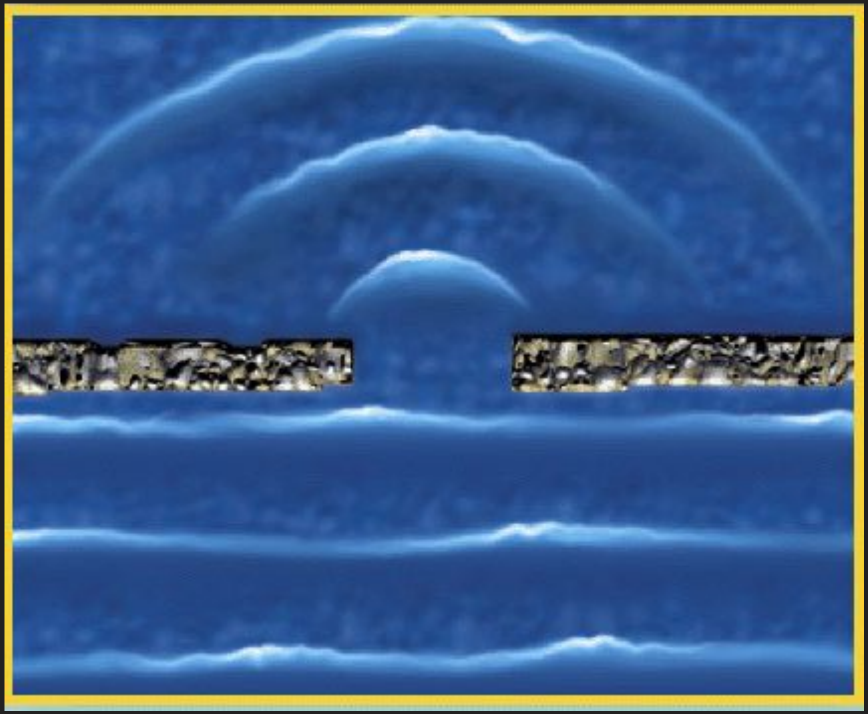
PHYS 434 Optics

Lecture 18: Diffraction through Slits

Reading: 10.1



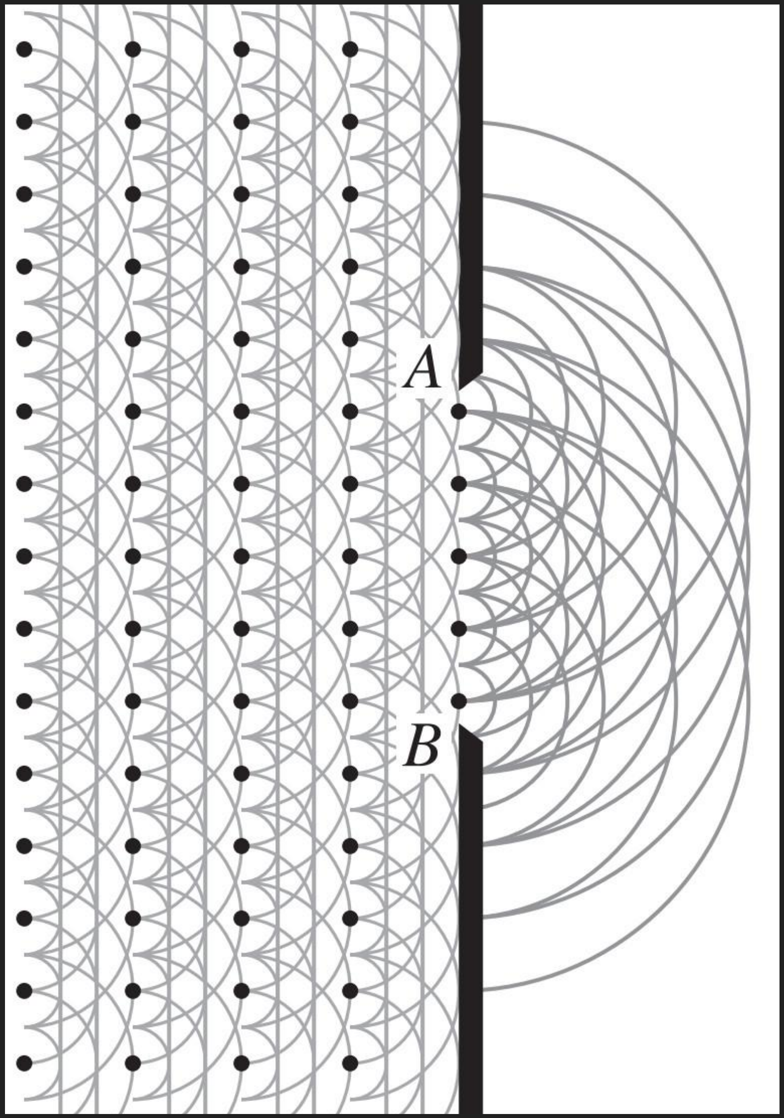
Summary Lecture 17

- 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.

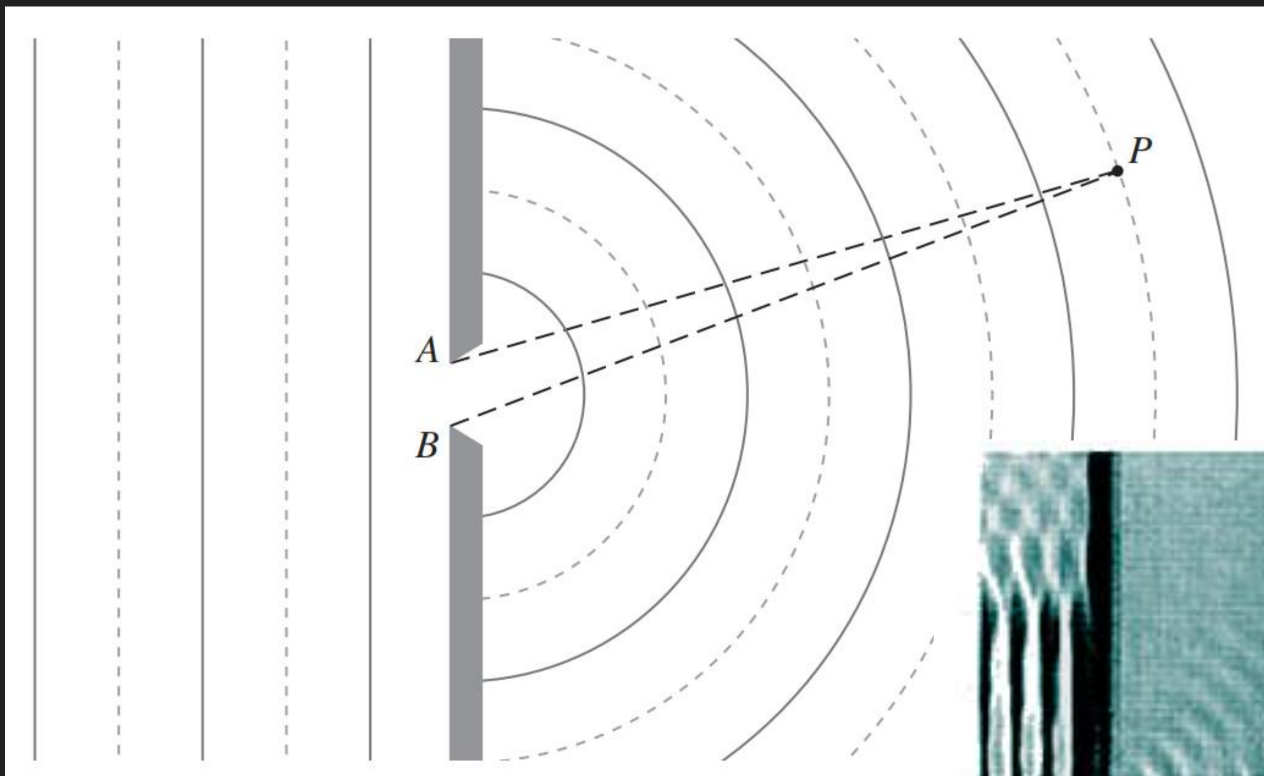
Why are coves round?

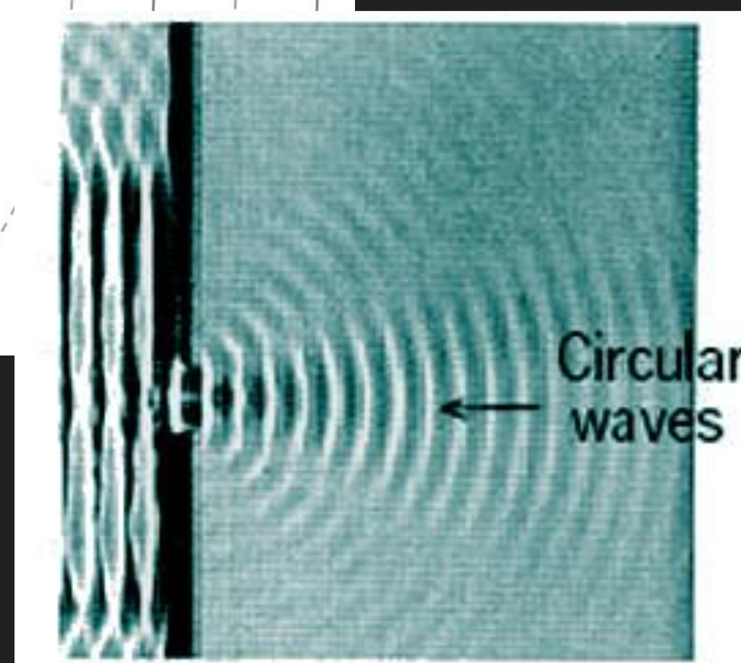
Why are coves round?

