Why do we want to polarize light? What is polarized light used for?

I feel like after the polarization lecture the Professor laughs and goes tell his friends, "I ran out of things to teach today so I made some stuff up and the students totally bought it."

I really wish you would explain the new right hand rule. I cant make it work in my mind

I can't wait to see what demos are going to happen in class!!! This topic looks like so much fun!!!!

With E related to B by \( E = cB \) where \( c = (\mu_0\varepsilon_0)^{-0.5} \), does the ratio between E and B change when light passes through some material m for which \( \varepsilon_m \neq \varepsilon_0 \)?

I feel like if specific examples of homework were done for us it would help more, instead of vague general explanations, which of course help with understanding the theory behind the material.

THIS IS SO COOL!

Could you explain what polarization looks like? The lines that are drawn through the polarizers symbolize what? Are they supposed to be slits in which light is let through?

Real talk? The Law of Malus is the most metal name for a scientific concept ever devised. Just say it in a deep, commanding voice, "DESPAIR AT THE LAW OF MALUS." Awesome!
So far we have considered plane waves that look like this:

\[ E_x = E_o \sin(kz - \omega t) \]

\[ B_y = B_o \sin(kz - \omega t) \]

From now on just draw \( \vec{E} \) and remember that \( B \) is still there:

\( \vec{E} \) Field determines Polarization

\[ \omega = k c \]
\[ E_o = c B_o \]
\[ c = \frac{1}{\sqrt{\mu_o \varepsilon_o}} \]
I was a bit confused by the introduction of the "e-hat" vector (as in its purpose/usefulness).

Linear Polarization

\[ E = \hat{e} E_o \sin(kz - \omega t + \phi) \]

\[ \omega = kc \]
\[ E_o = cB_o \]
\[ c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} \]

\[ E_x = E_o \cos \theta \sin(kz - \omega t + \phi) \]
\[ E_y = E_o \sin \theta \sin(kz - \omega t + \phi) \]

Wave Coming Out of the Screen
The molecular structure of a polarizer causes the component of the \( E \) field perpendicular to the Transmission Axis to be absorbed.
The molecular structure of a polarizer causes the component of the $E$ field perpendicular to the Transmission Axis to be absorbed.

Suppose we have a beam traveling in the $+z$ direction. At $t = 0$ and $z = 0$, the electric field is aligned along the positive $x$-axis and has a magnitude equal to $E_o$.

What is the component of $E_o$ along a direction in the $x - y$ plane that makes an angle of $\theta$ with respect to the $x$-axis?

A) $E_o \sin \theta$  B) $E_o \cos \theta$  C) 0  D) $E_o / \sin \theta$  E) $E_o / \cos \theta$
I can't believe your teaching us the law of "Malus" (Malice). I thought malice was to be avoided?

**Law of Malus**

\[ I_{\text{final}} = I_o \cos^2 \theta \]

Incident Polarized Light

Transmitted Polarized Light

Incident Unpolarized Light

Transmitted Polarized Light
Two Polarizers

An unpolarized EM wave is incident on two orthogonal polarizers.

What percentage of the intensity gets through both polarizers?

A. 50%  
B. 25%  
C. 0%

No light will come through.  \( \cos(90^\circ) = 0 \)
An unpolarized EM wave is incident on two orthogonal polarizers.

Is it possible to increase this percentage by inserting another Polarizer between the original two?

A. Yes  B. No
Circularly Polarized Light

There is no reason that $\phi$ has to be the same for $E_x$ and $E_y$:

$$E_x = E_o \cos \theta \sin(kz - \omega t + \phi_x)$$

$$E_y = E_o \sin \theta \sin(kz - \omega t + \phi_y)$$

Making $\phi_x$ different from $\phi_y$ causes circular or elliptical polarization:

Example:

$$\phi_x - \phi_y = 90^\circ = \frac{\pi}{2}$$

$$\theta = 45^\circ = \pi / 4$$

$$E_x = \frac{E_o}{\sqrt{2}} \cos(kz - \omega t)$$

$$E_y = \frac{E_o}{\sqrt{2}} \sin(kz - \omega t)$$

At $t = 0$

$$E_x = E_o \cos(kz)$$

$$E_y = E_o \sin(kz)$$

RCP
**Q:** How do we change the relative phase between $E_x$ and $E_y$?

