Coherent beams can be created by splitting the amplitudes of a single wave into different components. Accounting for different path lengths and phaseshifts, the interference patterns can be determined.

The most common set-up (Michelson-Interferometer) uses two mirrors and a beamsplitter. Because of its sensitivity, it is a very precise measuring device.

In many cases, we need to account for interference of a large number of beams. The resulting intensity is described by reflection/absorption coefficients.
Why are coves round?
Why are coves round?
Huygens-Fresnel principle I
Huygens-Fresnel principle II
Huygens-Fresnel principle III
Two types of diffraction
Far-field regime
Coherent oscillators
Phased arrays
Summary Lecture 18

• Shadow features that go beyond ray optics are called **diffraction**. While not physically distinct from interference, both are used in distinct situations.

• The **Huygens-Fresnel principle** provides an intuitive way to study diffraction: secondary wavelets of different amplitudes and phases **interfere** beyond obstacle.

• We distinguish **Fresnel (near-field)** and **Fraunhofer (far-field) diffraction**. To understand the resultant pattern consider behaviour of **coherent oscillators**.
Admin

- Groups for **Demo#3** are now on myCourses.

- Schedule a **time slot** with Dr. Lepo between **Monday, Mar 25** and **Friday, Apr 5**.

- Complete the report within **one week**, so that all the Homework Assignments are completed by the end of the term (**Friday, Apr 12**).
Summary Lecture 18

- Shadow features that go beyond ray optics are called **diffraction**. While not physically distinct from interference, both are used in distinct situations.

- The **Huygens-Fresnel principle** provides an intuitive way to study diffraction: secondary wavelets of different amplitudes and phases interfere beyond obstacle.

- We distinguish **Fresnel (near-field)** and **Fraunhofer (far-field) diffraction**. To understand the resultant pattern consider behaviour of coherent oscillators.
Coherent oscillators
Rectangular aperture I
Single-slit diffraction pattern
Wavelet picture
Wavelet picture
Phasors I

(a) 

(b) 

Point-1

\[ \begin{align*} 
\delta_1 &= 0 \\
\beta &= 0 \\
N &= 9 
\end{align*} \]
Phasors I

(a) \[ E_0(0) \]

\[ E_0(\theta_2) \]

\[ E_0(\theta_3) \]

\[ \beta = 0 \]

\[ \beta = \pi \]

\[ \beta = 2\pi \]

\[ \beta = \frac{\pi}{2} \]

\[ \beta = \frac{3\pi}{2} \]

(b) \[ E_0(0) \]

\[ \delta_1 = 0 \]

\[ \beta = 0 \]

\[ N = 9 \]

(c) \[ E_0(\theta_2) \]

\[ \delta_1 = \pi \]

\[ \beta = \frac{\pi}{2} \]

\[ N = 7 \]
Phasors I

(a) $E_0(0)$

(b) $E_0(0)$

Point-1

$\delta_1 = 0$
$\beta = 0$
$N = 9$

(c) $E_0(\theta_2)$

Point-2

$\delta_1 = \pi$
$\beta = \pi/2$
$N = 7$

(d) $E_0(\theta_2)$

Point-2

$\delta_1 = \pi$
$\beta = \pi/2$
$N$ very large

$\beta = 0$
$\beta = \pi$
$\beta = 2\pi$

$\beta = \frac{\pi}{2}$
$\beta = \frac{3\pi}{2}$
Phasors II

Point-3
\( E_0(\theta_3) = 0 \)
\( \delta_1 = 2\pi \)
\( \beta = \pi \)
\( N \) very large

Point-4
\( \delta_1 = 3\pi \)
\( \beta = \frac{3\pi}{2} \)
\( N \) very large

Point-5
\( \delta_1 = 4\pi \)
\( \beta = 2\pi \)
\( N \) very large
Double slit
Double-slit diffraction pattern

$\sin \theta$

$\frac{\lambda}{b}$ $\frac{\lambda}{a}$ $0$ $\frac{\lambda}{a}$ $\frac{\lambda}{b}$

$4I_0$

"Half-fringe"

Missing order

$a = 3b$
Single vs. double slit
Multi-slit diffraction pattern
In the far-field (Fraunhofer) regime, the emission of a line source can be represented by a point source.

The characteristic single-slit diffraction pattern is controlled by a function proportional to \( \text{sinc}^2 \), which can be understood in terms of wavelets or phasors.

For multi-slit configurations, we obtain a diffraction pattern that is given as an interference term, modulated by the single-slit diffraction pattern.

The concept is important for grating spectroscopy.
PHYS 434 Optics

Lecture 20: Fresnel Diffraction

Reading: 10.2.4, 10.3
In the far-field (Fraunhofer) regime, the emission of a line source can be represented by a point source.

The characteristic single-slit diffraction pattern is controlled by a function proportional to $\text{sinc}^2$, which can be understood in terms of wavelets or phasors.

For multi-slit configurations, we obtain a diffraction pattern that is given as an interference term, modulated by the single-slit diffraction pattern.

