Physics 228

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

Today:
Diffraction from Circular Apertures
Polarization of Light
Single Slit: Width of Central Peak

(a) $a = \lambda$

If the slit width is equal to or narrower than the wavelength, only one broad maximum forms.

(b) $a = 5\lambda$

The wider the slit (or the shorter the wavelength), the narrower and sharper is the central peak.

(c) $a = 8\lambda$

Width of central peak $\approx$ angle of first minimum

$\theta \approx \sin \theta = \frac{\lambda}{a}$
Circular apertures occur in telescopes, microscopes, your eyes, your phone camera, etc.

The light intensity as a function of angle is similar (but not identical) to the single slit.

The angle of the first dark ring is given by $\sin \theta = 1.22 \frac{\lambda}{D}$, where $D$ is the diameter of the aperture.

Generally objects this far apart are considered to be “resolved” in the image.
Your eyes have an aperture of about 3 mm and the wavelength of light is about 500 nm. At 1 m distance, how far apart do two small objects have to be so you can resolve them (assuming perfect vision)?

a) 0.02 mm

\[ \theta \approx \frac{1.22 \lambda}{D} \approx \frac{1.2 \times 500 \text{ nm}}{3 \text{ mm}} = 2 \times 10^{-4} \]

b) 0.2 mm

c) 2 mm

d) 2 cm

\[ y = 1 \text{ m} \times 2 \times 10^{-4} = 0.2 \text{ mm} \]

e) 20 cm
I want to use a perfect lens (no aberrations) to image two stars that are very close together. In order to maximize my chances to resolve the stars, should I:

a) Use the longest focal length lens available

b) Use the shortest focal length available

c) Use the largest diameter lens available

d) Use the smallest diameter lens available

e) If the lens is perfect, neither focal length nor diameter matter.
Clicker Question

You use a telescope lens to form an image of two closely-spaced, distant stars. Which of the following will increase the resolving power?

A) Use a filter so that only the blue light from the stars enters the lens.

B) Use a filter so that only the red light from the stars enters the lens.

C) Use a lens of smaller diameter.

D) more than one of the above
Polarization refers to the orientation of the electric (and magnetic) fields of a light wave. For example,

\[ \vec{E}(z, t) = E_0 \cos(kz - \omega t)\hat{x} \]
\[ \vec{B}(z, t) = B_0 \cos(kz - \omega t)\hat{y} \]

But the orientation of the fields could be different:

\[ \vec{E}(z, t) = E_0 \cos(kz - \omega t)\hat{y} \]
\[ \vec{B}(z, t) = -B_0 \cos(kz - \omega t)\hat{x} \]

Or:

\[ \vec{E}(z, t) = E_0 \cos(kz - \omega t)\frac{(\hat{x} + \hat{y})}{\sqrt{2}} \]
\[ \vec{B}(z, t) = B_0 \cos(kz - \omega t)\frac{(\hat{y} - \hat{x})}{\sqrt{2}} \]

\textbf{E} and \textbf{B} are perpendicular, and perpendicular to the propagation direction (subject to right-hand rule).
"Right handed circular polarization": As the light heads towards us, we see the fields rotating clockwise.

"Left-handed circular polarization": As the light heads towards us, we see the fields rotating counterclockwise.

Any direction of linearly polarized light can be represented as a sum of RH + LH circularly polarized light, and vice versa.
More Polarization States

Elliptically polarized light may be “right-handed” (shown) or “left-handed”.

Unpolarized light: Polarization direction fluctuates randomly on a very fast timescale.
Polarization of Waves on a String

With a rope, you can make a wave traveling to the right with the displacement in the vertical or in the horizontal direction.

(a) Transverse wave linearly polarized in the y-direction

(b) Transverse wave linearly polarized in the z-direction

By swinging the end of rope around in a circle we generate a circularly polarized wave, which can be linearly polarized by a vertical slit.

The slit acts as a “linear polarizer.”
Polarizing Visible Light

- Polaroid filter absorbs light of one linear polarization, transmits the other.

- This polarizer is based on long, thin molecules that are aligned in the material.

- Polarizers based on other principles also exist, i.e., total internal reflection or polarizing properties of crystals.
An ideal polarizer transmits 50% of incident unpolarized light.
Polarizer and Analyzer

Crossed polarizers block all light!

Malus's Law:

\[ I = I_M \cos^2 \theta \]
Crossed Polarizers

Two Polarizer Demo
I have 3 polarizers in a row, with the 1st in the x direction, the 2nd rotated 45°, and the 3rd in the y direction. What fraction of the light that makes it through the 1st polarizer also makes it through the 3rd polarizer?

a) 0 = cos(\phi_1-\phi_3) = cos(90).

b) 1/4 = \cos^2(45) \times \cos^2(45).

c) 1/2 = \cos(45) \times \cos(45).

d) It depends on whether the light is in the +x or -x direction initially.

e) It depends on whether the light is linearly polarized or circularly polarized.