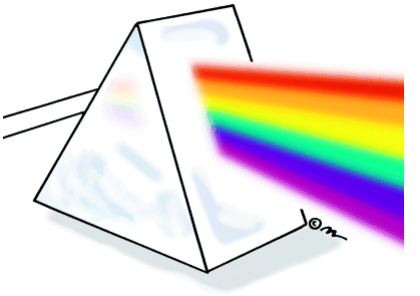
EP118 Optics

TOPIC 7

EM WAVES &

POLARIZATION



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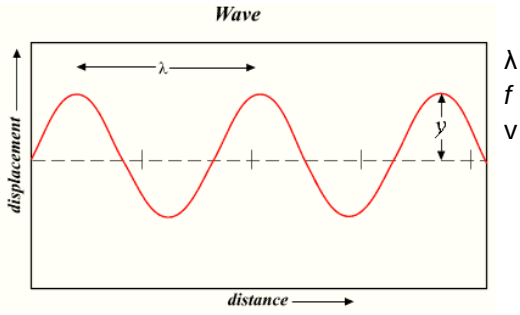
Content

7.1 Introduction

- In this section, we will investigate
  - basic properties of electromagnetic waves (EMW)
  - polarization of light and its applications.

7.2 Wave



λ : wavelength
f : frequency
v : speed of the wave

$v = f\lambda$

In mathematics and science,
a wave is a *disturbance* that travels through space and time, usually accompanied by the transfer of energy.

Mechanical Waves
sound
water
string waves …

Electromagnetic Waves
Light
Radio waves
X-ray …

Wave

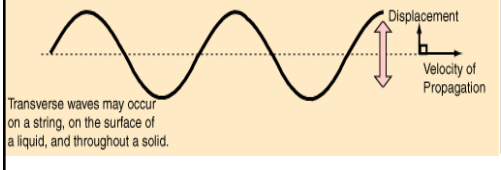
Quantum Mechanical Waves
to describe the probability density of a particle!

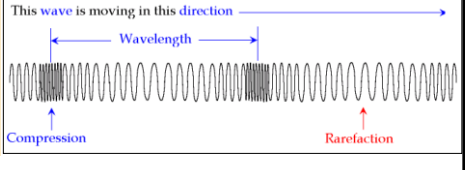
Gravitational Waves
disturbances in the curvature of space-time! (Not observed).

Wave

Transverse Waves
the displacement of the medium is perpendicular to the direction of propagation of the wave.
e.g. *Water wave, EMW*

Longitudinal Waves
the displacement of the medium is parallel to the propagation of the wave.
e.g. *sound wave.*

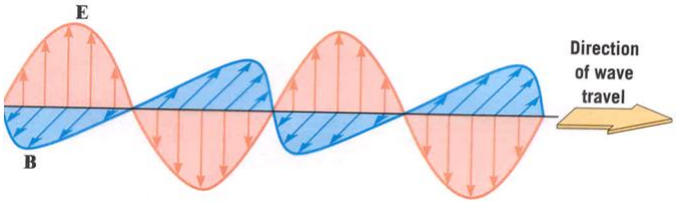




7.3 Electromagnetic Waves

EMW is a form of energy exhibiting wave-like behavior as it travels through space. EMW has both electric field (**E**) and magnetic field (**B**) components, which

* oscillate in *phase*
* perpendicular to each other and
* perpendicular to the direction of energy propagation

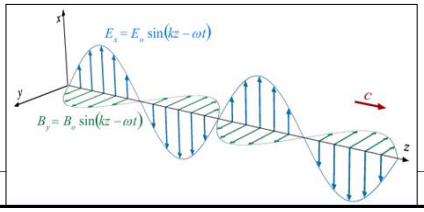


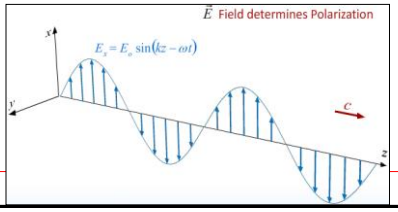
***** James Clerk Maxwell first theoretically postulated EMWs (in 1862).
***** These were confirmed by Heinrich Hertz experimentally (in 1886).

7.4 Polarization

Polarization is a property of certain types of waves that describes the orientation of their oscillations.

- Only **transverse waves** have polarization effect (e.g EMWs, GWs).
- Longitudinal waves do not have polarization since the direction of vibration and direction of propagation are the same (e.g. sound waves)
- To explain polarization effect for EMWs, it is sufficient to consider only the **electric field** component.



