Polarization

Unit: Light & Optics

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): 14.3.A, 14.3.A.2, 14.3.A.2.i, 14.3.A.2.ii, 14.3.A.3

Mastery Objective(s): (Students will be able to…)

- Explain how and under which circumstances light can be polarized.

Success Criteria:

- Explanation accounts for the filtering of waves of other orientations and for the specific direction.

Language Objectives:

- Explain how polarized sunglasses work.

Tier 2 Vocabulary: polarized

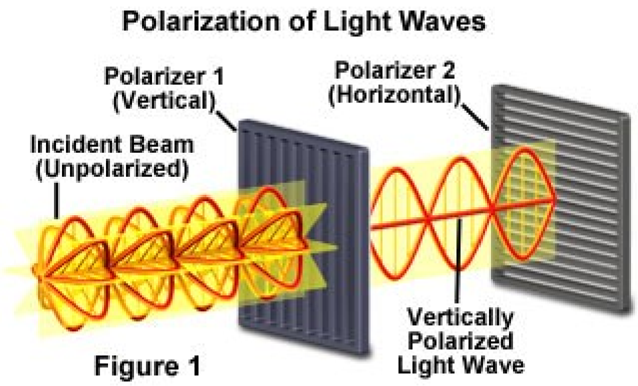
Labs, Activities & Demonstrations:

- polarizing filters

Notes:

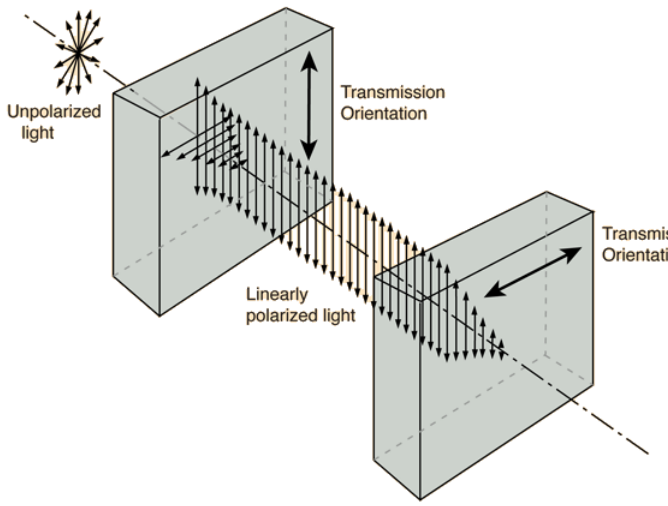
Light (and other electromagnetic waves) are transverse waves with amplitudes in all directions that are perpendicular to the direction of propagation. However, light can be filtered such that it travels in a single plane. This process is called polarization.

Polarization can occur when light waves are reflected under certain conditions (which will be discussed later in this topic), or when light is passed through a special filter called a polarizer, which allows light to pass through in only one plane (direction). The action of a polarizer is shown in the following diagram:



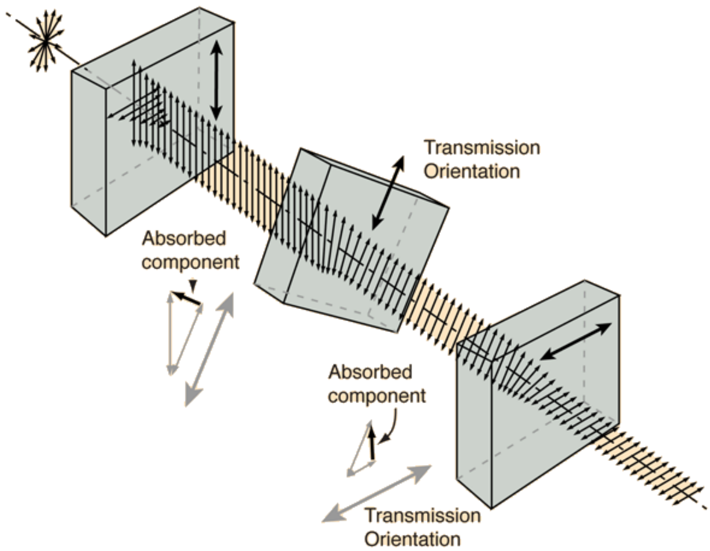
Light that is polarized in this manner is called plane-polarized light.

If you place two polarizers on top of each other and turn them so they polarize in different directions, no light passes through. This is called crossed polarization.



Two polarizers oriented 90° to each other

However, if a third polarizer is placed in-between at some angle that is not perpendicular to either of the other polarizers, light will pass through all of the polarizers. This phenomenon is known as the three-polarizer paradox. It occurs because polarizers do not just block light; they rotate the light passing through.



three polarizers oriented 45° to each other

A flat surface can act as a polarizer at certain angles. The Scottish physicist Sir David Brewster derived a formula for the angle of maximum polarization based on the indices of refraction of the two substances:

$$\theta_B = \tan^{-1}\left(\frac{n_2}{n_1}\right)$$

where:

θ_B = Brewster's angle, the angle of incidence at which unpolarized light striking a surface is perfectly polarized when reflected.

n_1 & n_2 = indices of refraction of the two substances

The two pictures below were taken with the same camera and a polarizing filter. Compare the window of the house in the middle of each picture.

In the picture on the left, the camera's polarizing filter is aligned with the light reflected off the window. In the picture on the right, the polarizing filter is rotated 90°, so that none of the reflected light from the window can get to the camera lens.

Another example is light reflecting off a wet road. When the sun shines on a wet road at a low angle, the reflected light is polarized parallel to the surface (*i.e.,* horizontally). Sunglasses that are polarized vertically (*i.e.,* that allow only vertically polarized light to pass through) will effectively block most or all of the light reflected from the road.

Yet another example is the light that creates a rainbow. When sunlight reflects off the inside of a raindrop, the angle of incidence is very close to Brewster's angle. This causes the light that exits the raindrop to be polarized in the same direction as the bows of the rainbow (*i.e.,* horizontally at the top). This is why you cannot see a rainbow through polarized sunglasses!

Note that polarization generally reduces the intensity of the light.

Note also that because the displacement of a longitudinal wave is along the direction of propagation rather than perpendicular to it, longitudinal waves cannot be polarized.