Huygens-Fresnel principle I

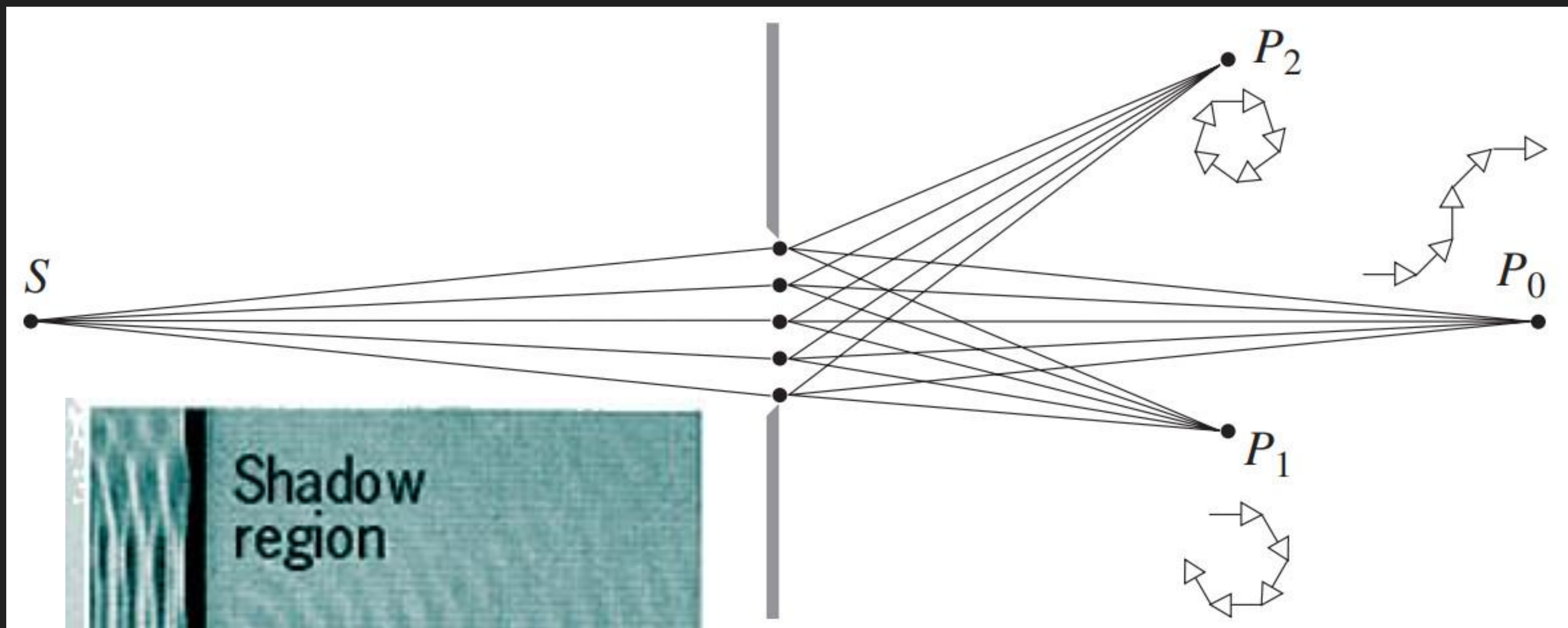


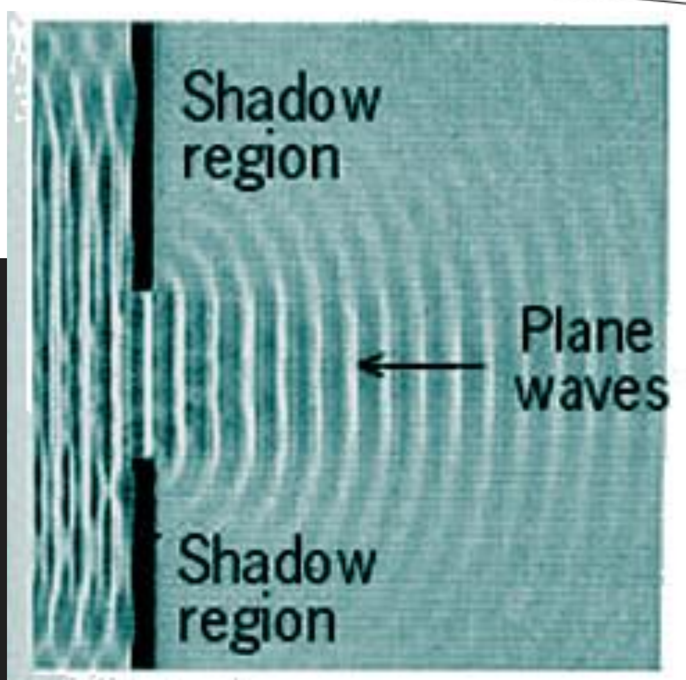
Huygens-Fresnel principle II



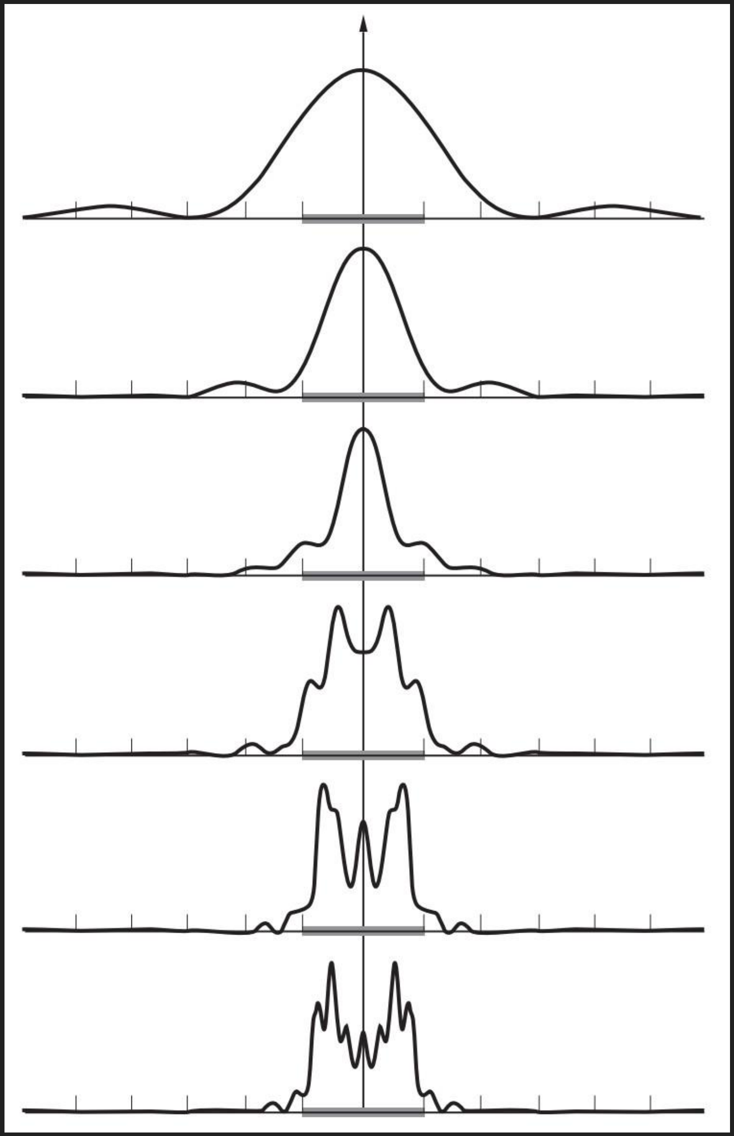


Huygens-Fresnel principle III

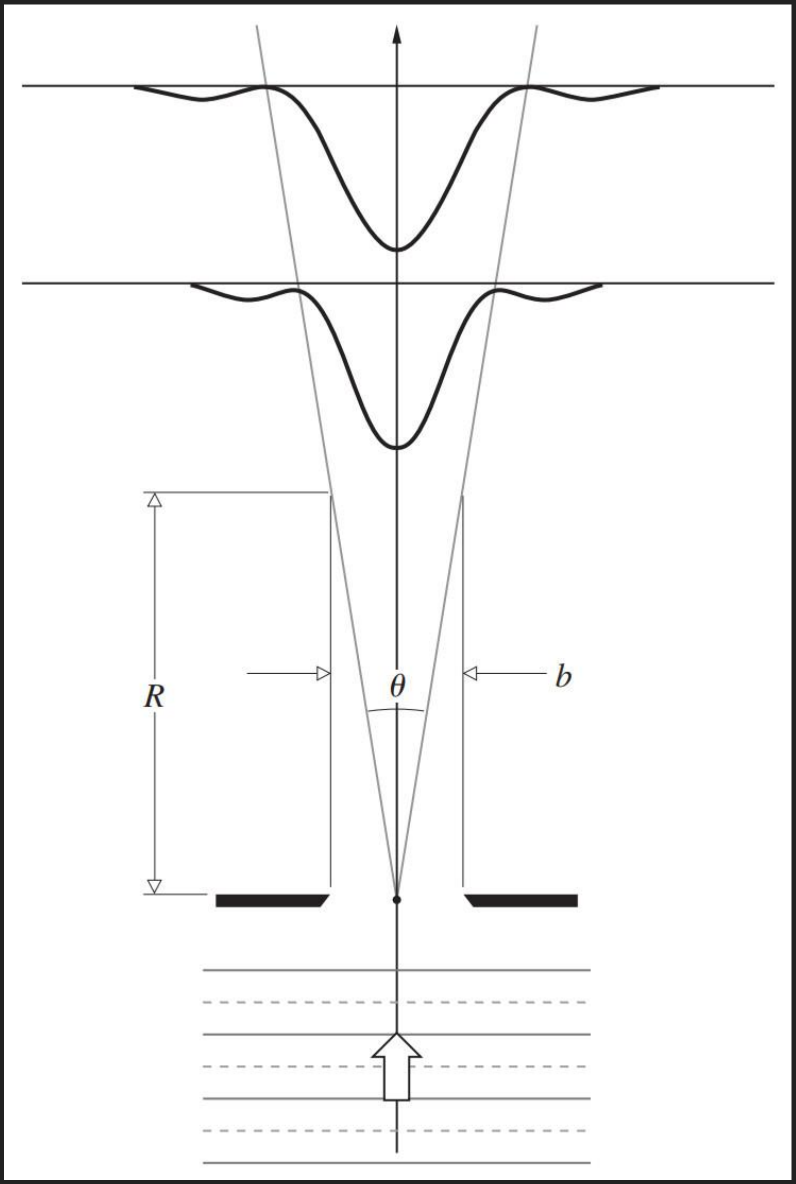




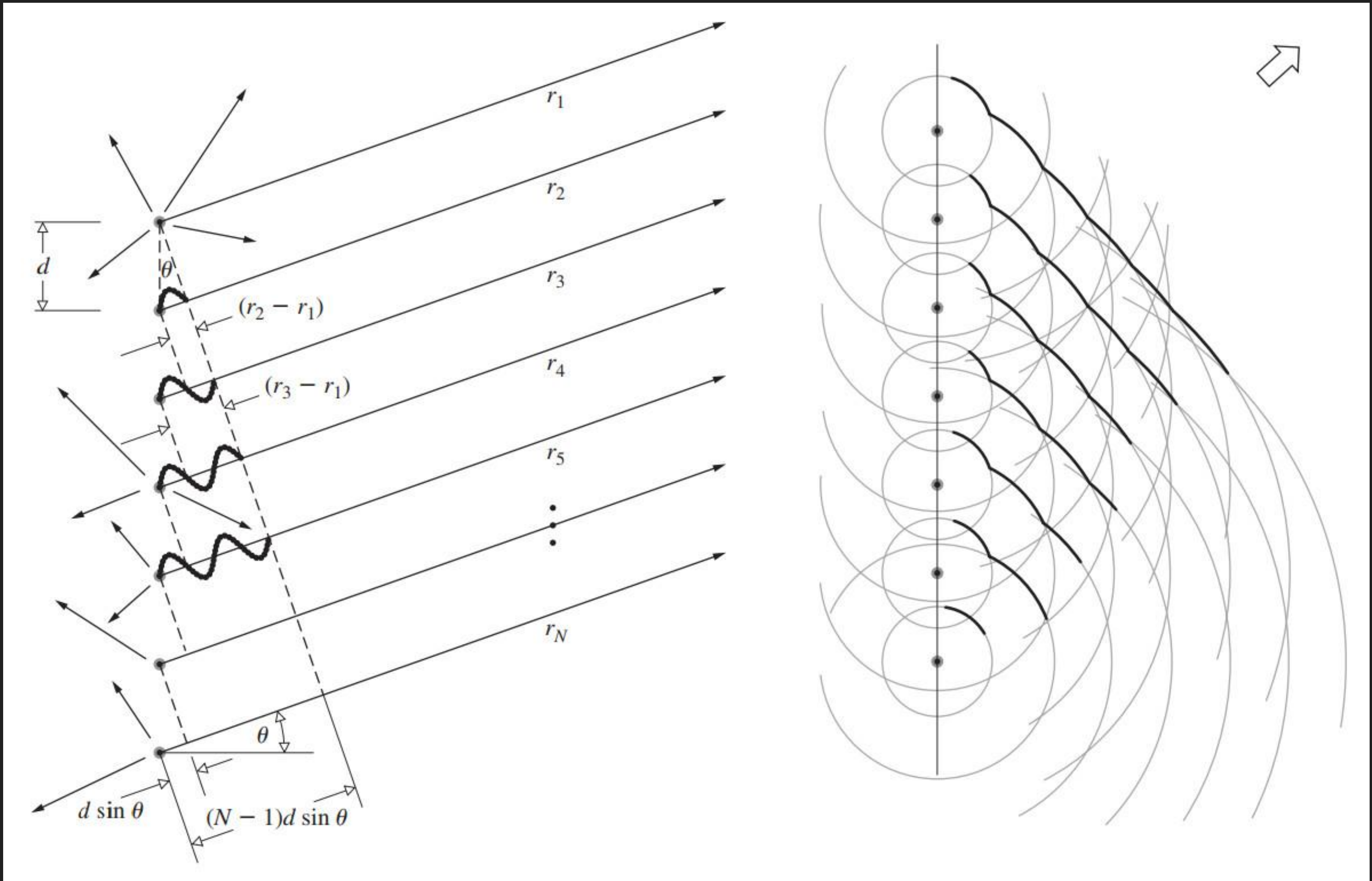
Two types of diffraction



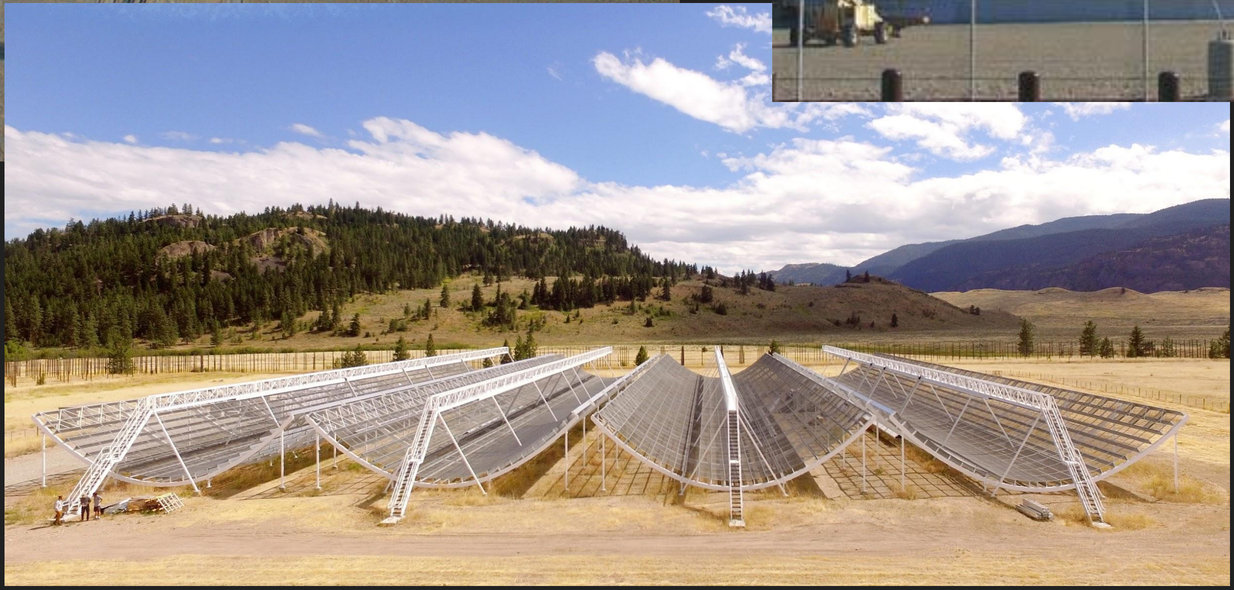
Far-field regime



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.

