

the Physics Classroom

(/)



(/Read- (/Practic Teacher-
Watch-ReviewTools)
InteractTest)

Physics Tutorial(/class)

1-D
Kinematics(/Physics-
Tutorial2/1-D-
Kinematics)

Newton's
Laws(/Physics-
Tutorial/Newton-s-
Laws)

Vectors - Motion and
Forces in Two
Dimensions(/class/vectors)

Momentum and Its
Conservation(/class/momentum)

Work, Energy, and
Power(/class/energy)

Circular Motion and
Satellite
Motion(/class/circles)

Thermal
Physics(/class/thermalP)

Static
Electricity(/class/estatics)

Current
Electricity(/class/circuits)

Waves(/class/waves)

Sound Waves and
Music(/class/sound)

**Light Waves and
Color(/class/light)**

Reflection and the
Ray Model of
Light(/class/refln)

Refraction and the
Ray Model of
Light(/class/refrn)

The Physics Classroom(/) » Physics Tutorial(/class) » Light Waves and
Color(/class/light) » Polarization

Light Waves and Color - Lesson 1

Polarization

Wavelike Behaviors of Light(/class/light/Lesson-
1/Wavelike-Behaviors-of-Light)

Two Point Source Interference(/class/light/Lesson-1/Two-
Point-Source-Interference)

Thin Film Interference(/class/light/Lesson-1/Thin-Film-
Interference)

Polarization

A light wave is an electromagnetic
wave(<http://www.physicsclassroom.com/Class/waves/u10l1c.cfm#emmech>)

that travels through the vacuum of outer space. Light
waves are produced by vibrating electric charges.

The nature of such electromagnetic waves is beyond
the scope of The Physics Classroom

Tutorial(<http://www.physicsclassroom.com/Class/index.cfm>).

For our purposes, it is sufficient to merely say that an
electromagnetic wave is a transverse

wave(<http://www.physicsclassroom.com/Class/waves/u10l1c.cfm#transverse>)
that has both an electric and a magnetic component.

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[Multimedia Studios\(/mmedia\)](#)

[The Review Session\(/reviews\)](#)

[Minds on Physics\(/mop\)](#)

[The Calculator Pad\(/calcpad\)](#)

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[The Laboratory\(/lab\)](#)

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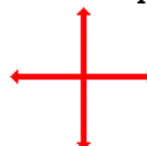
Physics-
Classroom/371507191836)

The transverse nature of an electromagnetic wave is quite different from any other type of wave that has been discussed in The Physics Classroom

A light wave is known to vibrate in a multitude of directions ...



... In general, a light wave can be thought of as vibrating in a vertical and in a horizontal plane.



Tutorial(<http://www.physicsclassroom.com/Class/index.cfm>).

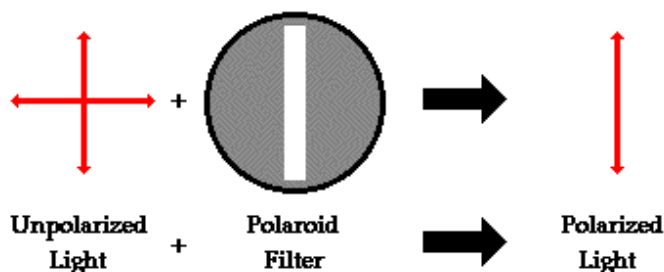
Let's suppose that we use the customary slinky to model the behavior of an electromagnetic wave. As an electromagnetic wave traveled towards you, then you would observe the vibrations of the slinky occurring in more than one plane of vibration. This is quite different than what you might notice if you were to look along a slinky and observe a slinky wave traveling towards you. Indeed, the coils of the slinky would be vibrating back and forth as the slinky approached; yet these vibrations would occur in a single plane of space. That is, the coils of the slinky might vibrate up and down or left and right. Yet regardless of their direction of vibration, they would be moving along the same linear direction as you sighted along the slinky. If a slinky wave were an electromagnetic wave, then the vibrations of the slinky would occur in multiple planes. Unlike a usual slinky wave, the electric and magnetic vibrations of an electromagnetic wave occur in numerous planes. A light wave that is vibrating in more than one plane is referred to as **unpolarized light**. Light emitted by the sun, by a lamp in the classroom, or by a candle flame is unpolarized light. Such light waves are created by electric charges that vibrate in a variety of directions, thus creating an electromagnetic wave that vibrates in a variety of directions. This concept of unpolarized light is rather difficult to visualize. In general, it is helpful to picture unpolarized light as a wave that has an average of half its vibrations in a horizontal plane and half of its vibrations in a vertical plane.