The concept is important for grating spectroscopy.
Arbitrary aperture
Rectangular aperture I
Square aperture
Obliquity factor
Rectangular aperture II
Fresnel integrals

\[ C(w) \quad S(w) \]

\[ w \]

Fresnel integrals
Cornu spiral I
Cornu spiral II
Cornu spiral III

\[ u_2 - u_1 \text{ is fixed} \]

\[ u_1 = -0.5, u_2 = 0.5 \]

\[ u_1 = 0, u_2 = 1 \]

\[ u_1 = 1.5, u_2 = 2.5 \]
Slit
Circular aperture
Fresnel zones

0.0 Fresnel zones

1.0 Fresnel zones

2.0 Fresnel zones

Angular distance (λ/D)

Angular distance (λ/D)

Angular distance (λ/D)

Irradiance

Irradiance

Irradiance

Angular distance (λ/D)

Angular distance (λ/D)

Angular distance (λ/D)
In the near-field regime, the approximations used for Fraunhofer diffraction are no longer applicable.

To bypass the shortcomings of the HF principle, we account for an obliquity factor as well as adjusting the strength of the sources in the aperture.

The intensity for a rectangular aperture can be expressed in terms of Fresnel integrals and illustrated on the Cornu spiral.

To describe the intensity of a circular aperture, we invoke the interference of different Fresnel zones.
Admin

- Remember to schedule a time slot for Demo#3.

- **PS#6** will be uploaded on Friday
  - Grader: Rigel
  - Due date: Monday, April 8
    (beginning of class)

- Make sure to check the (updated) formal requirements for your research paper and the rubric.

- Two guest lectures next week about Lasers and Terahertz optics.
Summary Lecture 20

- In the **near-field regime**, the approximations used for Fraunhofer diffraction are no longer applicable.

- To bypass the shortcomings of the HF principle, we account for an **obliquity factor** as well as **adjusting the strength of the sources** in the aperture.

- The intensity for a rectangular aperture can be expressed in terms of **Fresnel integrals** and illustrated on the **Cornu spiral**.

- To describe the intensity of a **circular aperture**, we invoke the interference of different **Fresnel zones**.
2D Signal
2D Fourier transform
Fraunhofer diffraction I
Fraunhofer diffraction II
Lens as a Fourier transformer
Convolution
Convolution integral
Convolution of a circle I
Convolution of a circle II
Convolution theorem

\[ f \ast h = g \]

\[
\mathcal{F}\{f\} \times \mathcal{F}\{h\} = \mathcal{F}\{g\}
\]

\[
d \text{sinc} (u) \times d \text{sinc} (u) = d^2 \text{sinc}^2 (u)
\]

\[
u = \frac{kd}{2}
\]
Array theorem
Imaging linear systems
Point-spread function
Point-spread function II

Diagram showing the point-spread function (PSF) and its effect on an object to produce an image.
Summary Lecture 21

- Fourier theory plays an important role in Optics.
- Field distribution in the Fraunhofer diffraction pattern is Fourier transform of the aperture function (each point in the image plane is a spatial frequency).
- A lens acts as a Fourier analyser.
- Diffraction of an array of identical apertures is pattern of one multiplied by that of individual point sources.
- The image formed by any optical system is the input intensity convolved with its point-spread function.
PHYS 434 Optics

Lecture 24: Gaussian Beams, Lens Transformations

Reading: 13.1
Divergence angle
Higher-order modes
The modes of lasers are very-well described by solutions to the paraxial Helmholtz equation.

The resulting beams have a Gaussian transverse intensity profile and are thus called Gaussian beams, characterised by their waist and Rayleigh range.

A lens affects the Gaussian beam by adding a phase, i.e. changing the wavefront curvature. It is possible to recover standard Geometric Optics expressions.

There is a family of modes (Hermite-Gaussian) that can be excited within cavities (different nodes).
PHYS 434 Optics

Lecture 25: Holography

Reading: 13.3
Admin

- Grades for **PS#6**, **Demo#3** and **research paper** will be uploaded in the next two weeks.

- Homework grade: **drop lowest grade** of the 6 problem sets **IF** it helps your final grade; 8 (3+5) homework grades contribute 50% of your final grade; otherwise 9 (3+6) grades contribute 50% of final grade.

- **New material** from Lectures 22 + 23 will not be part of the final exam.

- Contact me by **email** if you have any questions.
The modes of lasers are very-well described by solutions to the paraxial Helmholtz equation. The resulting beams have a Gaussian transverse intensity profile and are thus called Gaussian beams, characterised by their waist and Rayleigh range. A lens affects the Gaussian beam by adding a phase, i.e. changing the wavefront curvature. It is possible to recover standard Geometric Optics expressions. There is a family of modes (Hermite-Gaussian) that can be excited within cavities (different nodes).
Initial holographic set-up I
Transmission holography I
Transmission holography II
Characteristic fringe
Diffraction / reconstruction I
Diffraction / reconstruction II
Holographic fringes I
Holographic fringes II
Transmission holograms
Reflection holography
Summary Lecture 25

- When taking a photograph, we only store information about the irradiance of the light field but not its phase.

- To do so, we can combine the concepts of interference and diffraction in a two-step process: record a hologram of an object on a film (interference fringes) and reconstruct the image by illumination (diffraction).

- By recording phase and amplitude, we can encode all information of the original light field and recover a true 3D image, which has lots of applications.