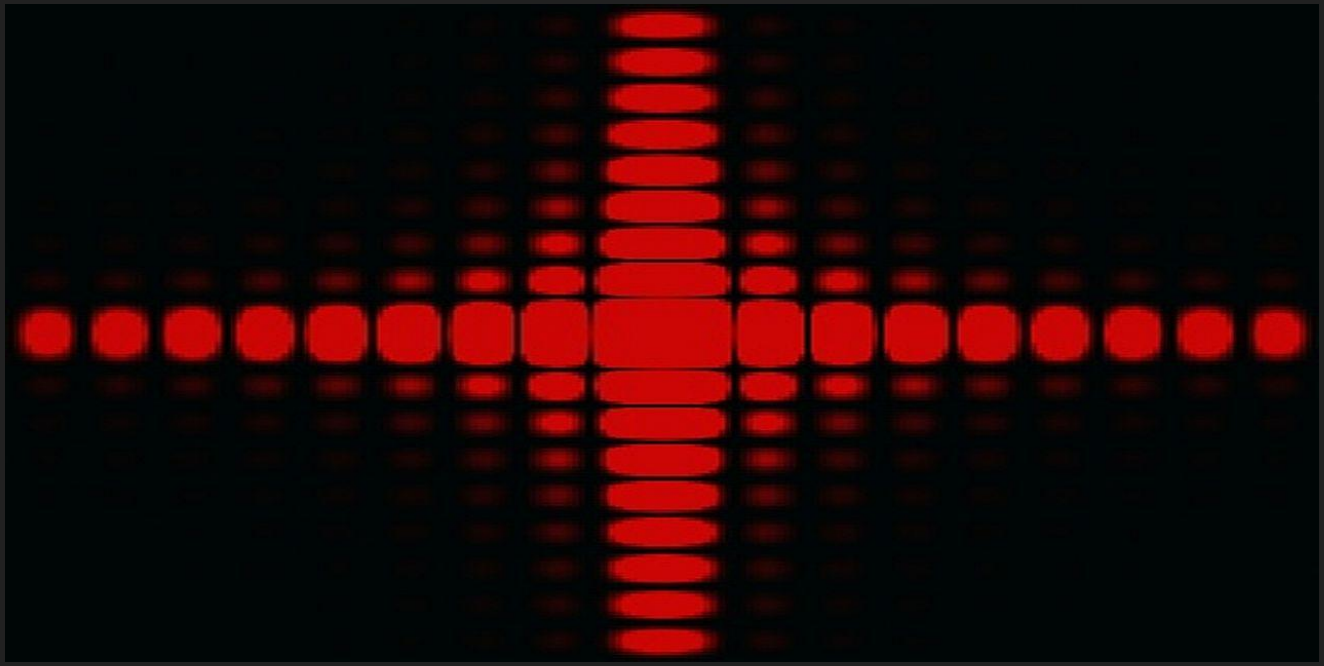
- The Huygens-Fresnel principle provides an intuitive way to study diffraction: secondary wavelets of different amplitudes and phases interfer beyond obstacle.

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

PHYS 434 Optics

Lecture 19: Fraunhofer Diffraction

Reading: 10.2



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).

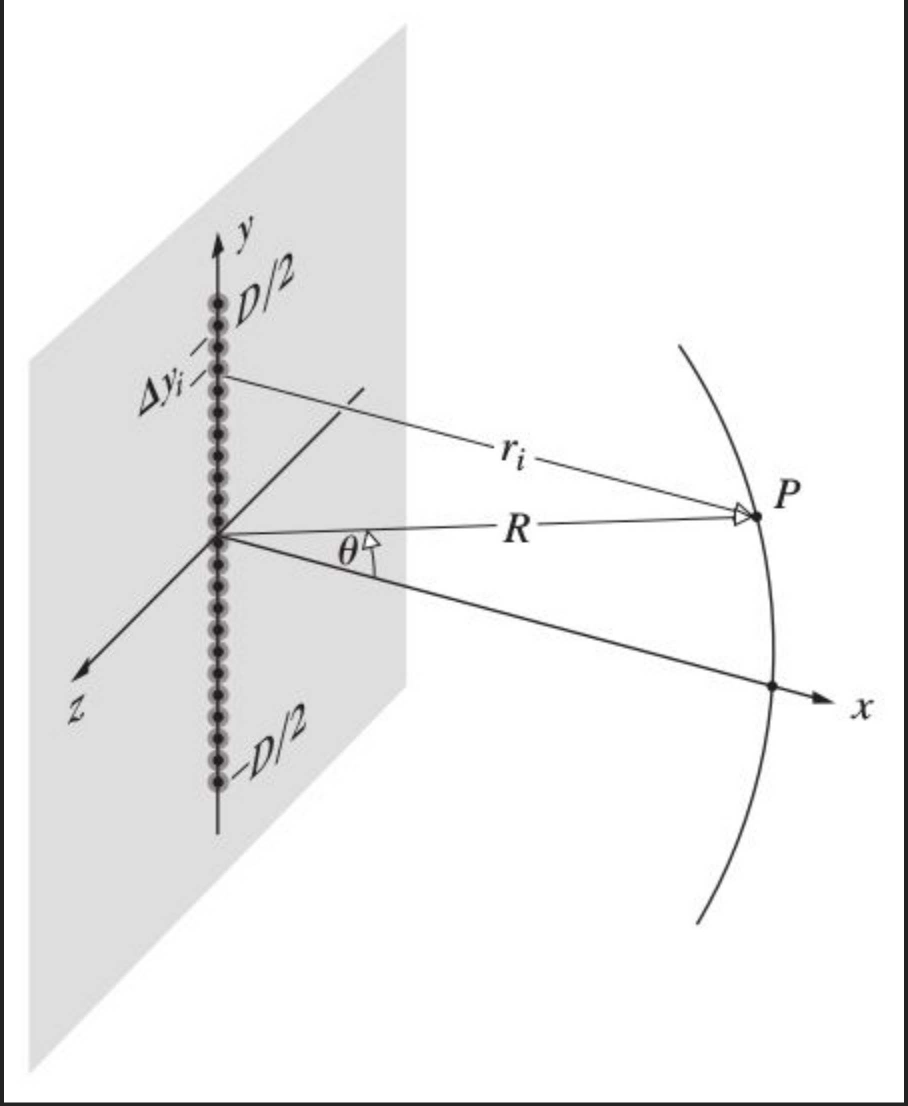
Summary Lecture 18

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

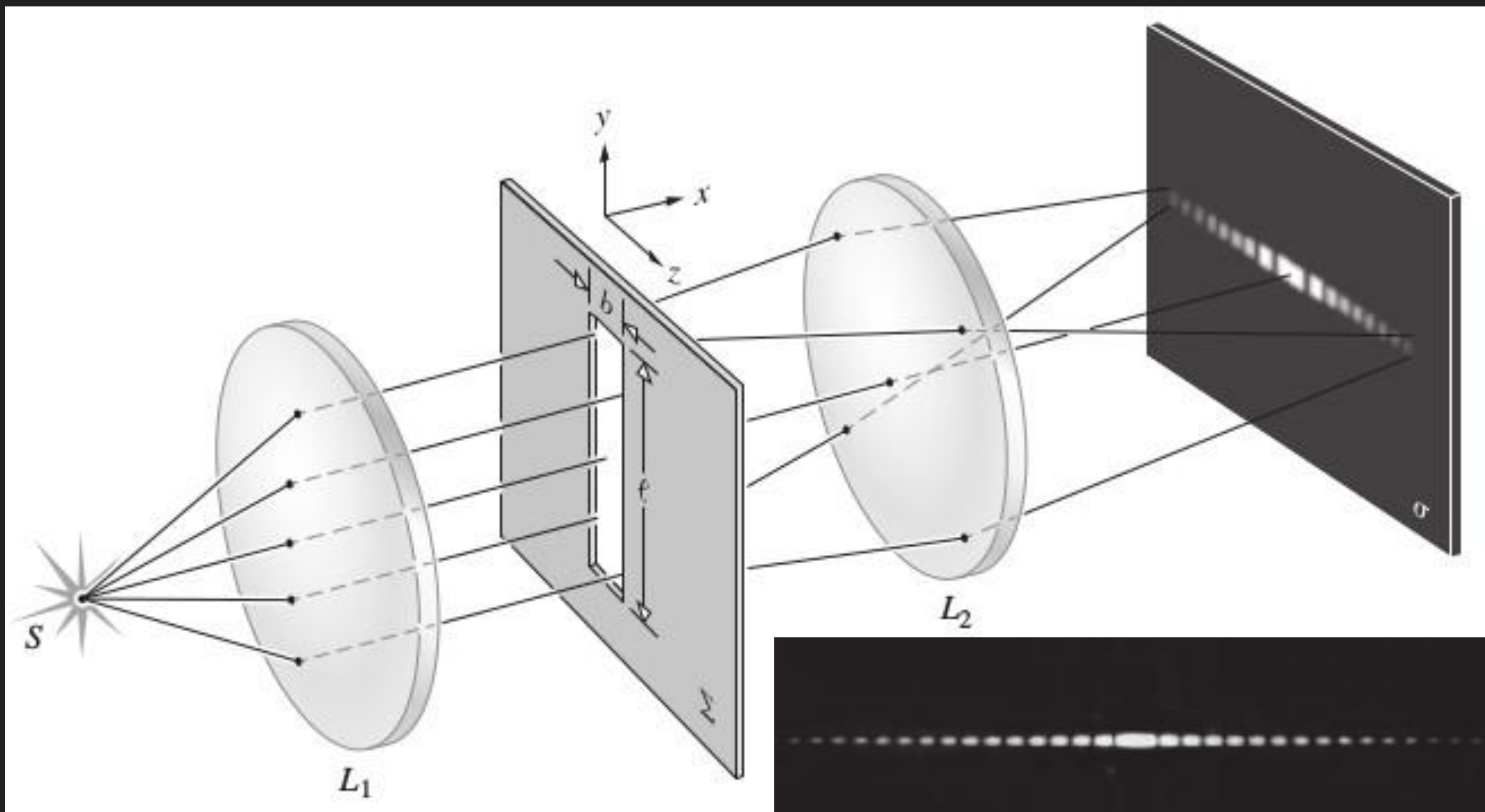
- The Huygens-Fresnel principle provides an intuitive way to study diffraction: secondary wavelets of different amplitudes and phases interfere beyond obstacle.