It is possible to transform unpolarized light into **polarized light**. Polarized light waves are light waves in which the vibrations occur in a single plane. The process of transforming unpolarized light into polarized light is known as **polarization**. There are a variety of methods of polarizing light. The four methods discussed on this page are:

- Polarization by Transmission(<http://www.physicsclassroom.com/Class/light/U12L1e.cfm#trair>)
- Polarization by Reflection(<http://www.physicsclassroom.com/Class/light/U12L1e.cfm#refln>)
- Polarization by Refraction(<http://www.physicsclassroom.com/Class/light/U12L1e.cfm#refrn>)
- Polarization by Scattering(<http://www.physicsclassroom.com/Class/light/U12L1e.cfm#scat>)

Polarization by Use of a Polaroid Filter

The most common method of polarization involves the use of a **Polaroid filter**. Polaroid filters are made of a special material that is capable of blocking one of the two planes of vibration of an electromagnetic wave. (Remember, the notion of two planes or directions of vibration is merely a simplification that helps us to visualize the wavelike nature of the electromagnetic wave.) In this sense, a Polaroid serves as a device that filters out one-half of the vibrations upon transmission of the light through the filter. When unpolarized light is transmitted through a Polaroid filter, it emerges with one-half the intensity and with vibrations in a single plane; it emerges as polarized light.

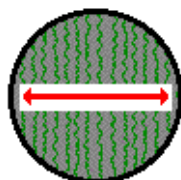


A Polaroid filter is able to polarize light because of the chemical composition of the filter material. The filter can be thought of as having long-chain molecules that are aligned within the filter in the same direction. During the fabrication of the filter,

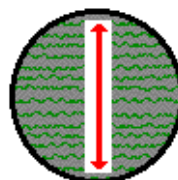
the long-chain molecules are stretched across the filter so that each molecule is (as much as possible) aligned in say the vertical direction. As unpolarized light strikes the filter, the portion of the waves vibrating in the vertical direction are absorbed by the filter. The general rule is that the electromagnetic vibrations that are in a direction parallel to the alignment of the molecules are absorbed.

The alignment of these molecules gives the filter a **polarization axis**. This polarization axis extends across the length of the filter and only allows vibrations of the electromagnetic wave that are parallel to the axis to pass through. Any vibrations that are perpendicular to the polarization axis are blocked by the filter. Thus, a Polaroid filter with its long-chain molecules aligned horizontally will have a polarization axis aligned vertically. Such a filter will block all horizontal vibrations and allow the vertical vibrations to be transmitted (see diagram above). On the other hand, a Polaroid filter with its long-chain molecules aligned vertically will have a polarization axis aligned horizontally; this filter will block all vertical vibrations and allow the horizontal vibrations to be transmitted.

Relationship Between Long-Chain Molecule Orientation and the Orientation of the Polarization Axis



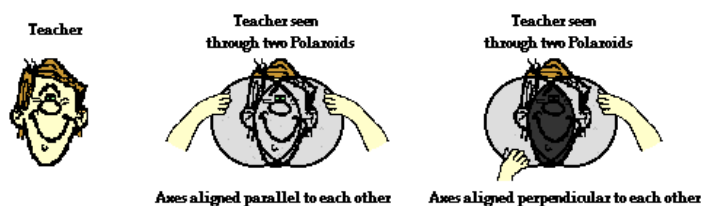
When molecules in the filter are aligned vertically, the polarization axis is horizontal.