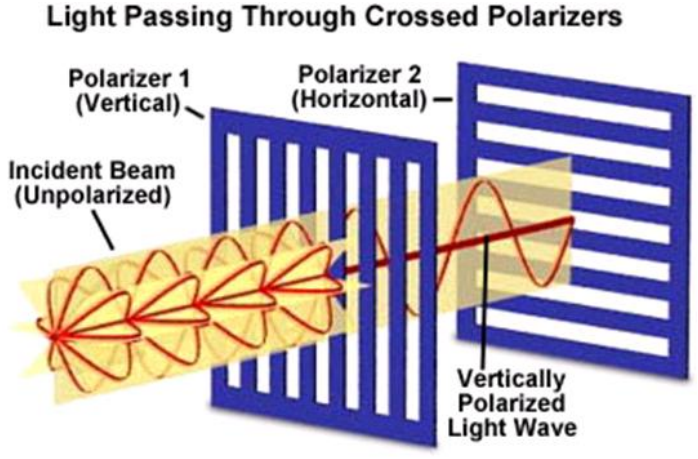


Polarization can be obtained from an unpolarized beam

- by Selective absorption
- by Reflection
- by Scattering

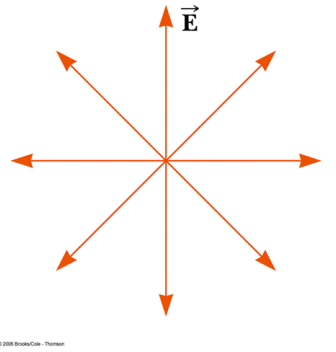
We'll only see selective absorbtion.

When the electric field vectors are restricted to a single plane by filtration, then the light is **polarized** with respect to the direction of propagation.



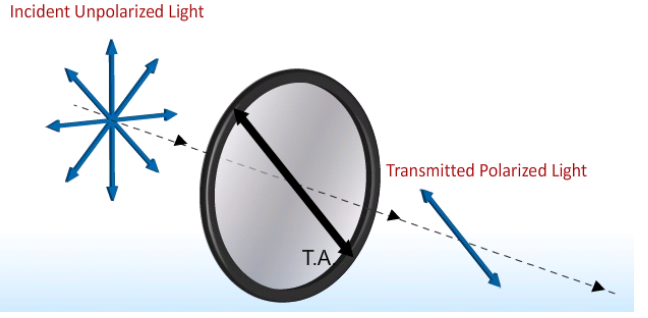
Each atom produces a wave with its own orientation of **E**.

All directions of the electric field vector (**E**) are equally possible and lie in a plane perpendicular to the direction of propagation.



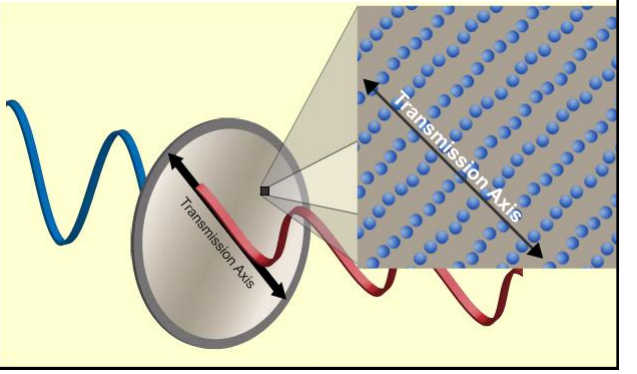
This is an “unpolarized” wave.

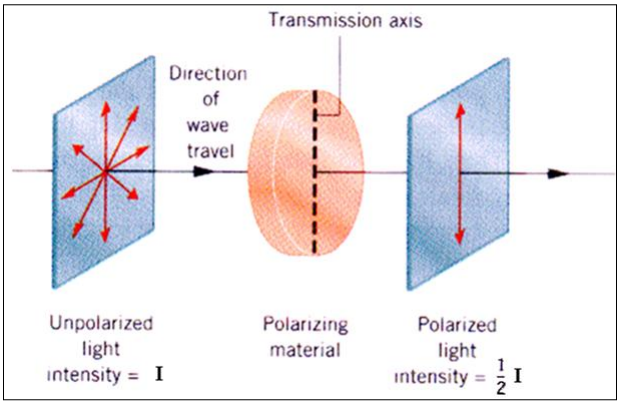
*A wave is said to be **linearly polarized** if the resultant electric field vibrates in the same direction at all times at a particular point.*



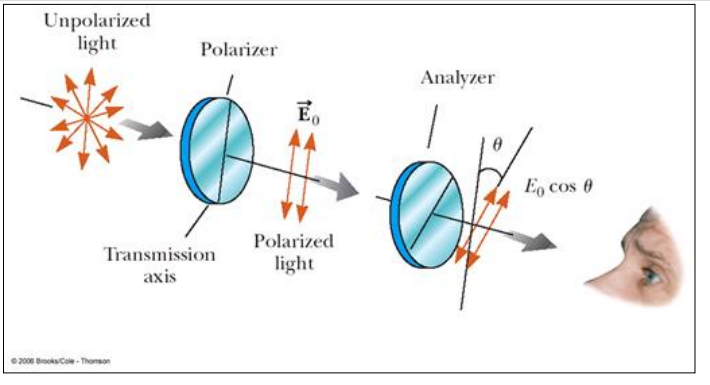
Polarizer (Polaroid):

The molecular structure of a polarizer causes the component of the **E** field perpendicular to the Transmission Axis to be absorbed.





The intensity of the polarized beam transmitted through a polarizing sheet is one-half of the original intensity of the unpolarized wave.