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

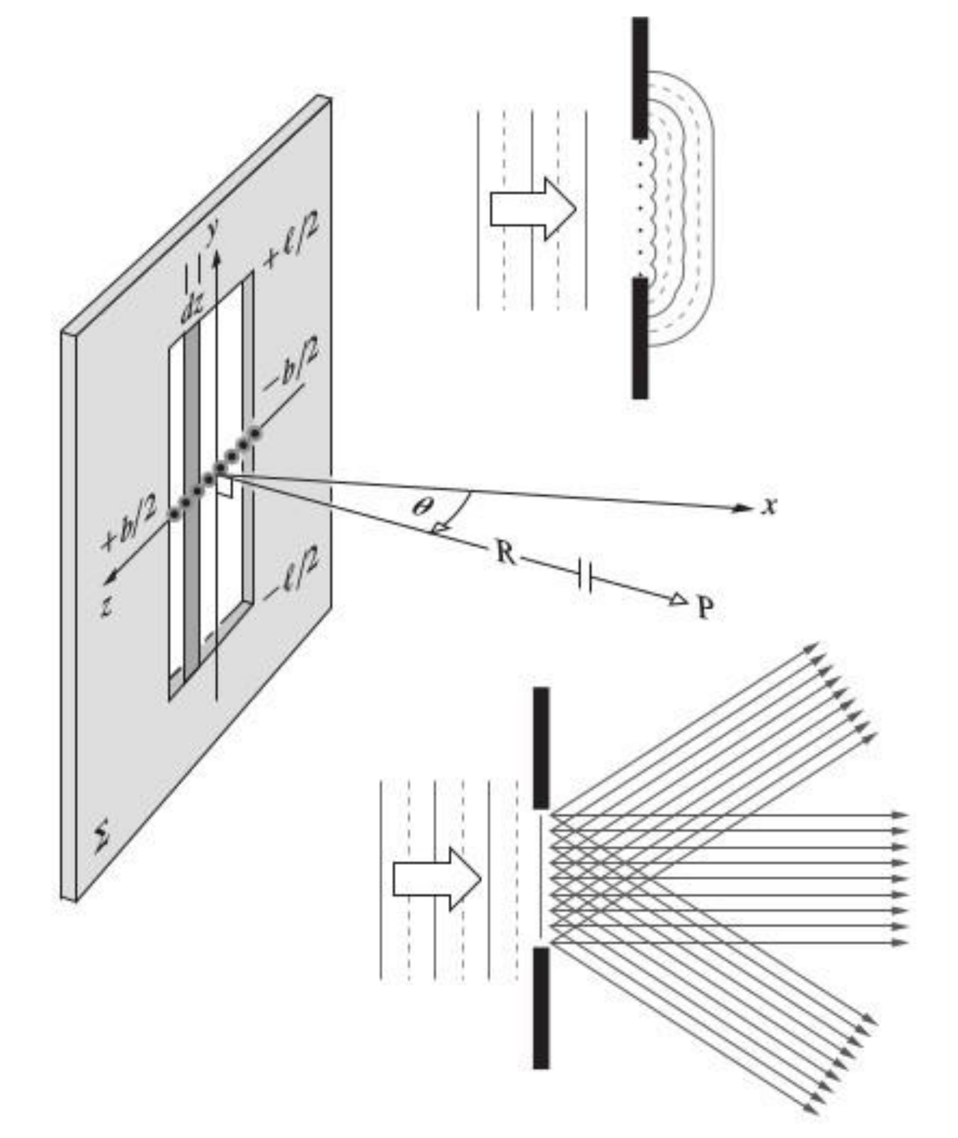
Coherent oscillators



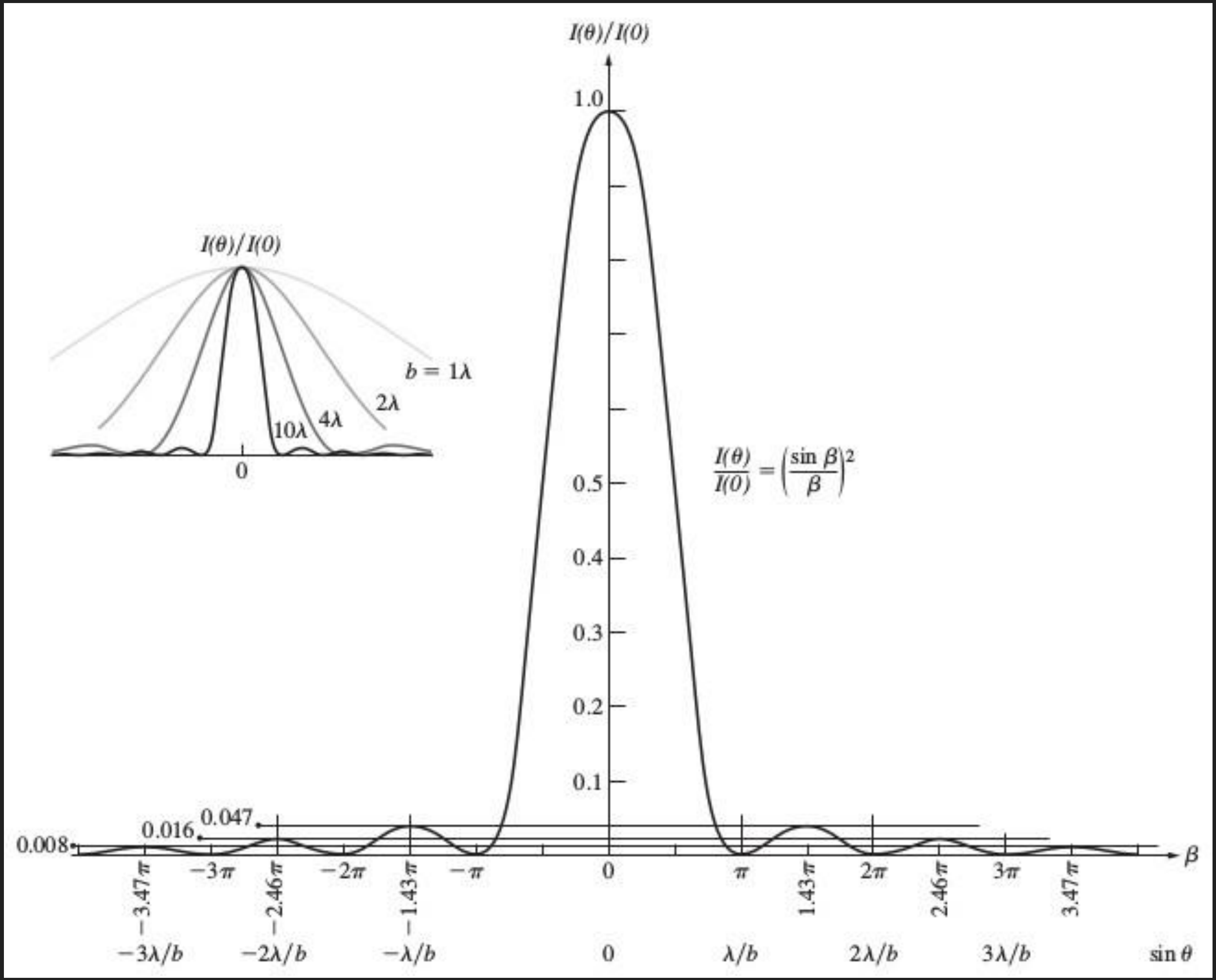
Rectangular aperture I



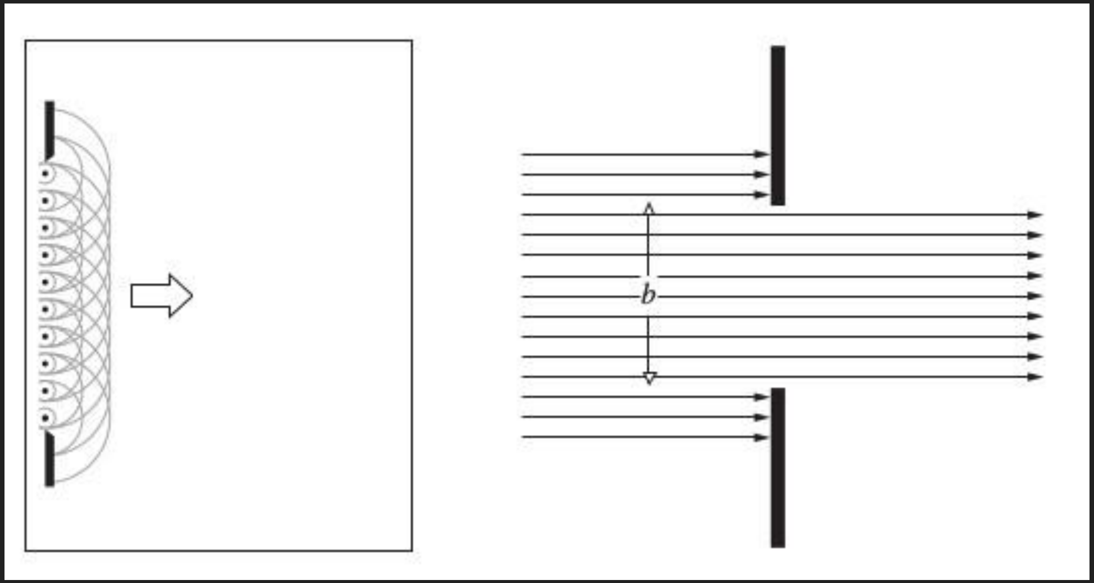
Rectangular aperture II



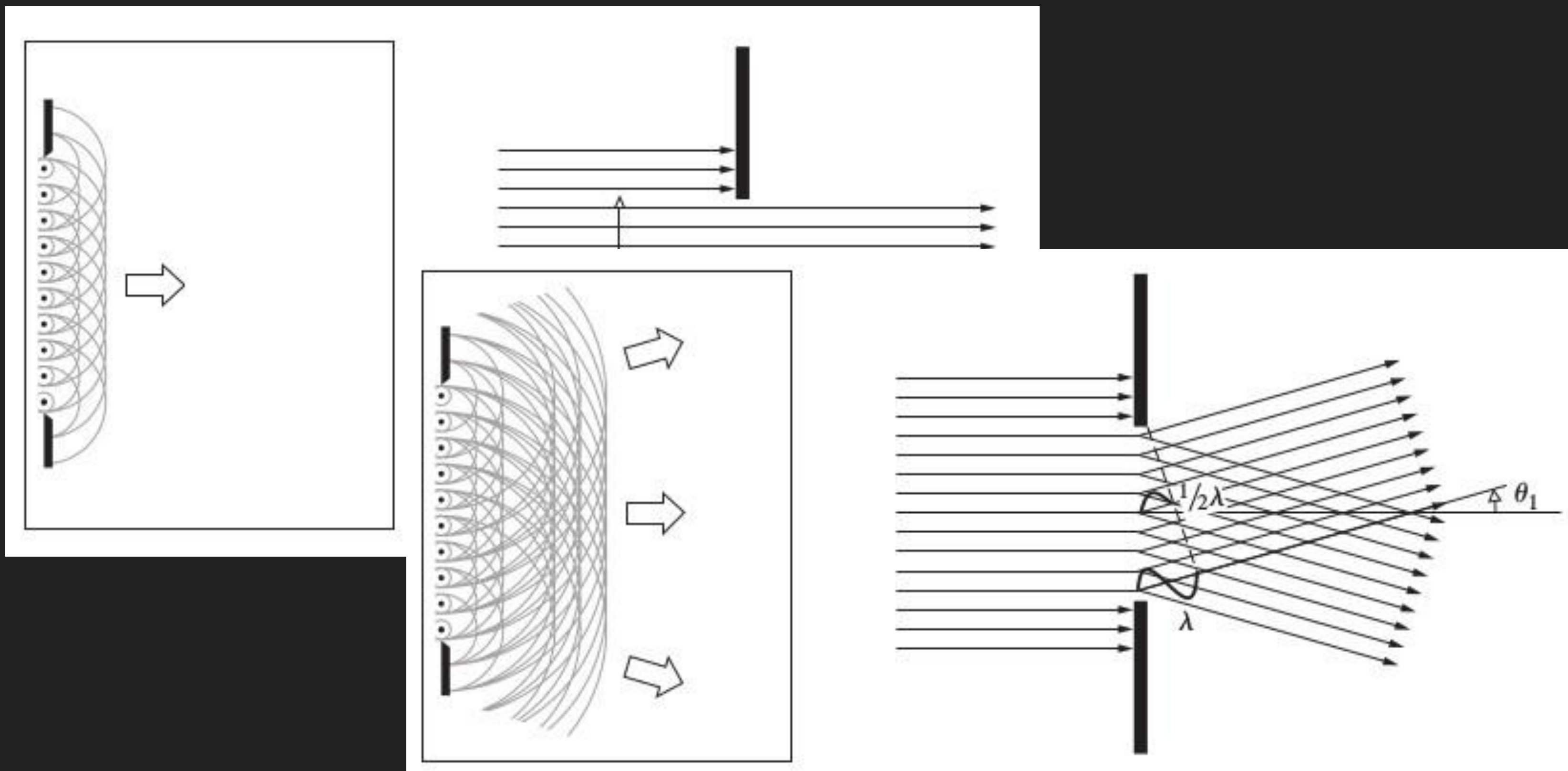
Single-slit diffraction pattern



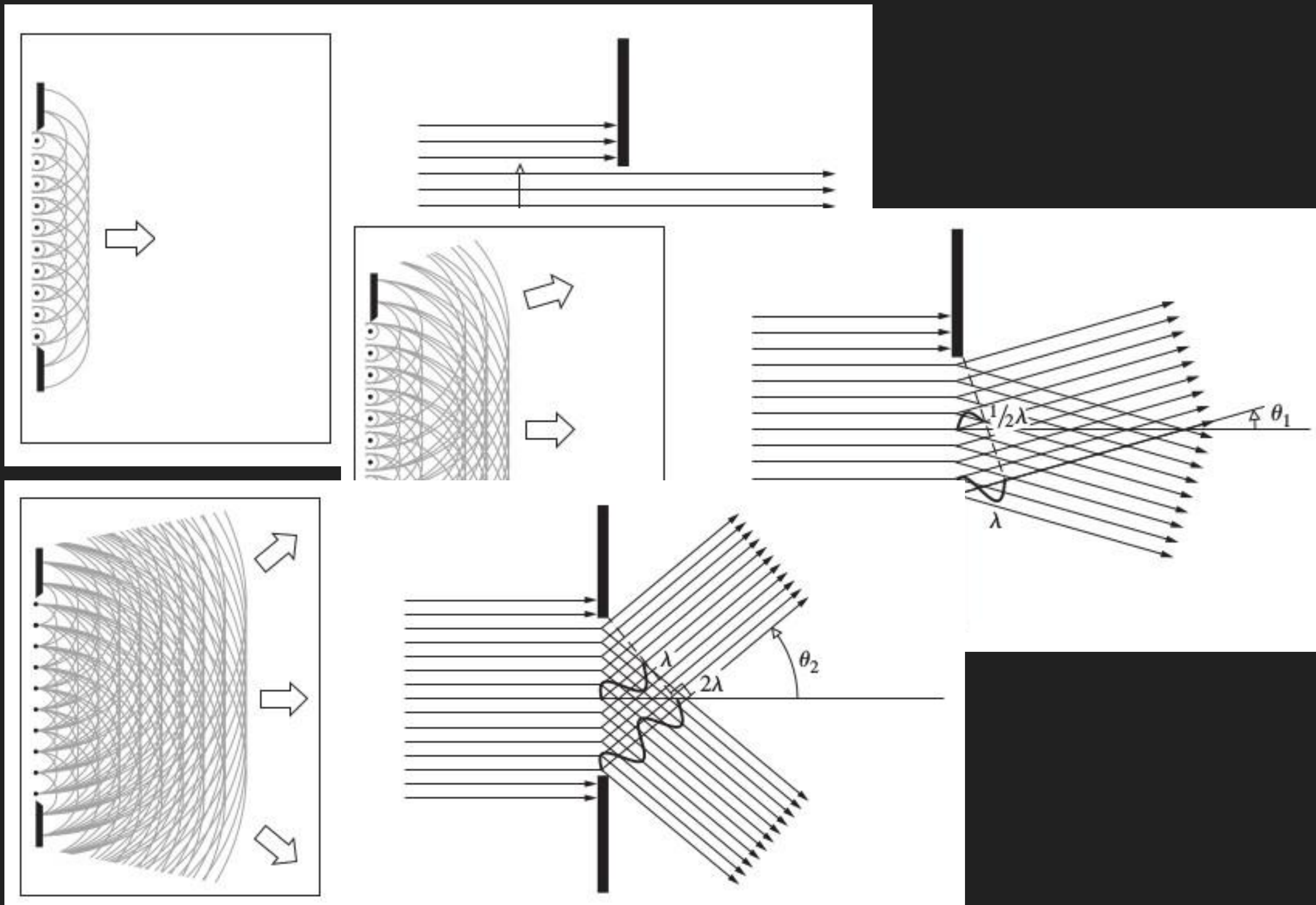
Wavelet picture



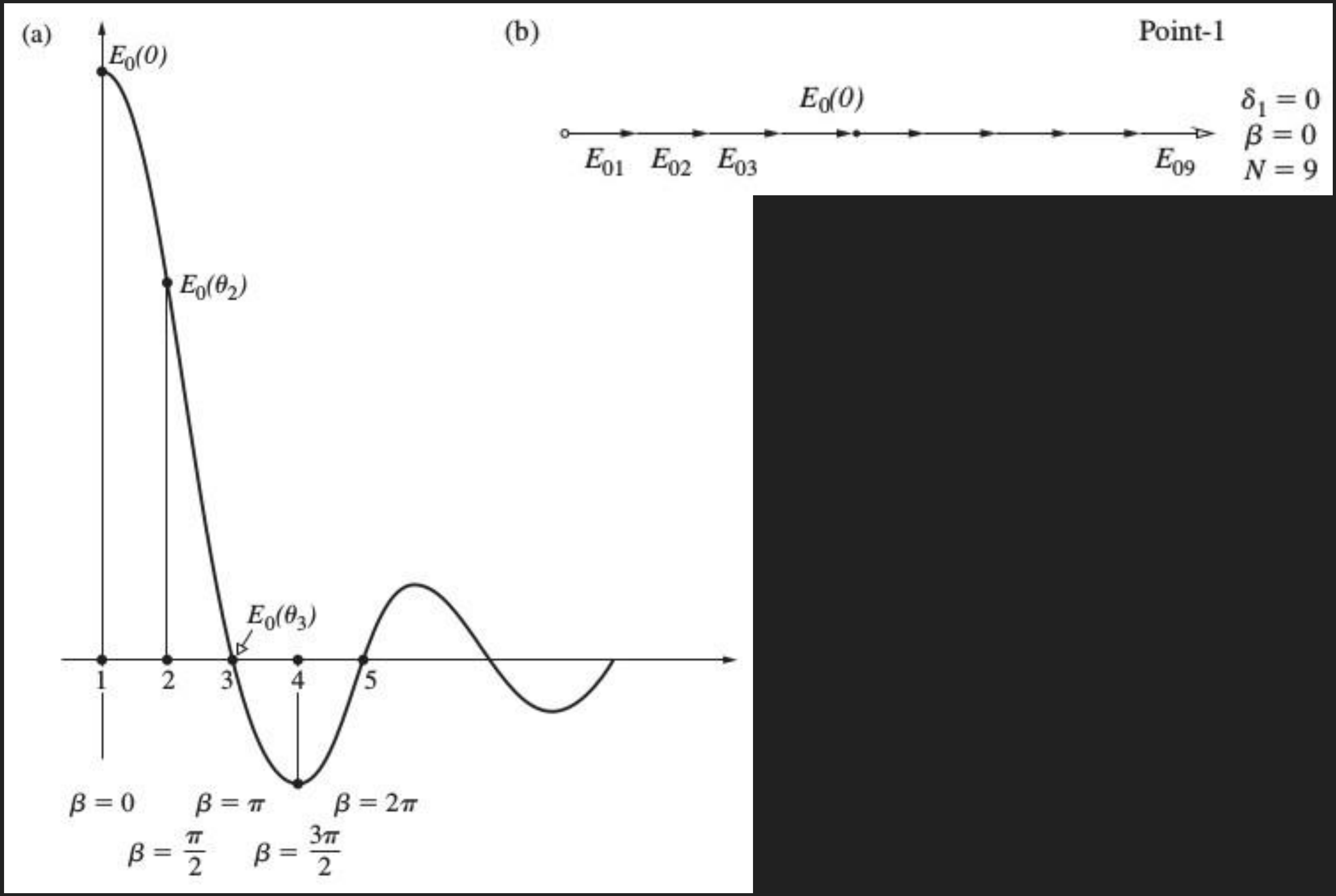
Wavelet picture



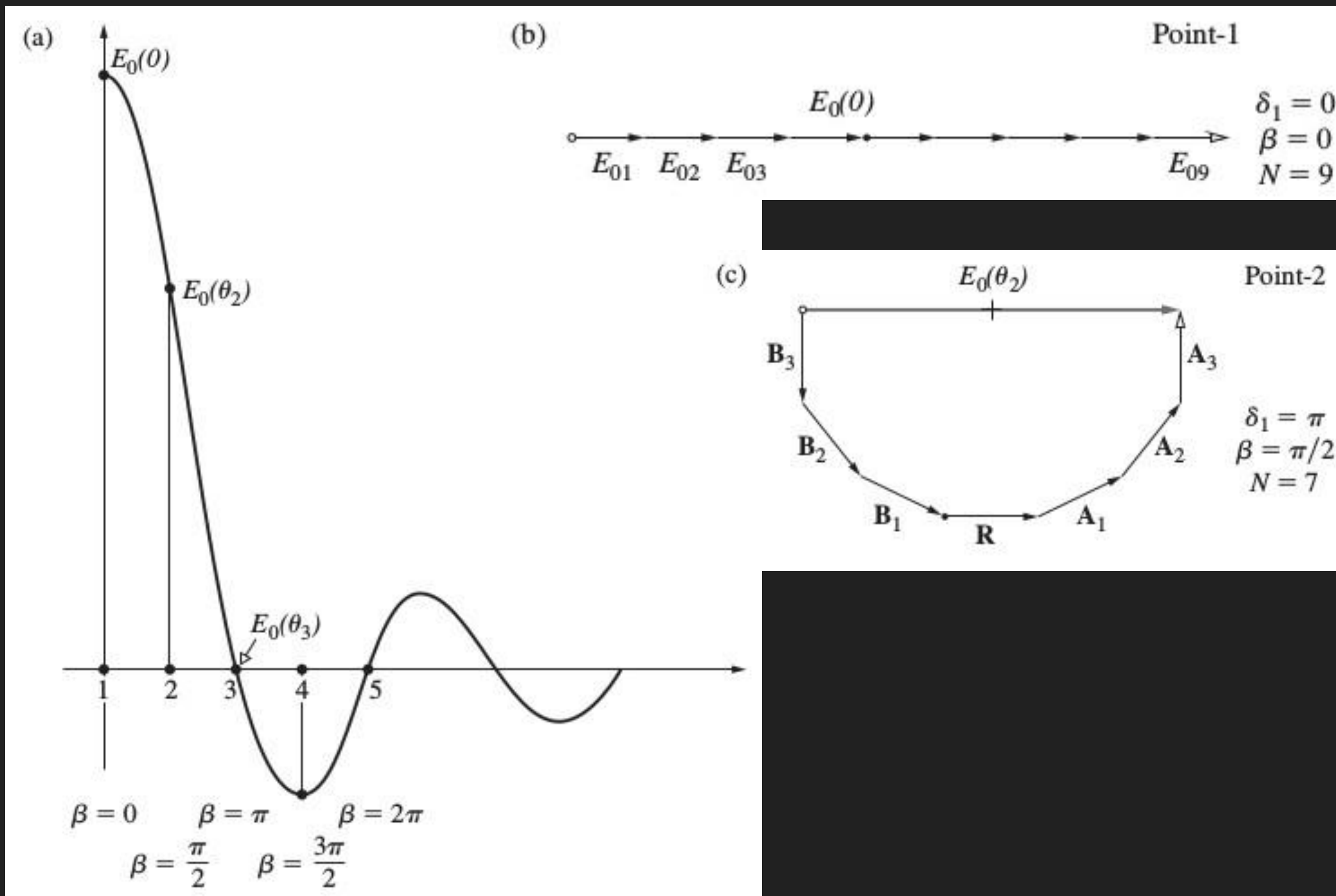
Wavelet picture



Phasors I

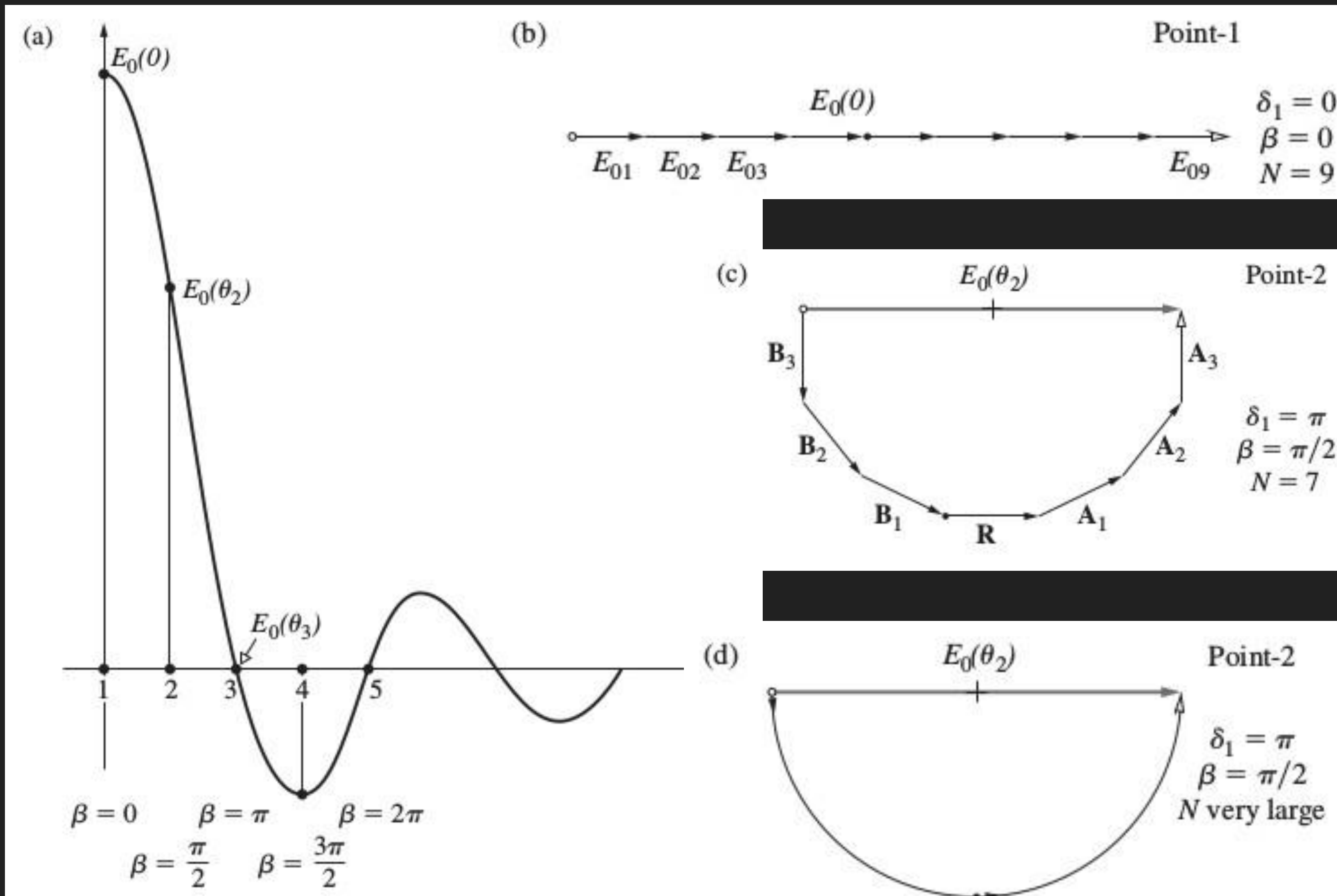

