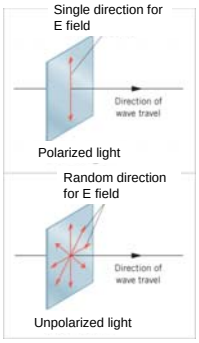
Polarized Light

1

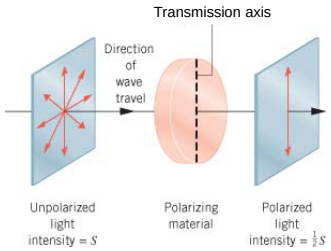
Polarized light

In linearly polarized light, the electric field vectors all lie in one single direction. So do the magnetic field vectors because they're perpendicular to the electric field vectors. Most light sources emit unpolarized light. A common way of producing polarized light is by the use of polarizers.



2

Action of a Polarizer



Polarized light may be produced from unpolarized light with the aid of polarizing material.

3

Polarizers: polarization by selective absorption

One way to polarize light is by selectively absorbing light with electric field vectors pointing in a particular direction. Certain materials, known as dichroic materials, do this by absorbing only light polarized one way. If the material is thick enough, the light emerging from the material will be linearly polarized.

Polarizers (such as the lenses of polarizing sunglasses) are made from this kind of material.

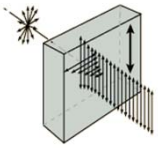
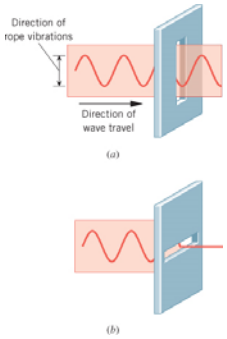


Illustration of a dichroic material. http://hyperphysics.phy-astr.gsu.edu/Hbase/phyopt/polabs.html

If unpolarized light passes through a polarizer, the intensity of the transmitted light is 1/2 of what it was coming in.

4

How does a linearly polarized wave interact with a linear polarizer?



This shows a linearly polarized wave on a rope. From here, we see that if a linearly polarized wave is allowed to pass through a polarizer with transmission axis parallel (perpendicular) to the polarization direction of the wave, the amplitude or intensity of the transmitted wave is unperturbed (zero).

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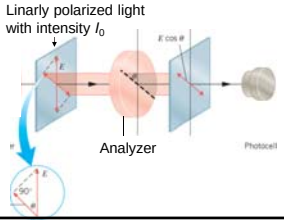
Malus' Law

In general, the intensity of a linearly polarized light passing through a polarizer is given by Malus' law: $I_1 = I_0\cos^2\theta$

where θ is the angle between the polarization direction of the light and the transmission axis of the polarizer. By using Malus' Law, one can determine the direction of polarization of a polarized light if the transmission axis of the polarizer is known. In this application, the polarizer is called an analyzer.



The intensity after passing through the analyzer (i.e., the 2nd polarizer) is $I_1=I_0\cos^2\theta$, where θ is the angle between the transmission axis of the first polarizer and that of the analyzer.

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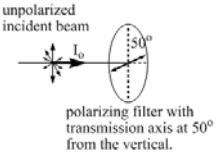
Polarizer example

Unpolarized light with an intensity of I_0 = 16 W/m^2 is incident on a pair of polarizers. The first polarizer has its transmission axis aligned at 50° from the vertical. The second polarizer has its transmission axis aligned at 20° from the vertical.

What is the intensity of the light when it emerges from the first polarizer?

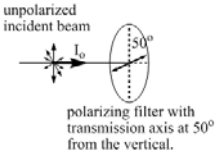
1. 4 W/m^2
2. 16 cos^2(50°) W/m^2
3. 8 W/m^2
4. 12 W/m^2



Through the first polarizer

The light incident on the first polarizer is unpolarized, so the angle is irrelevant – the intensity is reduced by a factor of 2.

$$I_1 = \frac{1}{2} I_0 = \frac{1}{2}\left(16 \text{ W/m}^2\right) = 8 \text{ W/m}^2$$

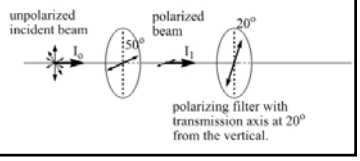


Polarizer example, continued

The light emerging from the first polarizer has an intensity of of I_1 = 8 W/m^2. The first polarizer has its transmission axis aligned at 50° from the vertical. The second polarizer has its transmission axis aligned at 20° from the vertical.

What is the intensity of the light when it emerges from the second polarizer?

