Resolution

Resolution is the property of an optical system that determines the conditions under which two objects close together can be distinguished as two separate objects.

Imaging

When a far enough point light source passes through an aperture, the source light will be coherent and it will diffract and the image of the light source will have a minimum size. Two point light sources next to each other will have their diffraction pattern overlap.

If the patterns overlap too much, you will not be able to distinguish between single pattern and two overlapping patterns. In this case, you are not able to resolve the two sources. The resolution is a measure of whether two point light sources can be resolved given a certain instrument aperture and source light wavelength.

The resolution can be increased by narrowing the aperture.

Note the overlap decreases quickly. However, the amount of light decreases quickly as well. Moreover, the amount of diffraction increases.

The issue here is that we want a smaller aperture for sharpness, but we want a larger aperture for light and to reduce diffraction. There is a balance between the two effects.
Angular Resolution

The result is a property called resolution that tells us the how close two points can be before an optical instrument can no longer produce an image that show them as two distinct objects. The **angular resolution** is the minimum angle at which two objects can be resolved as being two separate objects and not one larger object.

When the separation of the images is too small, you can not resolve two objects. When the separation of the image is large enough, you can resolve the two objects. Here are three examples of unresolved and resolved images.
Rayleigh's Criterion

The condition that separates resolved and unresolved images is called **Rayleigh's criterion**. It requires that the central maximum of one image to be at least at the first minimum of the other image.

For the single slit, the first minimum of the interference pattern is located here. With the small angle approximation, it is this. This is when the two sources are just resolved.

\[ w \sin \theta_{\text{min}} = (1) \lambda \quad \Rightarrow \quad \sin \theta_{\text{min}} \cong \theta_{\text{min}} = \frac{\lambda}{w} \]

The angle is the angle between the two objects at the aperture.

More precisely, Rayleigh's criterion is this.

\[ \theta_{\text{min}} = 1.22 \frac{\lambda}{w} \]

The reason for the 1.22 is because of the single slit diffraction pattern is wider in the middle than the normal cosine function.
Polarization

The direction of the electric field in light, or electromagnetic radiation, is referred to as the direction of polarization. It is represented by the electric field vector direction. Below represents polarized light in the horizontal direction.

Most normal light sources are unpolarized. There is no preferential direction for the electric field. The right contains electric field in all direction and the light itself is unpolarized.

A light source containing only one polarization direction is called linearly polarized light. There are many ways to produce linearly polarized light. Here are several easy to find sources. Light reflecting off of surfaces (or glare) tends to be polarized. Light passing through polarizers such as sunglasses is polarized. Scattered light from positions 90° from the sun is polarized. Finally LED displays produce polarized light.

Polarization from Transmission

Light passing through a linear polarizer becomes linearly polarized. A linear polarizer absorbs all of the light whose electric field component is not parallel to the direction it allows through. The simplest type of polarizer is a metal wire polarizer. It is just a set of metal wires aligned in a single direction with small gaps. This works well for infrared light. Electric fields along the wire are absorbed. The wires can be substituted with liquid crystals. This works well for visible light.

When unpolarized light strikes the wires, the electric fields of the light will try to oscillate the electrons in the wires so the wires absorb it. A vertical oscillating electric field will shake the electrons up and down since the electrons are allowed to travel up and down. However, a horizontal oscillating electric field will not be able to shake the electrons much at all since the electrons are confined by the width of the wires. Therefore, the above oriented polarizer will transmit light that is horizontally polarized. It is, in fact, a horizontal polarizer.
Polarizing Unpolarized Light

When linearly polarized light passes through a linear polarizer, the polarization direction of the light is rotated to the polarizer’s polarization direction. The intensity of the light decreases according to Malus’ law.

\[ I = I_o \cos^2(\theta) \]

The angle is the angle between the source light polarization direction and the polarizer polarization direction. The source intensity is \( I_o \).

When unpolarized light passes through a linear polarizer, the light will become linearly polarized.

The intensity of the light that is transmitted through the polarizer is half of the source intensity.

\[ I = \frac{1}{2} I_o \]
Rotating Polarization

Some materials rotate the polarization of the light based on the frequency of the light. The most common of these are plastics made of long chains of polymers. Here is how it works.

Here, an LED display shines white polarized light through a plastic CD case. The light from the display is polarized. The light that went through the plastic has its polarization rotated. You don’t see any effect because you can not detect polarization.

A linear polarizer is used to detect the polarization of the light. Since the background is now dark, we can infer that the polarizations of the display is perpendicular to that of the sunglasses. The sunglasses is used to see the polarization and it's function is called the analyzer.

Seeing light through the analyzer means that the polarization of has been rotated by the plastic
Polarization from Reflection

Light reflecting off of a surface is, in general, partially polarized. Here, we can tell that the reflected light is polarized by passing it through an analyzer.

Your can think of unpolarized light as having components parallel to the surface and perpendicular to the surface. The parallel component is the one that can reflect much better than the perpendicular component. The perpendicular component does not reflect strongly at the surface and is mostly transmitted through the surface. Here, most of the reflected light that is polarized parallel to the surface is reflected.

Sunglasses filter out the parallel component of the replete light but the small perpendicular component remain. There is an indecent angle at which all of the perpendicular component is transmitted through the surface. This is called Brewster’s angle.

As measured from the normal,
\[ \theta_{\text{Brewster}} + \theta_{\text{refracted}} = 90^\circ \]

Snell’s law says this.
\[ n_i \sin \theta_i = n_r \sin \theta_r \]

When the incident angle is Brewster’s angle,
\[ n_i \sin \theta_B = n_r \sin(90^\circ - \theta_i) = n_r \cos \theta_B \quad \Rightarrow \quad \tan \theta_B = \frac{n_r}{n_i} \]

The tangent of Brewster’s angle is the ratio of the indexes of refractions.