(a)
E0(0)
E0(θ2)
E0(θ3)
1
2
3
4
5
β = 0
β = π
β = 2π
β = π/2
β = 3π/2
(b)
Point-1
E0(0)
E01
E02
E03
E09
δ1 = 0
β = 0
N = 9

Phasors I



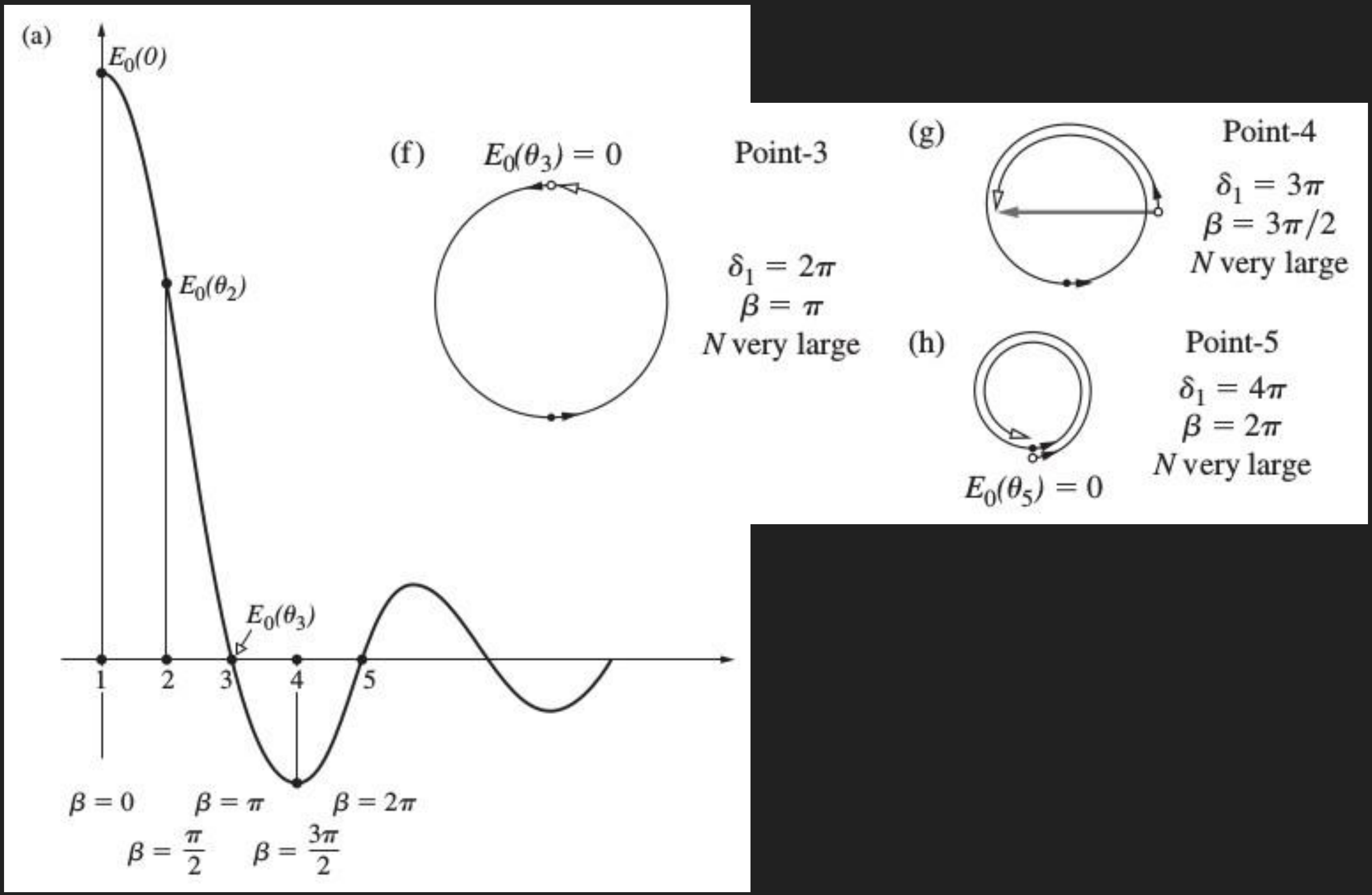
(a)
$E_0(0)$
$E_0(\theta_2)$
$E_0(\theta_3)$
1
2
3
4
5
$\beta = 0$
$\beta = \pi$
$\beta = 2\pi$
$\beta = \frac{\pi}{2}$
$\beta = \frac{3\pi}{2}$
(b)
Point-1
$E_0(0)$
E_{01}
E_{02}
E_{03}
E_{09}
$\delta_1 = 0$
$\beta = 0$
$N = 9$
(c)
$E_0(\theta_2)$
Point-2
$\mathbf{B}_3$
$\mathbf{A}_3$
$\mathbf{B}_2$
$\mathbf{A}_2$
$\mathbf{B}_1$
$\mathbf{A}_1$
R
$\delta_1 = \pi$