When molecules in the filter are aligned horizontally, the polarization axis is vertical.

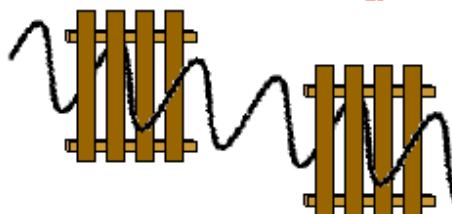
Polarization of light by use of a Polaroid filter is often demonstrated in a Physics class through a variety of demonstrations. Filters are used to look through and view objects. The filter does not distort the shape or dimensions of the object; it merely serves to produce a dimmer image of the object since one-half of the light is blocked as it passed through the filter. A pair of filters is often placed back to back in order to view objects looking through two filters. By slowly rotating the second filter, an orientation can be found in which all the light from an object is blocked and the object can no longer be seen when viewed through two filters. What happened? In this

demonstration, the light was polarized upon passage through the first filter; perhaps only vertical vibrations were able to pass through. These vertical vibrations were then blocked by the second filter since its polarization filter is aligned in a horizontal direction. While you are unable to see the axes on the filter, you will know when the axes are aligned perpendicular to each other because with this orientation, all light is blocked. So by use of two filters, one can completely block all of the light that is incident upon the set; this will only occur if the polarization axes are rotated such that they are perpendicular to each other.

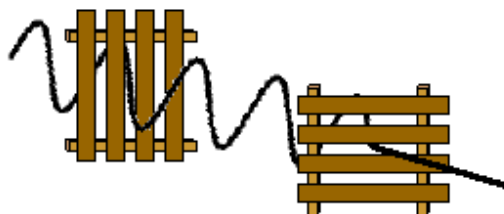


A picket-fence analogy is often used to explain how this dual-filter demonstration works. A picket fence can act as a polarizer by transforming an unpolarized wave in a rope into a wave that vibrates in a single plane. The spaces between the pickets of the fence will allow vibrations that are parallel to the spacings to pass through while blocking any vibrations that are perpendicular to the spacings. Obviously, a vertical vibration would not have the room to make it through a horizontal spacing. If two picket fences are oriented such that the pickets are both aligned vertically, then vertical vibrations will pass through both fences. On the other hand, if the pickets of the second fence are aligned horizontally, then the vertical vibrations that pass through the first fence will be blocked by the second fence. This is depicted in the diagram below.

The Picket Fence Analogy



When the pickets of both fences are aligned in the vertical direction, a vertical vibration can make it through both fences.



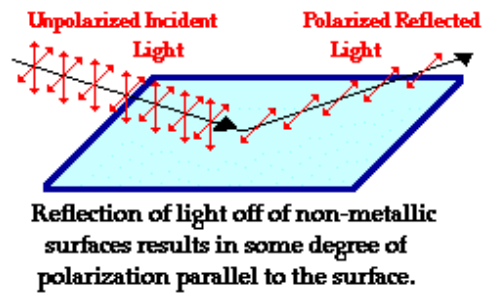
When the pickets of the second fence are horizontal, vertical vibrations which make it through the first fence will be blocked.

In the same manner, two Polaroid filters oriented with their polarization axes perpendicular to each other will block all the light. Now that's a pretty cool observation that could never be explained by a particle view of light.