**A:** Birefringence

By picking the right thickness we can change the relative phase by exactly 90°.

This changes **linear** to **circular** polarization and is called a **quarter wave plate**.
Intensity does not change!

“talk something about intensity”

*NOTE:* No Intensity is lost passing through the QWP!

**BEFORE QWP:**

\[
E = E_o \sin(kz - \omega t) \left[ \hat{i} + \frac{\hat{j}}{\sqrt{2}} \right]
\]

\[
I = c\varepsilon_0 \langle E^2 \rangle = c\varepsilon_0 \langle E_x^2 + E_y^2 \rangle
\]

\[
= c\varepsilon_0 \left( \frac{E_o^2}{2} + \frac{E_o^2}{2} \right) \langle \sin^2(kz - \omega t) \rangle = c\varepsilon_0 E_o^2 \frac{1}{2}
\]

**AFTER QWP:**

\[
E = \frac{E_o}{\sqrt{2}} \left[ \hat{i} \cos(kz - \omega t) + \frac{\hat{j}}{\sqrt{2}} \sin(kz - \omega t) \right]
\]

\[
I = c\varepsilon_0 \langle E^2 \rangle = c\varepsilon_0 \langle E_x^2 + E_y^2 \rangle
\]

\[
= c\varepsilon_0 \frac{E_o^2}{2} \langle \cos^2(kz - \omega t) + \sin^2(kz - \omega t) \rangle
\]

\[
= c\varepsilon_0 \frac{E_o^2}{2} \langle 1 \rangle = c\varepsilon_0 \frac{E_o^2}{2}
\]

**THE SAME!**
A linearly polarized EM wave is incident on a quarter-wave plate as shown above. The resulting wave is

A) Right Circularly Polarized

B) Left Circularly Polarized

C) Linearly Polarized

Curve fingers from slow to fast, thumb must be direction of propagation.
Circular Light on Linear Polarizer

Q: What happens when circularly polarized light is put through a polarizer along the \( y \) (or \( x \)) axis?

A) \( I = 0 \)
B) \( I = \frac{1}{2} I_0 \)
C) \( I = I_0 \)

\[
I = \varepsilon_0 c \left< E^2 \right>
= \varepsilon_0 c \left< E_x^2 + E_y^2 \right>
= \varepsilon_0 c \frac{E_0^2}{2} \left< \cos^2 (kz - \omega t) \right>
= \frac{1}{2} \cdot \frac{1}{2} \varepsilon_0 c E_0^2
\]

Half of before
Identical linearly polarized light at 45° from the y-axis and propagating along the z axis is incident on two different objects. In Case A the light intercepts a linear polarizer with polarization along the y-axis. In Case B, the light intercepts a quarter wave plate with fast axis along the y-axis.

Case A:
- $E_x$ is absorbed
- $I_A = 1/2 I_0$
- $I_A = I_0 \cos^2(45°)$

Case B:
- $(E_x, E_y)$ phase changed
- $I_B = I_0$

A. $I_A < I_B$
B. $I_A = I_B$
C. $I_A > I_B$
Identical linearly polarized light at 45° from the y-axis and propagating along the z axis is incident on two different objects. In Case A the light intercepts a linear polarizer with polarization along the y-axis. In Case B, the light intercepts a quarter wave plate with vast axis along the y-axis.

What is the polarization of the light wave in Case B after it passes through the quarter wave plate?

A. linearly polarized  B. left circularly polarized  C. right circularly polarized  D. undefined
Identical linearly polarized light at 45° from the y-axis and propagating along the z-axis is incident on two different objects. In Case A the light intercepts a linear polarizer with polarization along the y-axis. In Case B, the light intercepts a quarter wave plate with vast axis along the y-axis.

If the thickness of the quarter-wave plate in Case B is doubled, what is the polarization of the wave after passing through the wave plate?

A. linearly polarized  
B. circularly polarized  
C. undefined
Polarizers & QW Plates:

Birefringence

RCP

Executive Summary:
Light is incident on two linear polarizers and a quarter wave plate (QWP) as shown.

What is the intensity $I_3$ in terms of $I_1$?