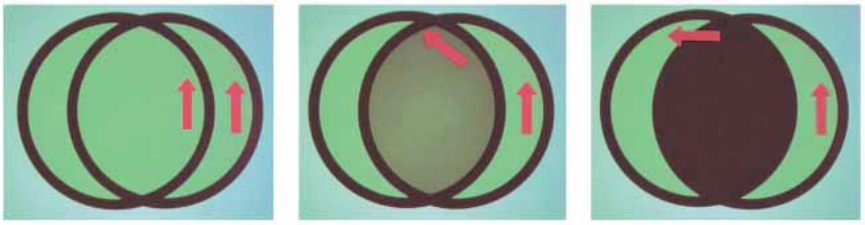


The intensity of the polarized beam transmitted through the second polarizing sheet (the analyzer) varies as:

$$I = I_0 \cos^2(\theta)$$

* I_o is the intensity of the polarized wave incident on the analyzer.
* This is known as **Malus' Law** and applies to any two polarizing materials whose transmission axes are at an angle of θ to each other.

The intensity of light transmitted through two polarizers depends on the relative orientation of their transmission axes



EXAMPLE 1

Unpolarized light passes through two Polaroid sheets.
The axis of the first is vertical, and that of the second is at 40 to the vertical. What fraction of the incident light is transmitted?

SOLUTION

Lets assume that light has the initial intensity I_0.

The light intensity after 1st Polaroid:

$$I_1 = I_0/2.$$

The light intensity after 2nd Polaroid:

$$I_2 = I_1 \cos^2(40°) = 0.59\ I_1 = 0.30\ I_0$$

EXAMPLE 2

Plane-polarized light is incident on a single polarizing disk with the direction of **E** parallel to the direction of the transmission axis. Through what angle should the analyzer disk be rotated so that the intensity in the transmitted beam is reduced by a factor of 5?

SOLUTION

Lets assume that polarized light has the intensity I_0.

The light intensity after analyzer: $I = I_0 \cos^2(\theta)$

or

$$\cos(\theta) = \sqrt{\frac{I}{I_0}} = \sqrt{\frac{1}{5}} = 0.447 \quad \rightarrow \quad \theta = 63.4^0$$

7.5 Applications

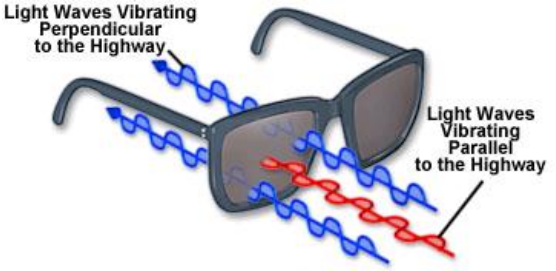
In photography, polarizing filters are used, mostly to improve the appearance of the sky (deeper blue, and clouds more visible):

The effects of a polarizing filter on the sky in a photograph. The picture on the right uses the filter

Sunglasses

The hazard of driving (or performing other daily activities) with a large amount of **glare** in one's eyes has resulted in the development of polarized sunglasses.

The lenses of such sunglasses contain polarizing filters that are oriented vertically with respect to the frames.



Polarized sunglasses eliminate the glare from the surface of a highway

3D Movies

- Polarization is also used for some 3D movies.
- Images intended for each eye are, typically, projected from a single projector with time multiplexed polarization.
- Polarized 3D glasses with suitable polarized filters ensure that each eye receives only the intended image.

Communication

- All radio transmitting and receiving antennas are intrinsically polarized.
- Most antennas radiate either horizontal, vertical, or circular polarization.
- AM and FM radio use vertical polarization, while television uses horizontal polarization.

7.6 Exercises

1. What is the difference between polarized and un-polarized wave?

2. Unpolarized light (like the light from the sun) passes through a polarizing sunglass (a linear polarizer). The intensity of the light when it emerges is
   a) zero
   b) 1/2 what it was before
   c) 1/3 what it was before
   d) 1/4 what it was before
   e) need more information

3. Horizontally polarized light passes through the sunglasses (which are vertically polarized). The intensity of the light when it emerges is
   a) zero
   b) 1/2 what it was before
   c) 1/3 what it was before
   d) 1/4 what it was before
   e) need more information

4. A polarizer for microwaves can be made as a grid of parallel metal wires about a centimeter apart. Is the electric field vector for microwaves transmitted through this polarizer (a) parallel or (b) perpendicular to the metal wires?

5. Unpolarized light passes through two polaroid sheets.
The axis of the first is vertical, and that of the second is at 15 to the vertical. What fraction of the incident light is transmitted and absorbed?

6. Plane-polarized light is incident on a single polarizing disk with the direction of **E** parallel to the direction of the transmission axis. Through what angle should the analyzer disk be rotated so that the intensity in the absorbed beam is increased by a factor of 0.3?

7.7 References

1. Serway, Beichner, **Physics for Scientists and Engineers** 6th ed, Brooks/Cole

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6. http://hyperphysics.phy-astr.gsu.edu/hbase/sound/tralon.html