Polarization of Light

Demonstration

This demonstration explains transverse waves and some surprising properties of polarizers.

Microbehunter

Number of Participants: Unlimited

Audience: Middle (ages 11-13) and up

Duration: 5-10 min

Difficulty: Level 1

Materials Required:

- 3 sheets of polarizing film – at least $(20mm)^2$
- Long spring or Slinky

Setup:

1. If necessary, prepare polarizing sheets by cutting a larger sheet into smaller pieces. While larger pieces of polarizing material are preferred, the demonstration works with smaller pieces.

Presenter Brief:

Light is a transverse wave because its two components, electric and magnetic fields, oscillate perpendicular to the direction of propagation. In general, a beam of light will consist of many photons traveling in the same direction but with arbitrary alignment of their electric and magnetic fields.

Specifically, for an unpolarized light beam the electromagnetic components of each photon, while confined to a plane, are not aligned. If light is polarized, photons have aligned electromagnetic components and travel in the same direction.

Vocabulary:

- Light – Electromagnetic radiation, which can be in the visible range.
- Electromagnetic – A transverse wave consisting of oscillating electric and magnetic components.
- Transverse wave – A wave consisting of oscillations perpendicular to the direction of propagation.
- Polarized light – A beam of photons propagating with aligned oscillating components.Polarizer – A material which filters homogenous light along a singular axis and thus blocks arbitrary orientations and allows a specific orientation of oscillations.

Physics & Explanation:

Middle (ages 11-13) and general public:

Light, or an electromagnetic wave, is a transverse wave with oscillating electric and magnetic components. Recall that in a transverse wave, the vibrations,” or oscillations, are perpendicular to the direction of propagation.

Use the long spring or Slinky to demonstrate a transverse wave.

However, unlike the Slinky, in an electromagnetic wave the oscillations occur in multiple planes.

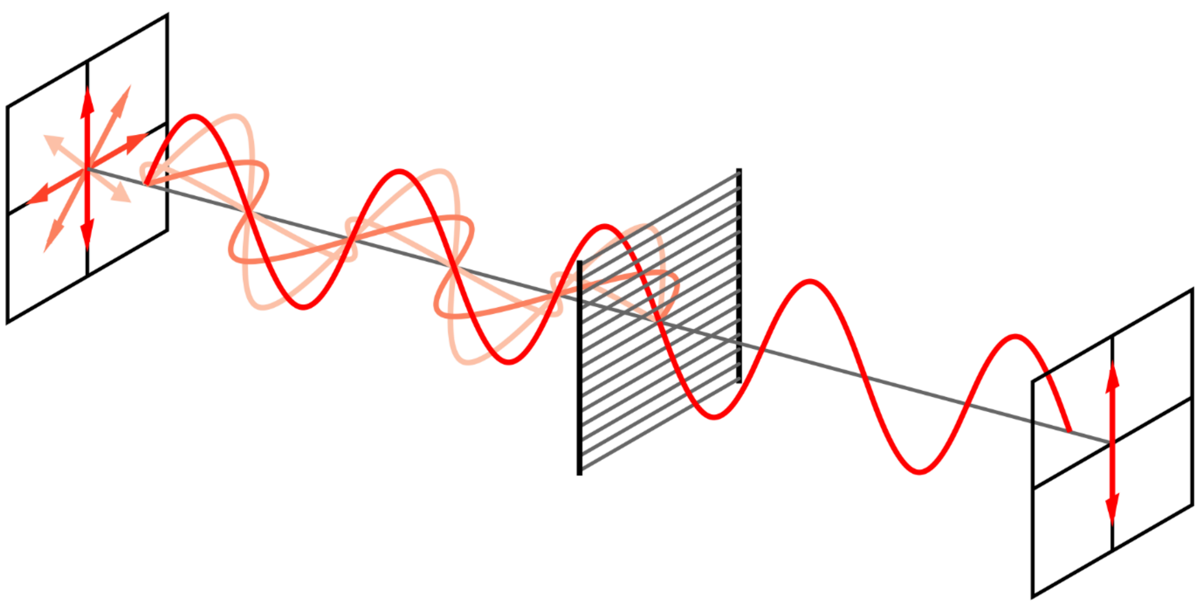


Figure 1: By User:Dr Bob (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0) or GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons

Show Figure 1to illustrate the difference between a transverse wave in one plane (like the Slinky) and a transverse wave in multiple planes. Instruct participants to hold the polarizer to the light (never look directly at the sun) and observe the decrease in intensity.

When light passes through a polarizer, only one orientation of the wave oscillation is allowed through. A good example would be to have the slinky oscillate between the slats of a fence: only one way of oscillation will work. Note: when light passes through a polarizer intensity is decreased by ½.

While there are many means of polarization, a polarizing filter is made of molecules with long chains of bonded atoms. The film is made so that the molecules are arranged in the same direction. When the light passes through, only the photons with an oscillating plane in the direction of the molecules is passed through.

Have participants hold up two sheets of the polarizer and rotate one relative to the other. The first polarizer will restrict the light to a single plane. Adding a second polarizer at 90° will block the only remaining plane and no light will be transmitted through.

Since electromagnetic waves (light) are transverse waves oscillating in multiple planes, a special arrangement of molecules (polarizing filter) can restrict the light to a single plane of oscillation. This will result in a decrease in intensity.

Highschool (14 +):

After completing the above section, assist the participant and insert a third filter between the two. Rotate to 45°. Light will become visible again, but dimmer.

The participants may be surprised when the light reappears with the addition of a third polarizer. However, this phenomenon is easily understandable with some simple geometry.

Use a whiteboard to recreate the following figures and explain the process of polarization as described below.

