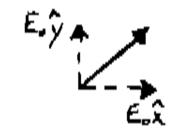


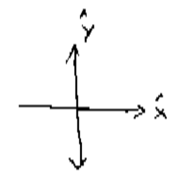
In this case, the observed electric field at a specific fixed location would be

$$\vec{E} = \hat{y}E_0 cos(\omega t + \phi) \ . \tag{2}$$

The only difference between the two waves is the direction in which the electric field points. This direction defines what is known as the POLARIZATION of the electromagnetic wave.

Now we can obviously have other polarizations, such as a wave where the electric field points in the direction halfway between the $\hat{x}$ and $\hat{y}$ directions. But this is just an equal superposition of the two polarizations above. For example, if we add a wave polarized in the $\hat{x}$ direction with amplitude E_0 to a wave polarized in the $\hat{y}$ direction with amplitude E_0, we get a wave polarized in the direction $\hat{n} = (\hat{x} + \hat{y})/\sqrt{2}$ with amplitude $\sqrt{2}E_0$. To illustrate this, we can just add up (1) and (2), to get





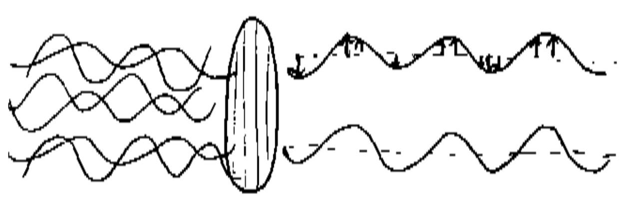
$$\begin{aligned} \vec{E} &= \hat{x}E_0 cos(\omega t + \phi) + \hat{y}E_0 cos(\omega t + \phi) \\ &= \hat{n}\sqrt{2}E_0 cos(\omega t + \phi) \end{aligned}$$

where $\hat{n}$ is the unit vector halfway between $\hat{x}$ and $\hat{y}$. By adding the two basic polarizations (1) and (2) with different amplitudes, we can get light with an electric field oscillating in any direction we want, so long as the direction is perpendicular to the direction of motion. So these two basic polarizations act like a basis for getting all the other polarizations.

Note that assuming we add the two basic polarizations with the same phase, the resulting electric field at any point will always just oscillate back and forth in a single direction perpendicular to the $\hat{z}$ direction. For this reason, we call such waves LINEARLY POLARIZED. We will consider what happens if we add the two polarizations out of phase below.

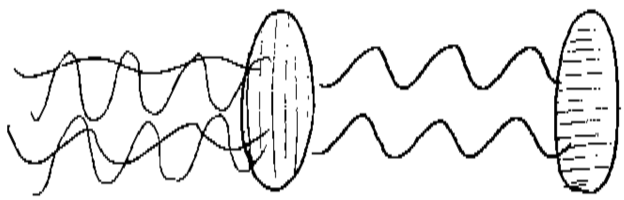
Polarizers

Most light is a mixture of waves with various polarizations. However, there are various ways to produce light with a specific polarization. Perhaps the simplest is through the use of a POLARIZER (or Polaroid). This is a film of material in which only light of one particular polarization can propagate, due to an intrinsic direction in the material. The material is transparent to light with polarization along this intrinsic direction, but opaque to light with polarization transverse to this. If we place a polarizer in front of any light source, the light passing through will all be polarized in one direction:

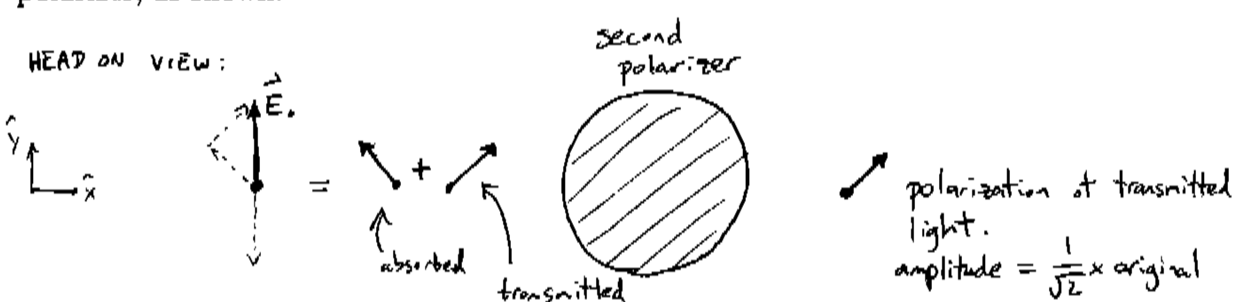


If we now place another polarizer in front of the first with the same orientation, all the light will pass through, since it is already polarized in the preferred direction.

On the other hand, if the second polarizer is oriented perpendicular to the first, then none of the light will pass through the second polarizer, since the original light is now polarized perpendicular to the preferred direction of the second polarizer.



What happens if we put the second polarizer at some other angle? To understand this, we need to remember that the light from the first polarizer can be thought of as a linear combination of light polarized in the preferred direction of the second polarizer, and light polarized perpendicular to this direction. If we think of these two components separately, then we know that one component will pass through, while the other one will be absorbed. If the angle between the two polarizers is θ, the amplitude of the component that passes through the second polarizer will be $\cos(\theta)$, so the intensity of the light passing through the second polarizer will be $cos^2(\theta)$ times the intensity of the light incident on the second polarizer. For example, if the polarizers are at 45 degrees to each other, the intensity of the light passing through the second polarizer will be half the intensity of the light incident on the second polarizer, as shown.



Circular Polarization

When we discussed adding two light waves with different polarizations, we previously assumed that the two waves were in phase. On the other hand, the most general combinations would have different amplitudes and different phases for the two polarizations. To see what this results in, let's see what the observed electric field would look like if we added up the two polarizations

90 degrees out of phase. So we add (1) with $\theta = 0$ to (2) with $\theta = \pi/2$. We get:

$$\begin{aligned} \vec{E} &= \hat{x}E_0cos(\omega t) + \hat{y}E_0cos(\omega t + \frac{\pi}{2}) \\ &= \hat{x}E_0cos(\omega t) - \hat{y}E_0sin(\omega t) \end{aligned}$$

Now, at $t = 0$ the electric field points in the $\hat{x}$ direction, at $t = \pi/(2\omega)$ the electric field points in the $-\hat{y}$ direction, at $t = \pi/(\omega)$ the electric field points in the $-\hat{x}$ direction, etc... . We find that the electric field in this case has a constant magnitude but a direction that rotates in the xy-plane. This is known as CIRCULARLY POLARIZED light. In the most general polarization, obtained by choosing different amplitudes and different phases for the two basic polarizations, the electric field vector moves in an ellipse.

HEAD ON VIEW OF $\vec{E}(t)$ at a fixed location: