Intensity and Polarization of Light (E9)

Objectives

- Analyze the light intensity versus the distance for a point source.
- Polarization by absorption.
- Malus's law.

Theory

Variation of Light Intensity with Distance.

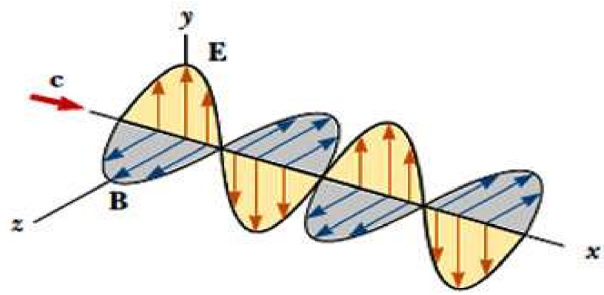
Consider a point source of light. If the light from that source propagates without disturbances, e.g., through vacuum or air, then the energy of waves is conserved as they spread from that source. Let us also center an imaginary sphere of radius r on the source. All the energy emitted from the source must pass through the sphere. Thus, the rate at which the energy is transferred through the sphere by the radiation must equal the rate at which energy is emitted by the source. The light intensity I at the sphere must then be inversely proportional to the distance.

$$I = \frac{Power}{4\pi r^2} = \frac{Power}{4\pi} * \frac{1}{r^2} = const. * \frac{1}{r^2} \quad , \tag{1}$$

where $4\pi r^2$ is the area of the sphere surrounding the point source. **The intensity of the light (or any other electromagnetic radiation) from a point source decreases with the square of the distance *r* from the source**.

Linear Polarization of Light.

Visible light is an electromagnetic wave with the wavelength in the range from 380 nm to 750 nm. An electromagnetic wave is a combination oscillating electric and magnetic fields. Both electric and magnetic fields oscillate with the same frequency and are perpendicular to each other. The electromagnetic wave is a transverse wave with both electric and magnetic fields perpendicular to the direction of wave propagation.



Electromagnetic waves are **polarized** if their electric field vectors are oscillating along a single direction, called the direction of polarization.

Electromagnetic waves coming from ordinary sources like such as light bulbs are unpolarized. The electric field at any given point is always perpendicular to the direction of travel of the waves, but changes directions randomly.

Since the human eye is insensitive to polarization, it is difficult to easily determine whether light beam is polarized or not. In 1929, E. Land patented thin polarizing filters made from long polymer molecular chains, which tend to align parallel to each other during the manufacturing process. Because of this internal molecular alignment, the optical properties of the polarizing filter (or polarizer) are highly anisotropic. In particular, a polarizer can selectively transmit light with electrical field vectors oriented parallel to the aligned molecular chains.

We can transform unpolarized light into polarized light by sending it through a polarizer. A **polarizer** transmits an electric field component parallel to the polarizing direction; a component perpendicular to it is absorbed. This process is called polarization by absorption.

Light Passing Through Crossed Polarizers

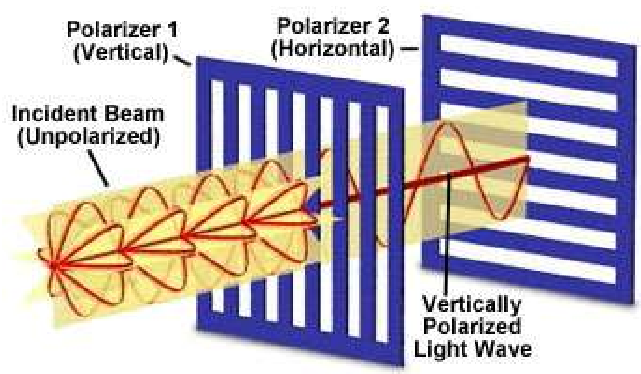


Figure 1

Two Polarizers.

If we have two polarizers, then the light reaching the second polarizer is already polarized. We can resolve the electric filed **E** into two components relative to the polarizing direction of the second polarizer: parallel component E_y is transmitted by the second polarizer, and the perpendicular component E_x is absorbed. Since θ is the angle between **E** and the polarization direction of the second polarizer or "analyzer", the transmitted component is equal to

$$E_y = E\cos\theta \,.$$

The intensity of an electromagnetic wave (such as our light wave) is proportional to the square of the electric field magnitude. Therefore,

$$I \propto E_y^2 = E^2\cos^2\theta \quad \Rightarrow \quad I = I_0\cos^2\theta \tag{2}$$

Equation (2) is known as the **law of Malus** after its discoverer.

A more general version of this equation that takes background light intensity I_B into account has the following form:

$$I = I_0\cos^2\theta + I_B \tag{3}$$

Unpolarized light (e.g., light emitted by an incandescent lamp) is a combination of many separate light rays. Each of these rays is linearly polarized, but has a random polarization direction. The light intensity that you observe is an average intensity for a randomly distributed polarization direction. If unpolarized light goes through a single polarizer, then we can use Malus's law to calculate intensity.

$$I = I_0\left(\cos^2(\theta)\right)_{average} \quad \text{, with } I_B << I_0$$

Since the average of $\left(\cos^2\theta\right)_{average}$ for $0 < \theta < 360°$ is equal to 1/2, the intensity of unpolarized light that goes through a single polarizer drops to half of the initial intensity.

$$I = \frac{1}{2}I_0 \tag{4}$$

Make sure to complete the following tasks:

You must submit the answers to the prelaboratory questions online. (3.5 points)

1. Three graphs from *Activities 1, 2 and 3.* (3 points)

   (Title and write your name and those of your partners on each graph.)

2. Your completed Data Sheets. (3.5 points)

3. Return the completed lab report to your lab TA.