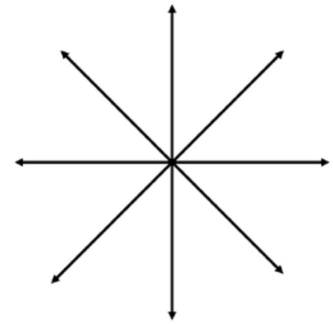


Figure 2: The unpolarized wave seen "head on."

Recall that light is an electromagnetic wave oscillating in multiple planes. If we could see the unpolarized wave in Figure 1 "head on," it would look something like Figure 2.

Now, imagine this light going through a polarizing filter that only allows the horizontal components through. Where do the vertical components go?

To understand this, let us examine a single plane of oscillation in Figure 3.

When the oscillating plane in red encounters the polarizer, only the horizontal

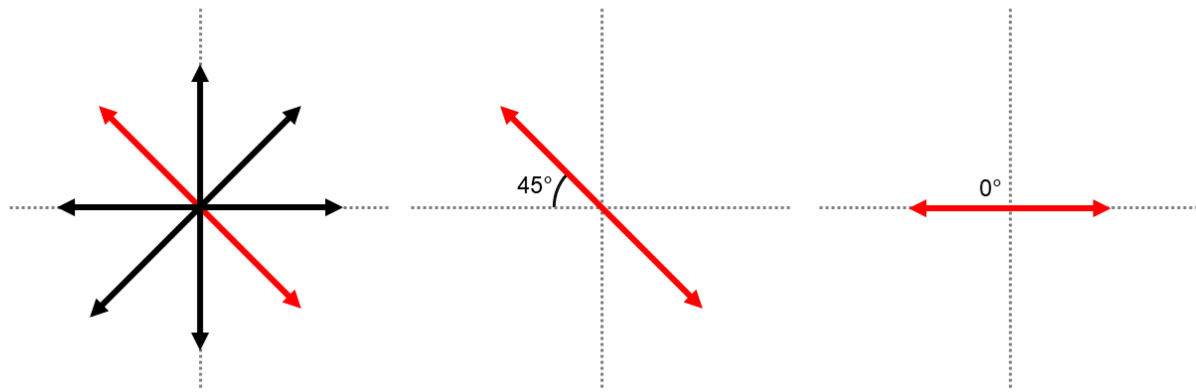


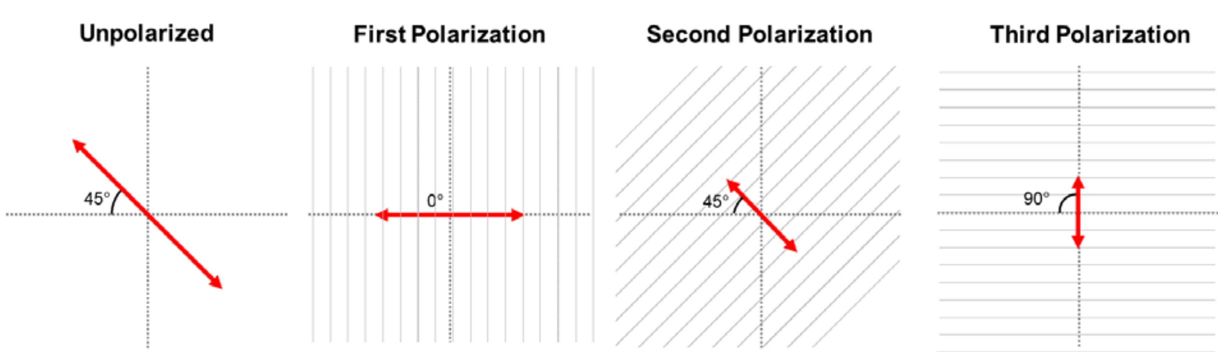
Figure 3: A single plane of oscillation (in red) passing through a polarizer which removes the vertical component. Only the horizontal component remains and the magnitude is decreased.

components pass through. However, the plane is not simply rotated from a 45° angle to a 0° angle. If this were the case, the magnitude of light would not be affected by a polarizer. We know the intensity of light decreases (not all of it makes it through). Instead, the vertical component is completely removed and only the horizontal component remains.

If the length of the red arrow represents the magnitude, or intensity, of light, Figure 3 shows that the magnitude decreases when being polarized from 45° to 0°. This occurs for all planes of oscillation.

When light passes through a polarizer, a single component of the oscillating electromagnetic waves is removed, which decreases the intensity.

Next, revisit the idea of adding the third polarizer between the two. With the understanding of how polarizers affect light, recreate the figures below and explain how the magnitude is affected by three filters.



The 45° component of an unpolarized wave.

The component is restricted to 0° after passing through the first polarizer.

The component is restricted to 45° after passing through the second (middle) polarizer.

The component is restricted to 90° after passing through the third polarizer.

Once again, we examine a single plane of oscillation at 45°. After passing through the first polarizer, the vertical components are restricted and only the horizontal components pass through.

When the horizontally polarized wave passes through the second (middle) filter which is angled at 45°, the components are restricted to 45°.

When the 45° polarized wave passes through the third filter, the components are restricted to 90°. Notice that after every polarization, the magnitude is decreased.

Additional Resources:

- 3-polarizer explanation http://alienryderflex.com/polarizer/
- Hecht, Eugene. *Optics*, 1998. Ch. 8 Section 2 (Polarizers & Malus' Law. 326)
- Pedrotti, Frank L. Pedrotti, Leno S. *Introduction to* Optics, 1993. (298-301)
- In-depth explanation of polaroid films http://www.physicsclassroom.com/class/light/Lesson-1/Polarization