$\beta = \pi/2$
$N = 7$

Phasors I



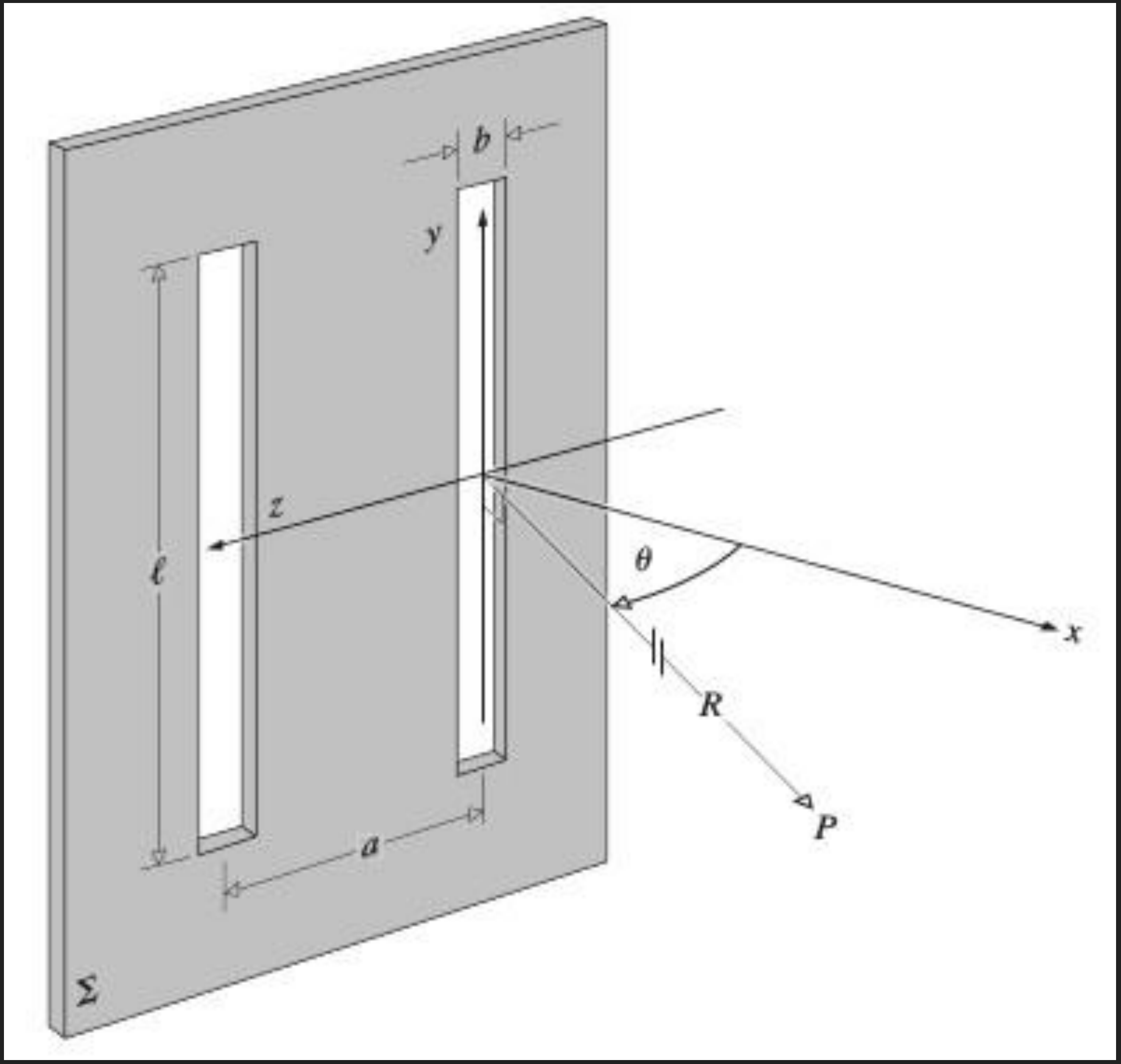
(a)
$E_0(0)$
$E_0(\theta_2)$
$E_0(\theta_3)$
1
2
3
4
5
$\beta = 0$
$\beta = \pi$
$\beta = 2\pi$
$\beta = \frac{\pi}{2}$
$\beta = \frac{3\pi}{2}$
(b)
Point-1
$E_0(0)$
E_{01}
E_{02}
E_{03}
E_{09}
$\delta_1 = 0$
$\beta = 0$
$N = 9$
(c)
$E_0(\theta_2)$
Point-2
$\mathbf{B}_3$
$\mathbf{A}_3$
$\mathbf{B}_2$
$\mathbf{A}_2$
$\mathbf{B}_1$
$\mathbf{R}$
$\mathbf{A}_1$
$\delta_1 = \pi$
$\beta = \pi/2$
$N = 7$
(d)
$E_0(\theta_2)$
Point-2
$\delta_1 = \pi$
$\beta = \pi/2$
N very large

Phasors II

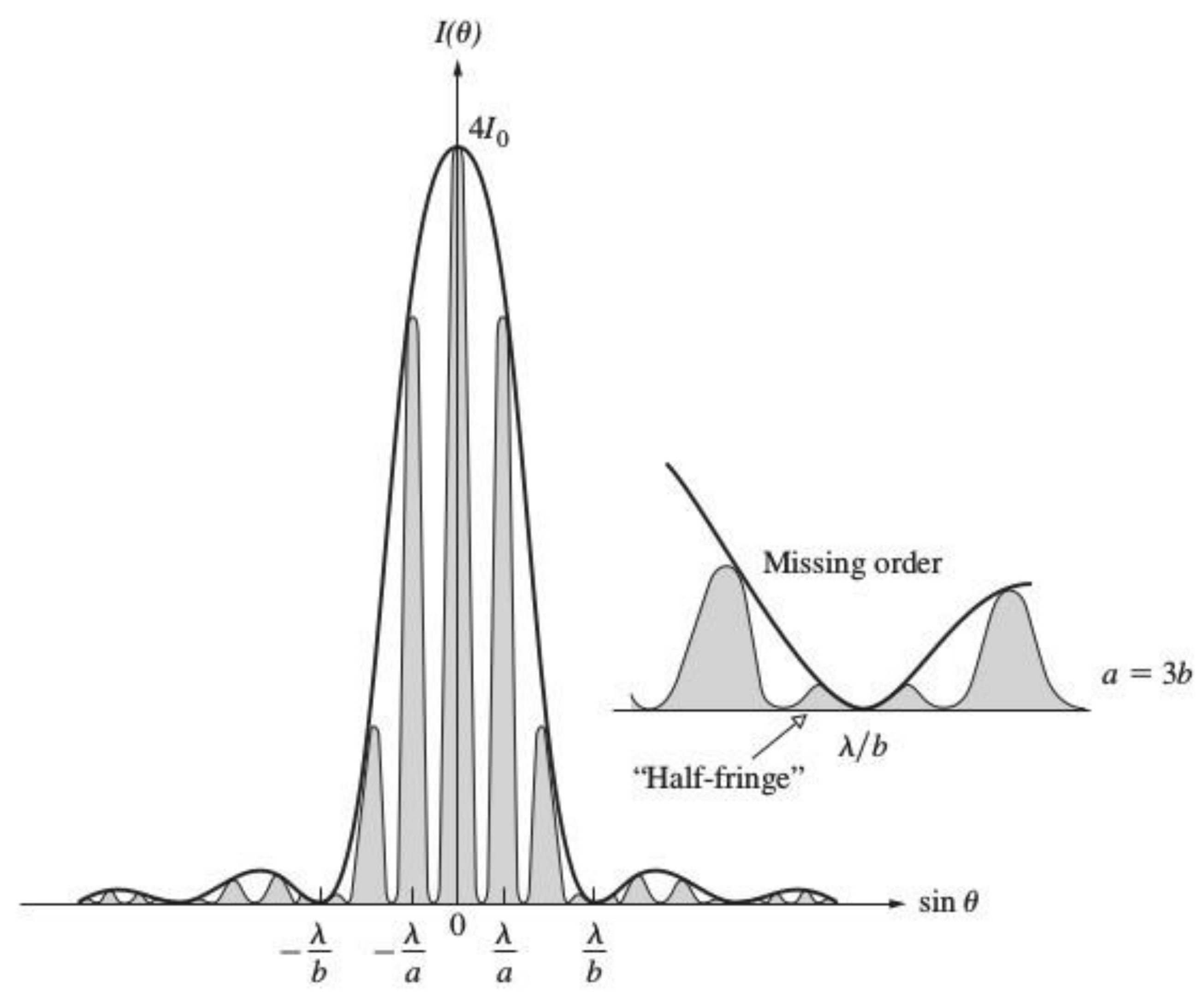


(a)
$E_0(0)$
$E_0(\theta_2)$
$E_0(\theta_3)$
1
2
3
4
5
$\beta = 0$
$\beta = \pi$
$\beta = 2\pi$
$\beta = \frac{\pi}{2}$
$\beta = \frac{3\pi}{2}$
(f)
$E_0(\theta_3) = 0$
Point-3
$\delta_1 = 2\pi$
$\beta = \pi$
N very large
(g)
Point-4
$\delta_1 = 3\pi$
$\beta = 3\pi/2$
N very large
(h)
Point-5
$\delta_1 = 4\pi$
$\beta = 2\pi$
N very large
$E_0(\theta_5) = 0$

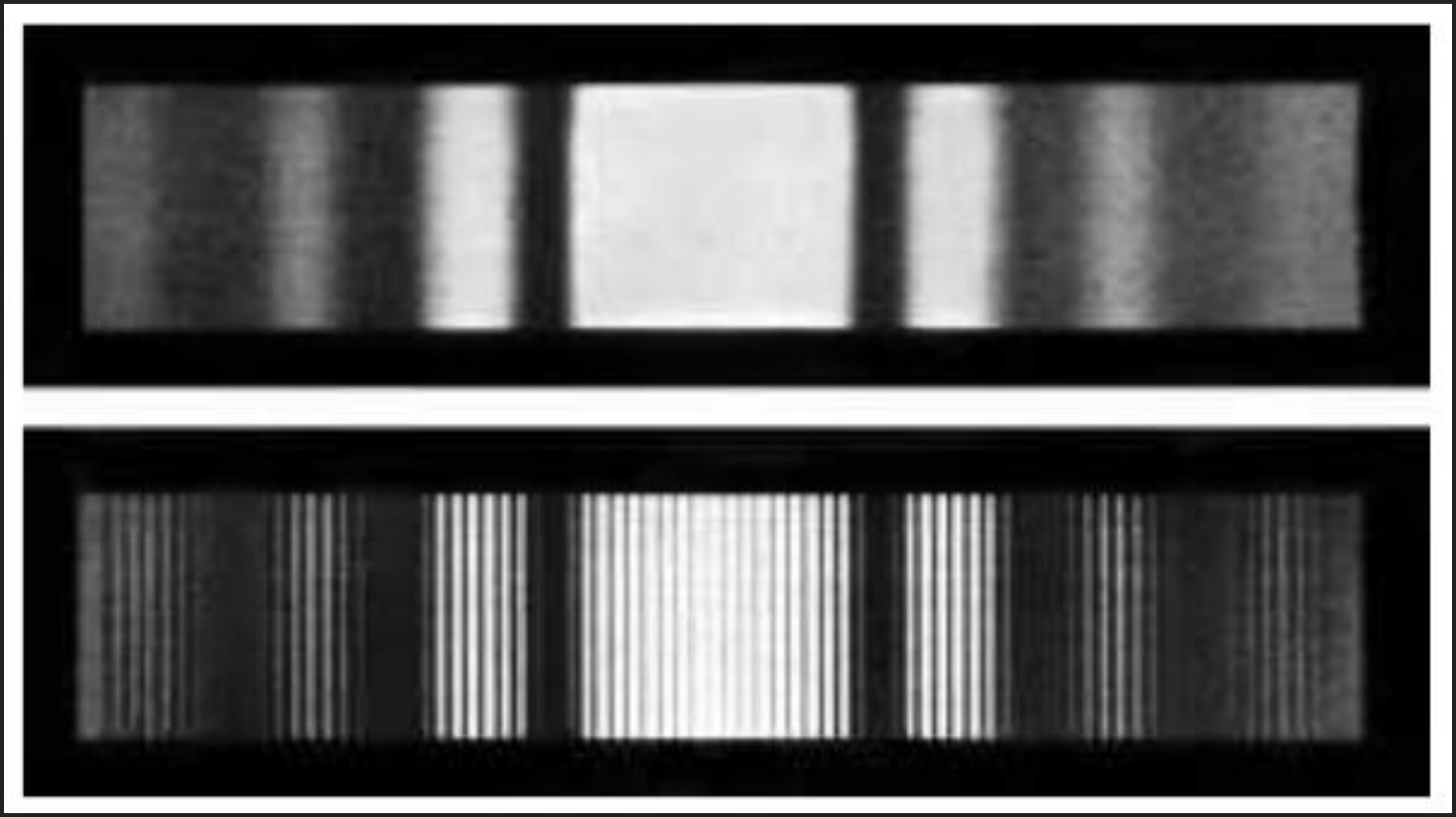
Double slit



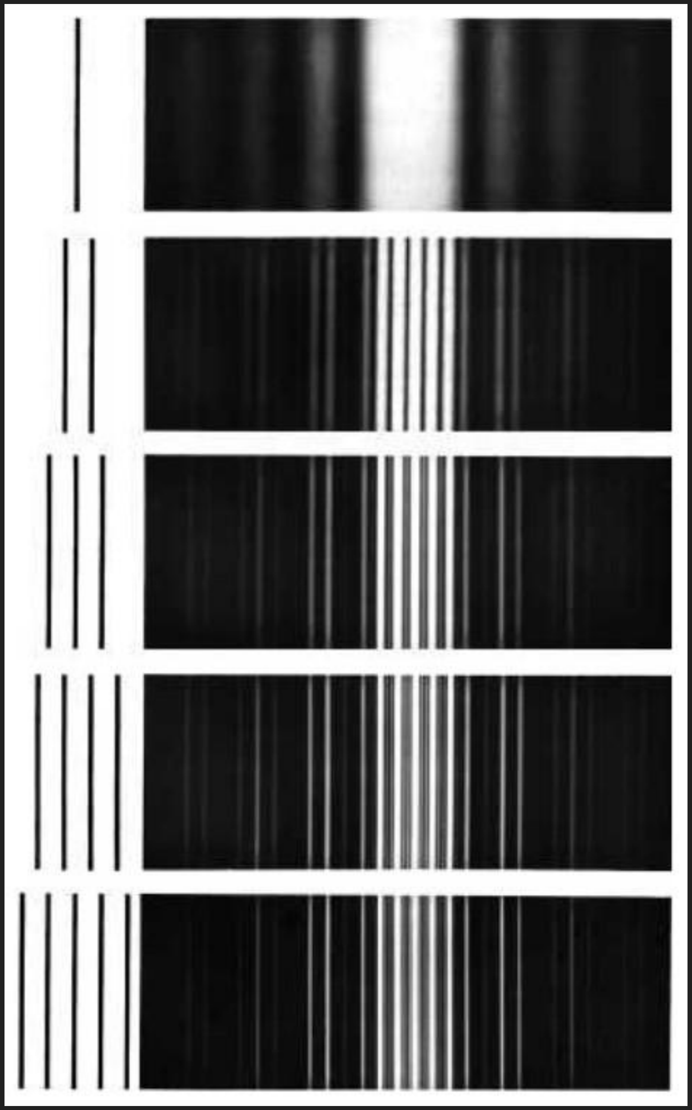
Double-slit diffraction pattern



Single vs. double slit



Multi-slit diffraction pattern



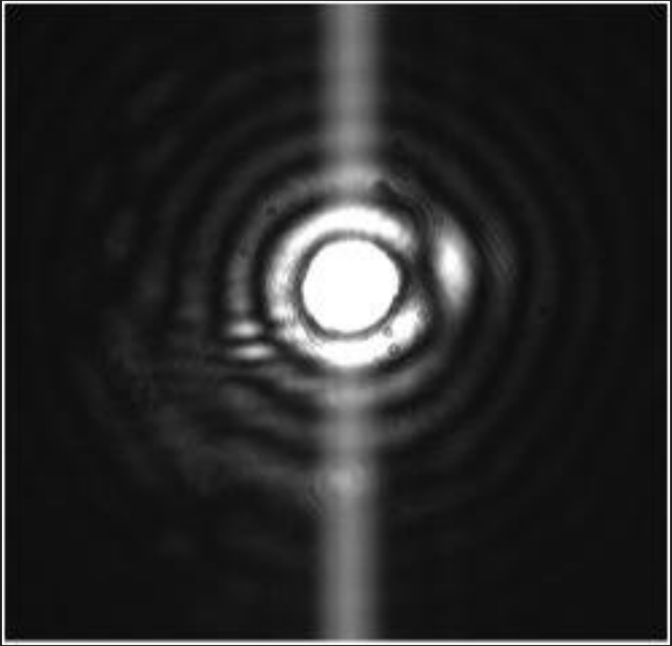
Summary Lecture 19

- 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 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