1. 4 W/m^2
2. 8 cos^2(20°) W/m^2
3. 6 W/m^2



Through the second polarizer

When it emerges from the first polarizer the light is linearly polarized at 50°. The angle between this and the transmission axis of the second polarizer (20°) is 30°. Therefore:

$$I_2 = I_1 \cos^2\left(50° - 20°\right)$$
$$= 8 \text{ W/m}^2 \times \cos^2\left(30°\right)$$
$$= 8 \text{ W/m}^2 \times \left(\frac{\sqrt{3}}{2}\right)^2 = 6 \text{ W/m}^2$$

$\frac{3}{4}$

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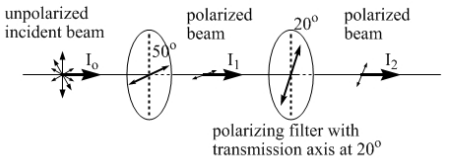
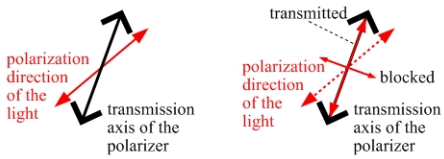
Through the second polarizer





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Polarizer example, version 2

Light that is linearly polarized, with its polarization direction at 20° to the vertical, has an intensity of I_0 = 16 W/m^2. The light is incident on a pair of polarizers. The first polarizer has its transmission axis aligned at 50° from the vertical. The second polarizer has its transmission axis aligned at 20° from the vertical.

What is the intensity of the light when it emerges from the first polarizer?

1. 16 cos^2(20°)
2. 16 cos^2(50°) W/m^2
3. 8 W/m^2
4. 12 W/m^2

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Through the first polarizer

The light is polarized, so this time we apply Malus' Law.

$$I_1 = I_0 \cos^2(50° - 20°)$$
$$= 16\ \text{W/m}^2 \times \cos^2(30°)$$
$$= 16\ \text{W/m}^2 \times \left(\frac{\sqrt{3}}{2}\right)^2 = 12\ \text{W/m}^2$$

$\frac{3}{4}$

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Polarizer example 2, continued

The light emerging from the first polarizer has an intensity of of I_1 = 12 W/m^2. The first polarizer has its transmission axis aligned at 50° from the vertical. The second polarizer has its transmission axis aligned at 20° from the vertical (the way the light was originally polarized).

What is the intensity of the light when it emerges from the second polarizer?

1. 6 W/m^2
2. 12 cos^2(20°) W/m^2
3. 9 W/m^2
4. 12 W/m^2

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Through the second polarizer

When it emerges from the first polarizer the light is linearly polarized at 50°. The angle between this and the transmission axis of the second polarizer (20°) is 30°. Therefore:

$$I_2 = I_1 \cos^2(50° - 20°)$$
$$= 12\ \text{W/m}^2 \times \cos^2(30°)$$
$$= 12\ \text{W/m}^2 \times \left(\frac{\sqrt{3}}{2}\right)^2 = 9\ \text{W/m}^2$$

$\frac{3}{4}$

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Polarization by scattering

Scattering in the atmosphere occurs when light is absorbed by an atom or molecule, and then emitted again, usually in a different direction. Light scattering off atoms and molecules in the atmosphere is unpolarized if the light keeps traveling in the same direction, is linearly polarized if it scatters in a direction perpendicular to the way it was traveling, and somewhere in between if it scatters at another angle.

If you wear polarized sunglasses you can observe this in the sky. On a clear day, look about 90° from the Sun. If you then tilt your head one way and then the other you will see the sky darken and lighten. When it's darker there's not as much light reaching you, and when it's lighter there's more.

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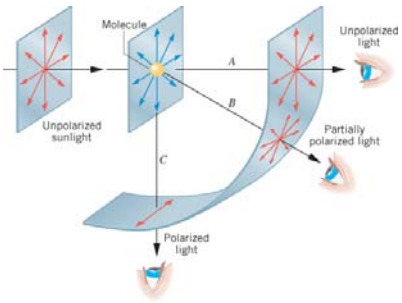
Polarization by scattering



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Polarization by reflection

Polarized sunglasses are designed to block light that reflects off horizontal surfaces. The process of reflection can at least partly (and sometimes completely) polarize the light horizontally, so polarized sunglasses block horizontally polarized light.

When the incident angle is equal to the so-called Brewster angle, θ_B, which depends on the two media adjacent to the reflection surface, the reflected light is completely polarized horizontally.

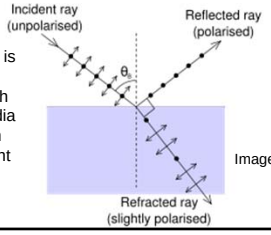

Image from Wikipedia

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Applications: Polaroid sunglasses

(Above) Photographs taken with a camera polarizer filter rotated to two different angles. In the first picture, the polarizer is rotated to maximize reflections, and in the second, it is rotated 90° to minimize reflections - almost all reflected sunlight is eliminated. (Taken from Wikipedia)

When Polaroid sunglasses are Crossed, the intensity of the transmitted light is reduced to zero.

Applications: IMAX movie projector

IMAX movie projectors produce two pictures simultaneously that simulate the two images our two eyes “see” separately. (Close each of your two eyes in sequence and you will find that the images they see do not overlap. By processing the difference, our brain constructs the 3-dimensional perception we sense.) For IMAX to work, the light carrying the two pictures are linearly polarized along two orthogontal directions. The viewer wear polarized eye-glasses that allows each eye to see only one picture, which results in a 3-directional perspective of the picture upon processing by the viewer’s brain.