Unpolarized Light Passes Through Two Polarizers Whose Transmission Axes Are At An Angle Of 35.0 With

Unpolarized Light Passes Through Two Polarizers Whose Transmission Axes Are At An Angle Of 35.0° With

Understanding how polarized light interacts with polarizing filters is fundamental in optics, with numerous applications ranging from photography to scientific instrumentation. When unpolarized light encounters polarizers, its intensity and polarization state change depending on the relative orientation of the polarizers' transmission axes. In this article, we explore the behavior of unpolarized light passing through two polarizers whose transmission axes are at an angle of 35.0° to each other, focusing on the principles involved, calculations of transmitted intensity, and practical implications.

Introduction to Polarized and Unpolarized Light

What is Unpolarized Light?

Unpolarized light consists of electromagnetic waves vibrating in multiple planes perpendicular to the direction of propagation. Common sources such as the sun or incandescent bulbs emit unpolarized light.

What is Polarized Light?

Polarized light has its electric field oscillating in a single plane. Polarization can be achieved through various methods, including passing unpolarized light through a polarizer, which aligns the electric field vectors in a specific direction.

Polarizers and Their Transmission Axes

Understanding Polarizer Orientation

A polarizer's transmission axis is a reference line along which the electric field component of the incoming light is transmitted. The orientation of this axis determines how much of the incident light's electric field is allowed through.

Effect of Polarizer Orientation on Light Intensity

- When light passes through a polarizer, the transmitted intensity depends on the angle between the light’s polarization direction and the polarizer’s transmission axis.
- For unpolarized light passing through a polarizer, the transmitted intensity is reduced by half, since half of the components are aligned with the polarizer.

Behavior of Unpolarized Light Passing Through Two Polarizers

Initial Transmission Through the First Polarizer

When unpolarized light encounters the first polarizer:
- The intensity of transmitted light is reduced to half of the incident intensity.
- The transmitted light becomes linearly polarized along the transmission axis of the first polarizer.

Subsequent Transmission Through the Second Polarizer

The second polarizer, with its transmission axis at an angle θ (here, 35.0°) relative to the first, affects the transmitted light as follows:
- The intensity of the light after passing through the second polarizer depends on the angle θ between the polarization direction of the light and the second polarizer’s axis.
- The polarization state of the light after the first polarizer is aligned with the first polarizer’s transmission axis.

Calculating the Transmission of Light Through the Two Polarizers

Step 1: Intensity After the First Polarizer

For unpolarized light with an incident intensity I_0:
- The intensity transmitted through the first polarizer is:

$$
I_1 = \frac{1}{2} I_0
$$

- The transmitted light is now linearly polarized along the first polarizer’s transmission axis.

Step 2: Intensity After the Second Polarizer

Using Malus’ Law, which states that the transmitted intensity I through a polarizer is related to the incident intensity $I_{incident}$ and the angle θ between the incident polarization and the polarizer’s axis:

$$
I = I_{incident} \cos^2 \theta
$$

- Since the light after the first polarizer is polarized along its axis, the intensity after passing through the second polarizer is:

$$
I_{2} = I_1 \cos^2 \theta
$$

- For $\theta = 35.0^\circ$:

$$
I_{2} = \frac{1}{2} I_0 \times \cos^2 35.0^\circ
$$

Numerical Calculation

Using $\cos 35.0^\circ \approx 0.8192$:

$$
I_{2} = \frac{1}{2} I_0 \times (0.8192)^2 = \frac{1}{2} I_0 \times 0.671
$$

$$
I_{2} \approx 0.3355 I_0
$$

This means that approximately 33.55% of the initial unpolarized light’s intensity passes through both polarizers when their axes are at a 35.0° angle.

Implications and Applications

Optical Devices and Polarization Control

Understanding how the orientation of polarizers affects transmitted light is crucial in designing optical devices such as:
- Polarization filters for photography to reduce reflections and glare.
- Liquid crystal displays (LCDs) that rely on polarized light manipulation.
- Optical communication systems where polarization states encode information.

Scientific and Experimental Uses

Experiments involving polarizers help in:
- Measuring the degree of polarization of light sources.
- Studying birefringence in materials.
- Investigating the polarization dependence of various optical phenomena.

Extended Considerations

Varying the Angle Between the Polarizers

- At 0°, the polarizers are aligned, allowing maximum transmission.
- At 90°, no light passes through if the initial light is polarized after the first polarizer.
- The transmitted intensity varies as \(\cos^2 \theta \), which is a hallmark of Malus' Law.

Impact of Multiple Polarizers

- Adding more polarizers at different angles can further control the polarization state and intensity.
- This principle is used in complex optical systems to achieve desired polarization effects.