Polarization by Reflection

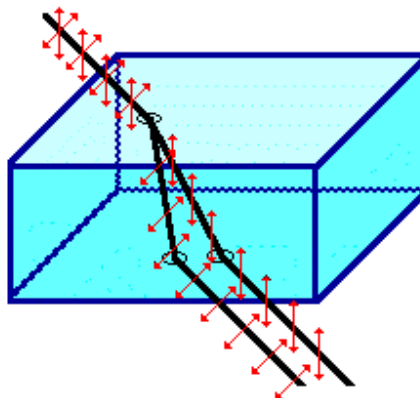
Unpolarized light can also undergo polarization by reflection off of nonmetallic surfaces. The extent to which polarization occurs is dependent upon the angle at which the light approaches the surface and upon the material that the surface is made of. Metallic surfaces reflect light with a variety of vibrational directions; such reflected light is unpolarized. However, nonmetallic surfaces such as asphalt roadways, snowfields and water reflect light such that there is a large concentration of vibrations in a plane parallel to the reflecting surface. A person viewing objects by means of light reflected off of nonmetallic surfaces will often perceive a glare if the extent of polarization is large. Fishermen are familiar with this glare since it prevents them from seeing fish that lie below the water. Light reflected off a lake is partially polarized in a direction parallel to the water's surface. Fishermen know that the use of glare-reducing sunglasses with the proper polarization axis allows for the blocking of this partially polarized light. By blocking the plane-

polarized light, the glare is reduced and the fisherman can more easily see fish located under the water.



Polarization by Refraction

Polarization can also occur by the refraction of light. Refraction occurs when a beam of light passes from one material into another material. At the surface of the two materials, the path of the beam changes its direction. The refracted beam acquires some degree of polarization. Most often, the polarization occurs in a plane perpendicular to the surface. The polarization of refracted light is often



The two refracted rays passing through the Iceland Spar crystal are polarized with perpendicular orientations.

demonstrated in a Physics class using a unique crystal that serves as a double-refracting crystal. Iceland Spar, a rather rare form of the mineral calcite, refracts incident light into two different paths. The light is *split* into two beams upon entering the crystal. Subsequently, if an object is viewed by looking through an Iceland Spar crystal, two images will be seen. The two images are the result of the double refraction of light. Both refracted light beams are polarized - one in a direction parallel to the surface and the other in a direction perpendicular to the surface. Since these two refracted rays are polarized with a perpendicular orientation, a polarizing filter can be used to completely block one of the images. If the polarization axis of the filter is aligned perpendicular to the plane of polarized light, the light is completely blocked by the filter; meanwhile the second image is as bright as can be. And if the filter is then turned 90-degrees in either direction, the second image reappears and the first image disappears. Now that's pretty neat observation that could never be observed if light did not exhibit any wavelike behavior.

Watch It!

In the demonstration below, the word PHUN (as in

Physics is ...) is written on the glass panel of a classroom-style overhead projector. A sample of Iceland spar is placed over the word PHUN. Two images of the word PHUN can be faintly seen in the early seconds of the movie. The crystal double refracts light that passes through it. At about the 8-second mark, a Polaroid filter is placed over the crystal and rotated. As it rotates, the two images alternately fade in and out. The light passing through the crystal becomes polarized and when the Polaroid filter is rotated, it blocks and transmits the two light paths in alternating fashion. The result is that the two images of PHUN can be seen one at a time. Pretty cool stuff!

Polarization by Scattering

Polarization also occurs when light is scattered while traveling through a medium. When light strikes the atoms of a material, it will often set the electrons of those atoms into vibration. The vibrating electrons then produce their own electromagnetic wave that is radiated outward in all directions. This newly generated wave strikes neighboring atoms, forcing their electrons into vibrations at the same original frequency. These vibrating electrons produce another electromagnetic wave that is once more radiated outward in all directions. This absorption and reemission of light waves causes the light to be scattered about the medium. (This process of scattering contributes to the blueness of our skies, a topic to be discussed later(<http://www.physicsclassroom.com/Class/light/u12l2f.cfm>).

This scattered light is partially polarized. Polarization by scattering is observed as light passes through our atmosphere. The scattered light often produces a glare in the skies. Photographers know that this partial polarization of scattered light leads to photographs characterized by a *washed-out* sky. The problem can easily be corrected by the use of a Polaroid filter. As the filter is rotated, the partially polarized light is blocked and the glare is reduced. The photographic secret of capturing a vivid blue sky as the backdrop of a beautiful foreground lies in the physics of polarization and Polaroid filters.

