Physics 228

Exam this Sunday 2/26, 6:10 - 7:30 pm, Chapters 33-36

Today:
Polarization in Reflection
Birefringence

Intro to Special Relativity:
Reference Frames
Clicker Question

Three polarizing filters are stacked with the polarizing axes of the second and third filters oriented at 45° and 90°, respectively, relative to the polarizing axis of the first filter. **Unpolarized** light of intensity $I_0$ is incident on the first filter. The intensity of light emerging from the third filter is

A) 0  
B) $I_0 / \sqrt{2}$  
C) $I_0 / 2$  
D) $I_0 / 4$  
E) $I_0 / 8$
Clicker Question

The middle polarizing filter is then removed. What is now the intensity of the resulting light?

A) $0$
B) $I_o / \sqrt{2}$
C) $I_o / 2$
D) $I_o / 4$
E) $I_o / 8$
Polarization in Reflection

• When light impinges on a surface, it generally partially refracts and partially reflects.
• The “plane of incidence” is the plane that contains the incident and reflected light rays.
• The electric field can be split into components: “p-polarization” in the plane of incidence, and “s-polarization” perpendicular to the plane of incidence.
• The efficiency of reflection is not the same for the two polarization components, so the reflected and transmitted beams are partially polarized.
Brewster’s Angle

- The reflectivity for p-polarized light is exactly zero at a certain angle of incidence.
- This angle is called Brewster’s angle.
- At Brewster’s angle, the reflected and refracted rays are perpendicular.
- This behavior is described by the Fresnel equations mentioned before (derived from Maxwell’s equations).
- For light incident from medium \( a \) into medium \( b \), Brewster’s angle \( \theta_p \) satisfies

\[
\tan(\theta_p) = \frac{n_b}{n_a}
\]
Brewster’s Angle Applications

• So-called “Brewster windows” are used inside lasers and other optical instruments where reflections must be completely eliminated.

• Sunlight reflected from horizontal surfaces has a large horizontal polarization, the glare of which can be largely eliminated with vertical polarizing sunglasses.
Brewster’s Angle iClicker

The other day, when I was spying on my neighbors, I was able to eliminate all glare by using a polarizer. Was my polarizer

a. Horizontal  
b. Vertical  
c. Right-circular  
d. Left-circular  
e. Elliptical?

without polarizer: glare from sky obscures inside  
with polarizer: no glare, window glass invisible

Unfortunately, nothing interesting can be seen here. 😞  
(The other pictures I can’t show.)
Scattering of Light by Clouds

- Clouds consist of microscopic water droplets that scatter light.
- Thin clouds are white because they scatter all wavelengths equally.
- The bottom of thick clouds appears gray because much of the light is absorbed.
- The scattered light is unpolarized.
Scattering of Light by Air

- The sky is blue because the scattering of light by air molecules is proportional to $1/\lambda^4$.
- Blue (450 nm) scatters more than red (750 nm) by a factor of $(750/450)^4 \approx 8$.
- The blue light from the sky is polarized in a direction perpendicular to the line toward the sun.
Birefringence

Calcite is a crystal for which the index of refraction depends on the polarization of the light (birefringence).

The light is refracted into two images, each polarized differently.

Application: Make efficient polarizers!
Unpolarized light is incident on two ideal polarizers that are crossed at an angle of 60 degrees. Recall that \( \cos(60 \text{ deg}) = 1/2 \).

What fraction of incident light is transmitted through both polarizers?

a) 1/2.
b) 1/4.
c) 1/8.
d) 1/16.
e) It depends on whether the incident light is linearly or circularly unpolarized.
Theory of Relativity

- **Special Relativity:** A. Einstein, 1905
  - Concerns relative motion between observers (kinematics, as well as electromagnetism).

- **General Relativity:** A. Einstein, 1916
  - This is a geometric theory of gravitation.
  - A graduate-level physics course of its own (not covered here).
Frames of Reference - Coordinate Systems

We can have several observers using different coordinate systems observing the same physics happening.

The frames can move relative to one another. If the movement is at a low, constant speed, the transformation from one to another is pretty simple.

Velocities add. If an object moves at velocity \( v \) in frame 1, and frame 2 moves at velocity \( u \) in frame 1, then the object moves at velocity \( v - u \) in frame 2.