Limitations and Practical Considerations

- Real polarizers are not perfect; they have finite extinction ratios.
- Scattering, absorption, and imperfections can reduce the transmitted intensity beyond ideal calculations.
- Temperature and material properties can influence the performance of polarizers.

Summary

Passing unpolarized light through two polarizers with their transmission axes at an angle of 35.0° results in a transmitted intensity roughly 33.55% of the original. This outcome is derived from the initial polarization after the first polarizer and the application of Malus' Law for the second polarizer's effect. Mastery of these principles enables precise control of light in various technological and scientific applications, from improving image quality to exploring fundamental optical phenomena.

Final Thoughts

Understanding the interplay between unpolarized light and polarizers enhances our ability to manipulate light for diverse purposes. The simple yet profound relationship described by Malus' Law offers deep insights into the nature of light polarization and continues to be a cornerstone in the field of optics. Whether designing advanced optical instruments or exploring the fundamental properties of light, the principles outlined here serve as essential tools for scientists and engineers alike.

Frequently Asked Questions

What happens to unpolarized light when it passes through two polarizers with axes at a 35.0° angle?

The intensity of the transmitted light is reduced according to Malus's Law, resulting in a transmitted intensity of $I = I_0 \times (1/2) \times \cos^2(35.0°)$.

How is the transmitted intensity calculated for unpolarized light passing through two polarizers at a 35.0° angle?

The transmitted intensity is given by $I = I_0 \times (1/2) \times \cos^2(35.0°)$, where I_0 is the initial light intensity.

What is the significance of the 35.0° angle between the polarizer axes?

The 35.0° angle determines how much the light's polarization is rotated, affecting the amount of light transmitted according to Malus's Law.

Can unpolarized light completely pass through two polarizers at an angle less than 90°?

Yes, unpolarized light always passes through the first polarizer, and the transmitted intensity depends on the angle between the polarizers; it can be partially or fully transmitted depending on the angle.

What is the transmitted intensity if the initial unpolarized light has an intensity I_0 after passing through the first polarizer?

The intensity after the first polarizer is $I_1 = I_0 / 2$; then, after the second polarizer at 35.0°, the transmitted intensity is $I = I_1 \times \cos^2(35.0°) = (I_0 / 2) \times \cos^2(35.0°)$.

How does the angle between polarizers affect the brightness of the transmitted light?

The brightness is proportional to $\cos^2(\theta)$, so increasing the angle reduces transmitted light, with maximum transmission at 0° and minimum at 90°.

What is the role of Malus's Law in analyzing light passing through two polarizers?

Malus's Law states that the transmitted intensity is proportional to $\cos^2(\theta)$, which helps predict the amount of light transmitted based on the angle between polarizer axes.

If the transmission axes are at 35.0°, what fraction of the initial unpolarized light intensity is transmitted after both polarizers?

The fraction transmitted is $(1/2) \times \cos^2(35.0°)$, approximately $0.25 \times \cos^2(35.0°)$.

Why does unpolarized light lose some intensity when passing through the first polarizer?

Because the first polarizer only transmits the component of light aligned with its axis, reducing the initial unpolarized light to half its original intensity.

Additional Resources

Polarization Phenomenon

Introduction

Understanding how light interacts with polarizing materials is fundamental in optics, with applications ranging from photography and sunglasses to scientific instrumentation. One classic yet profound experiment involves passing unpolarized light through two polarizers whose transmission axes are set at a specific angle—in this case, 35.0°. This scenario not only elucidates the principles of polarization but also offers insights into the behavior of light as it undergoes multiple transformations.

In this article, we explore the detailed physics behind this process, analyze the intensity variations, and discuss the practical implications of such an arrangement, all presented with the clarity of an expert review.

Foundations of Light Polarization

What Is Unpolarized Light?

Unpolarized light consists of electromagnetic waves oscillating in multiple planes perpendicular to the direction of propagation. Sunlight, incandescent bulbs, and many artificial sources emit such light, characterized by a random distribution of polarization directions.

Polarizers and Their Transmission Axes

A polarizer is an optical filter that selectively transmits light oscillating in a specific plane—the transmission axis. When unpolarized light passes through a polarizer:

- The transmitted light becomes linearly polarized along the polarizer's axis.
- The intensity is reduced to roughly half of the incident light, assuming ideal polarizers.

Mathematically, the transmitted intensity I after passing through a polarizer is governed by the initial intensity and the polarization state.

The Physics of Light Passing Through Two Polarizers

Initial Encounter: Unpolarized Light and the First Polarizer

Imagine a beam of unpolarized light incident on the first polarizer:

- Initial Intensity: I_0 (say, normalized to 1 for simplicity).
- Transmission: Since the light is unpolarized, the polarizer transmits half of the incident intensity:

$$
I_1 = \frac{1}{2} I_0
$$

- Resulting Polarization: The transmitted light is now linearly polarized along the polarizer's transmission axis.