**Conceptual Analysis**

- Linear Polarizers: absorbs $E$ field component perpendicular to $TA$
- Quarter Wave Plates: Shifts phase of $E$ field components in fast-slow directions

**Strategic Analysis**

Determine state of polarization and intensity reduction after each object
Multiply individual intensity reductions to get final reduction.
Light is incident on two linear polarizers and a quarter wave plate (QWP) as shown.

What is the polarization of the light after the QWP?

A) LCP  B) RCP  C)  D)  E) un-polarized

Light incident on QWP is linearly polarized at 45° to fast axis

LCP or RCP? Easiest way: Curl fingers of RH back to front
Right Hand Rule: Thumb points in dir of propagation if right hand polarized.

Light will be circularly polarized after QWP

RCP
No absorption: Just a phase change!

What is the intensity $I_2$ of the light after the QWP?

A) $I_2 = I_1$

B) $I_2 = \frac{1}{2} I_1$

C) $I_2 = \frac{1}{4} I_1$

Before:

$E_x = \frac{E_1}{\sqrt{2}} \sin(kz - \omega t)$

$E_y = \frac{E_1}{\sqrt{2}} \sin(kz - \omega t)$

No absorption: Just a phase change!

$I = \varepsilon_0 c \left[ \langle E_x^2 \rangle + \langle E_y^2 \rangle \right]$

Same before & after!

After:

$E_x = \frac{E_1}{\sqrt{2}} \cos(kz - \omega t)$

$E_y = \frac{E_1}{\sqrt{2}} \cos(kz - \omega t)$
Absorption: only passes components of $E$ parallel to $TA$ ($\theta = 60^\circ$).

$E_3 = E_x \sin \theta + E_y \cos \theta$

$E_3 = \frac{E_1}{\sqrt{2}} (\sin(kz - \omega t + \theta))$

$E_3 = \frac{E_1}{\sqrt{2}} (\cos(kz - \omega t) \sin \theta + \sin(kz - \omega t) \cos \theta)$

What is the polarization of the light after the $60^\circ$ polarizer?

A) LCP  
B) RCP  
C)  
D)  
E) un-polarized

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What is the intensity $I_3$ of the light after the $60^\circ$ polarizer?

A) $I_3 = I_1$  
B) $I_3 = \frac{1}{2} I_1$  
C) $I_3 = \frac{1}{4} I_1$

$E_3 = \frac{E_1}{\sqrt{2}}$

$I \propto E^2$

$I_3 = \frac{1}{2} I_1$

NOTE: This does not depend on $\theta$!
Follow-Up 1

Replace the 60° polarizer with another QWP as shown.

What is the polarization of the light after the last QWP?

A) LCP  B) RCP  C)  D)  E) un-polarized

Easiest way:

$E_{fast}$ is $\lambda / 4$ ahead of $E_{slow}$

Brings $E_x$ and $E_y$ back in phase!
Replace the 60° polarizer with another QWP as shown.

What is the intensity $I_3$ of the light after the last QWP?

A) $I_1$

B) $\frac{1}{2} I_1$

C) $\frac{1}{4} I_1$

Before:

No absorption: Just a phase change!

$E_x = \frac{E_1}{\sqrt{2}} \cos(kz - \omega t)$

$E_y = \frac{E_1}{\sqrt{2}} \sin(kz - \omega t)$

$I_{\text{before}} = \frac{E_1^2}{2}$

Intensity = $< E^2 >$

After:

$E_x = \frac{E_1}{\sqrt{2}} \cos(kz - \omega t)$

$E_y = \frac{E_1}{\sqrt{2}} \cos(kz - \omega t)$

$I_{\text{after}} = \frac{E_1^2}{2}$
Consider light incident on two linear polarizers as shown. Suppose $I_2 = 1/8 I_0$.

What is the possible polarization of the input light?

A) LCP
B) C)
C) un-polarized
D) all of above
E) none of above

After first polarizer: LP along $y$–axis with intensity $I_1$

After second polarizer: LP at $60^\circ$ wrt $y$–axis

Intensity: $I_2 = I_1 \cos^2(60^\circ) = \frac{1}{4} I_1$

$I_2 = 1/8 I_0 \Rightarrow I_1 = \frac{1}{2} I_0$

Question is: What kind of light loses $\frac{1}{2}$ of its intensity after passing through vertical polarizer?

Answer: Everything except LP at $\theta$ other than $45^\circ$