Applications of Polarization

Polarization has a wealth of other applications besides their use in glare-reducing sunglasses. In industry, Polaroid filters are used to perform stress analysis tests on transparent plastics. As light passes through a plastic, each color of visible light is polarized with its own orientation. If such a plastic is placed between two polarizing plates, a colorful pattern is revealed. As the top plate is turned, the color pattern changes as new colors become blocked and the formerly blocked colors are transmitted. A common Physics demonstration involves placing a plastic protractor between two Polaroid plates and placing them on top of an overhead projector. It is known that structural stress in plastic is signified at locations where there is a large concentration of colored bands. This location of stress is usually the location where structural failure will most likely occur. Perhaps you wish that a more careful stress analysis were performed on the plastic case of the CD that you recently purchased.

Polarization is also used in the entertainment industry to produce and show 3-D movies. Three-dimensional movies are actually two movies being shown at the same time through two projectors. The two movies are filmed from two slightly different camera locations. Each individual movie is then projected from different sides of the audience onto a metal screen. The movies are projected through a polarizing filter. The polarizing filter used for the projector on the left may have its polarization axis aligned horizontally while the polarizing filter used for the projector on the right would have its

polarization axis aligned vertically. Consequently, there are two slightly different movies being projected onto a screen. Each movie is cast by light that is polarized with an orientation perpendicular to the other movie. The audience then wears glasses that have two Polaroid filters. Each filter has a different polarization axis - one is horizontal and the other is vertical. The result of this arrangement of projectors and filters is that the left eye sees the movie that is projected from the right projector while the right eye sees the movie that is projected from the left projector. This gives the viewer a perception of depth.

Our model of the polarization of light provides some substantial support for the wavelike nature of light. It would be extremely difficult to explain polarization phenomenon using a particle view of light. Polarization would only occur with a transverse wave. For this reason, polarization is one more reason why scientists believe that light exhibits wavelike behavior.

Watch It!

The pattern of a hot air balloon was sketched onto a glass plate. Cellophane tape was then added to the pattern such that each "sector" of the balloon consisted of tape aligned in a distinctly different direction than adjacent "sectors". A hobby knife was used to carefully remove overlap of tape from one sector into adjoining sectors. The cellophane tape is able to rotate the axis of polarization of the wavelengths (i.e., color) of polarized light different amounts.

In the demonstration, a polaroid filter is placed upon the glass panel of a classroom style overhead projector. Light passing through the filter becomes polarized. Different sectors of the taped glass will rotate the axes of polarization of the different wavelengths of light different amounts. A second filter is then placed over the taped glass. This second

filter permits passage of wavelengths (i.e. colors) of light whose axis of polarization line up with the transmitting axis of the filter; other wavelengths are blocked. Thus, different sectors appear different colors when viewed through both filters.

Check Your Understanding

1. Suppose that light passes through two Polaroid filters whose polarization axes are parallel to each other. What would be the result?

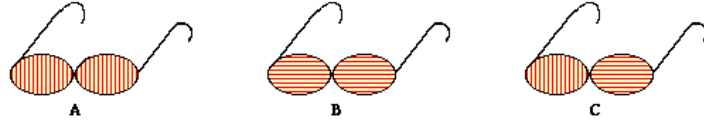
See Answer

2. Light becomes partially polarized as it reflects off nonmetallic surfaces such as glass, water, or a road surface. The polarized light consists of waves vibrate in a plane that is _____ (parallel, perpendicular) to the reflecting surface.

See Answer

3. Consider the three pairs of sunglasses below. Identify the pair of glasses is capable of eliminating the glare resulting from sunlight reflecting off the

calm waters of a lake? _____ Explain. (The polarization axes are shown by the straight lines.)



See Answer

Jump To Next Lesson:
The Electromagnetic and Visible
Spectra(/class/light/Lesson-2/The-Electromagnetic-and-
Visible-Spectra)

0