Second Encounter: Polarized Light and the Second Polarizer at 35°

The second polarizer (analyzer) is oriented at an angle $\theta = 35.0^\circ$ relative to the first:

- Incident Intensity on the second polarizer:

$$
I_1 = \frac{1}{2} I_0
$$

- Transmission through the second polarizer:

The intensity after passing through depends on the angle between the incoming polarization and the polarizer's axis, according to Malus's Law:

$$
I_2 = I_1 \cos^2 \theta
$$

Substituting I_1:

$$
I_2 = \frac{1}{2} I_0 \cos^2 35^\circ
$$

This formula encapsulates the core physics: the transmitted intensity diminishes based on the relative orientation of the polarization axes.

Quantitative Analysis of the Transmitted Intensity

Calculating the Final Intensity

Given I_0 (say, normalized to 1 for simplicity):

$$
I_2 = \frac{1}{2} \times 1 \times \cos^2 35^\circ
$$

Using the cosine value:

$$
\cos 35^\circ \approx 0.8192
$$

Thus,

$$
I_2 \approx 0.5 \times (0.8192)^2 \approx 0.5 \times 0.671 \approx 0.336
$$

Result: Approximately 33.6% of the initial unpolarized light's intensity passes through both polarizers at a 35° angle.

Summary of Key Results

Step	Description	Formula	Result (assuming $I_0 = 1$)
1	Light passes through first polarizer	$I_1 = \frac{1}{2} I_0$	0.5
2	Light passes through second polarizer at $\theta = 35^\circ$	$I_2 = I_1 \cos^2 \theta$	0.336

Generalized Expression

For any angle θ between the two polarizers, the transmitted intensity is:

$$
I_{transmitted} = \frac{1}{2} I_0 \cos^2 \theta
$$

This fundamental relation is invaluable in designing optical systems, understanding light behavior, and analyzing experimental results.

Visualizing the Polarization Behavior

Polar Plot Representation

Visual tools like polar plots can illustrate how the electric field vector of the polarized light aligns with the transmission axes:

- Unpolarized light: Random electric field directions.
- First polarizer: Filters out all but the component aligned with its axis.
- Second polarizer: Transmits the component aligned at θ, explaining the $\cos^2 \theta$ dependence.

Experimental Setup

A typical setup involves:

- A broadband or monochromatic light source emitting unpolarized light.
- A polarizer fixed along a reference axis.
- An adjustable second polarizer (analyzer) set at various angles.
- A photodetector to measure transmitted intensity.

This arrangement visually demonstrates the theoretical predictions and confirms the $\cos^2 \theta$ law.

Practical Implications and Applications

Polarization in Photography and Optics

Understanding the passing of unpolarized light through polarizers at specific angles informs:

- Polarizing filters: Used to reduce reflections and glare.
- Liquid crystal displays (LCDs): Rely on polarization control.
- Optical instrumentation: Polarization filters improve contrast and measurement accuracy.

Polarization Filters in Scientific Instruments

In spectrometers and other devices, precise control of polarization states enhances data fidelity. The behavior of unpolarized light passing through multiple polarizers at different angles is crucial to calibration and measurement.

Safety and Design Considerations

Designers of optical devices must account for intensity losses due to polarization filtering. The formula $I = \frac{1}{2} I_0 \cos^2 \theta$ guides the expected transmitted light and system efficiency.

Advanced Considerations

Non-Ideal Polarizers

Real-world polarizers are not perfect:

- Extinction ratio: The ratio of transmitted to blocked light for the undesired polarization.
- Transmission losses: Slight deviations from ideal 50% transmission for unpolarized light.

Wavelength Dependence

Polarizer effectiveness varies with wavelength, affecting applications across the electromagnetic spectrum.

Multiple Polarizer Configurations

Stacking multiple polarizers at various angles creates complex polarization states, enabling sophisticated control in optical systems.

Conclusion

Passing unpolarized light through two polarizers separated by an angle of 35.0° exemplifies fundamental polarization physics. The process results in a transmitted intensity approximately 33.6% of the initial, governed by the simple yet profound law:

$$
I_{transmitted} = \frac{1}{2} I_0 \cos^2 \theta
$$

This experiment underscores how the orientation of polarizers dramatically influences light transmission, offering both educational insight and practical utility. Whether in scientific research, photography, or optical engineering, understanding this behavior enhances our ability to manipulate and utilize polarized light effectively.

References

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Note: The calculations assume ideal polarizers and monochromatic light for simplicity. Real-world scenarios may involve additional complexities such as depolarization, wavelength dependence, and non-ideal transmission.

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