Summary Lecture 19

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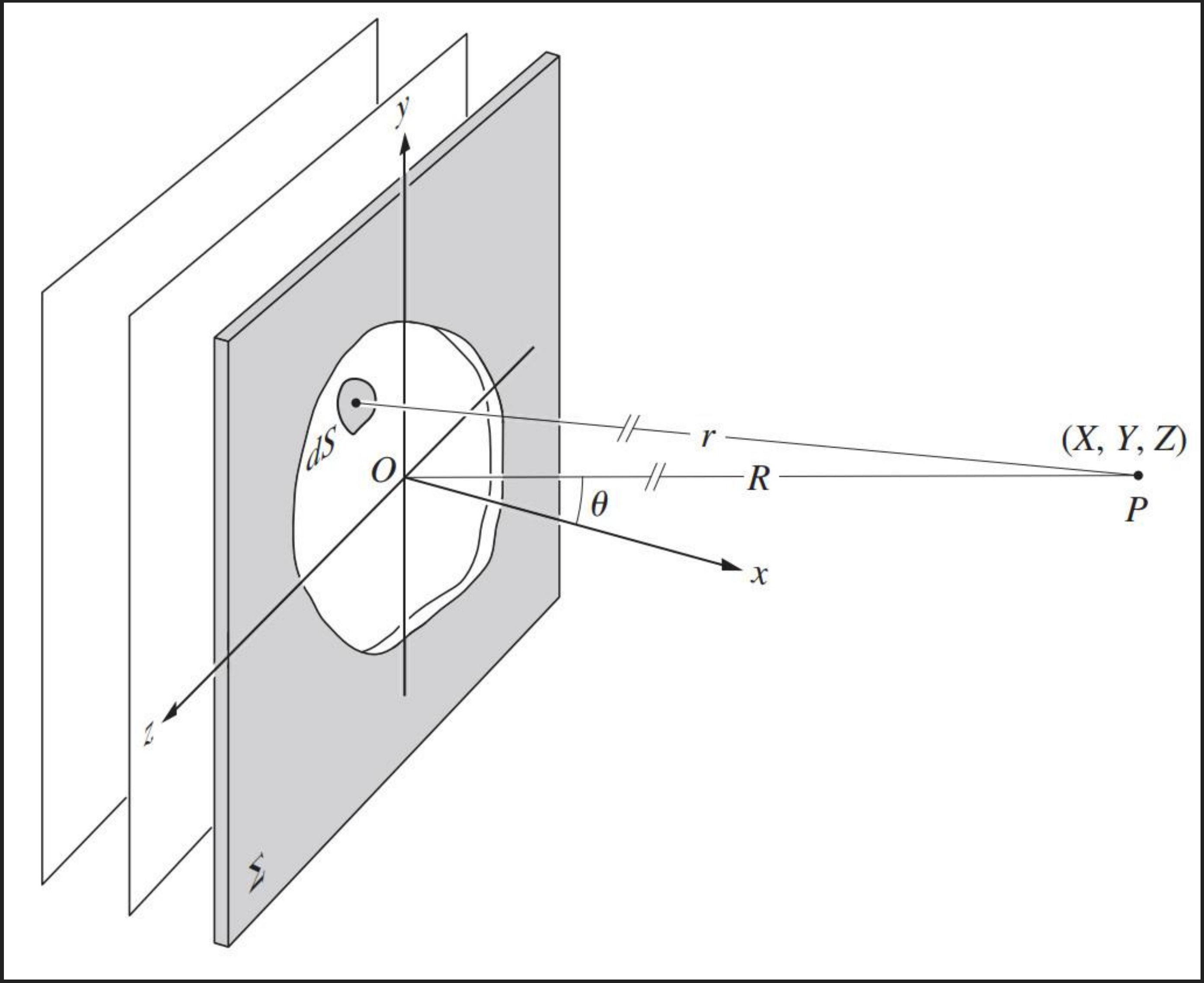
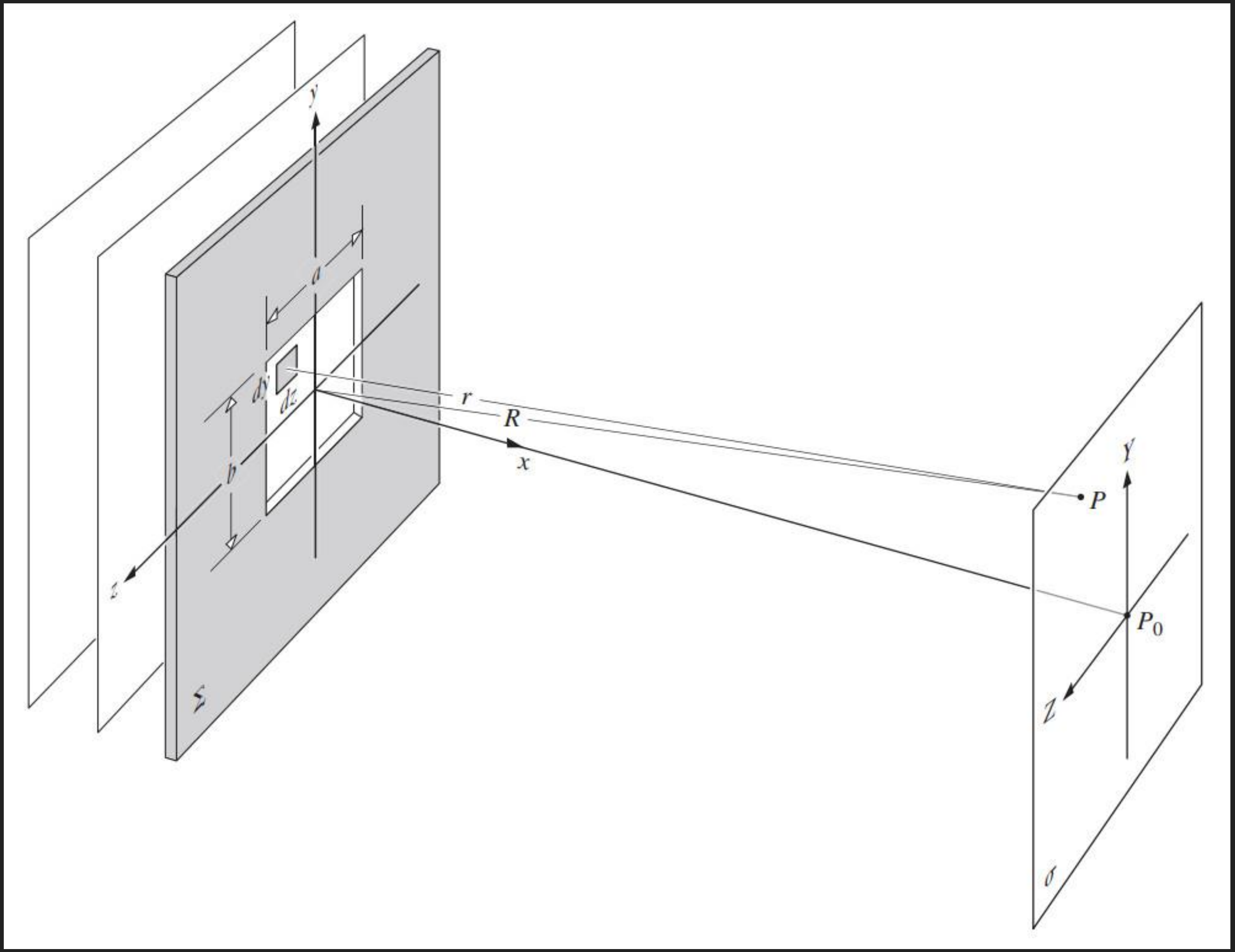
- For multi-slit configurations, we obtain a diffraction pattern that is given as an interference term, modulated by the single-slit diffraction pattern.
- The concept is important for grating spectroscopy.

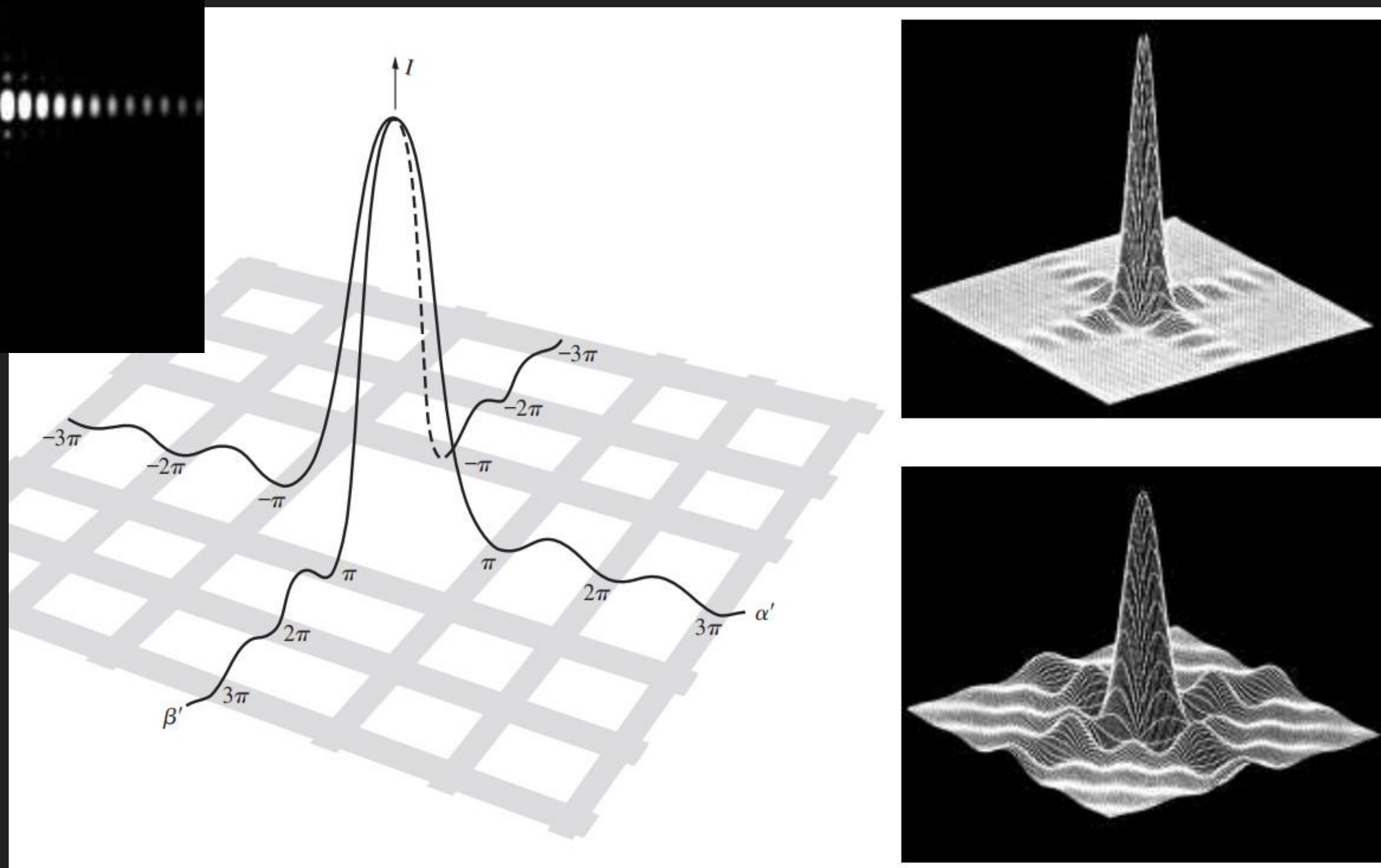
Arbitrary aperture



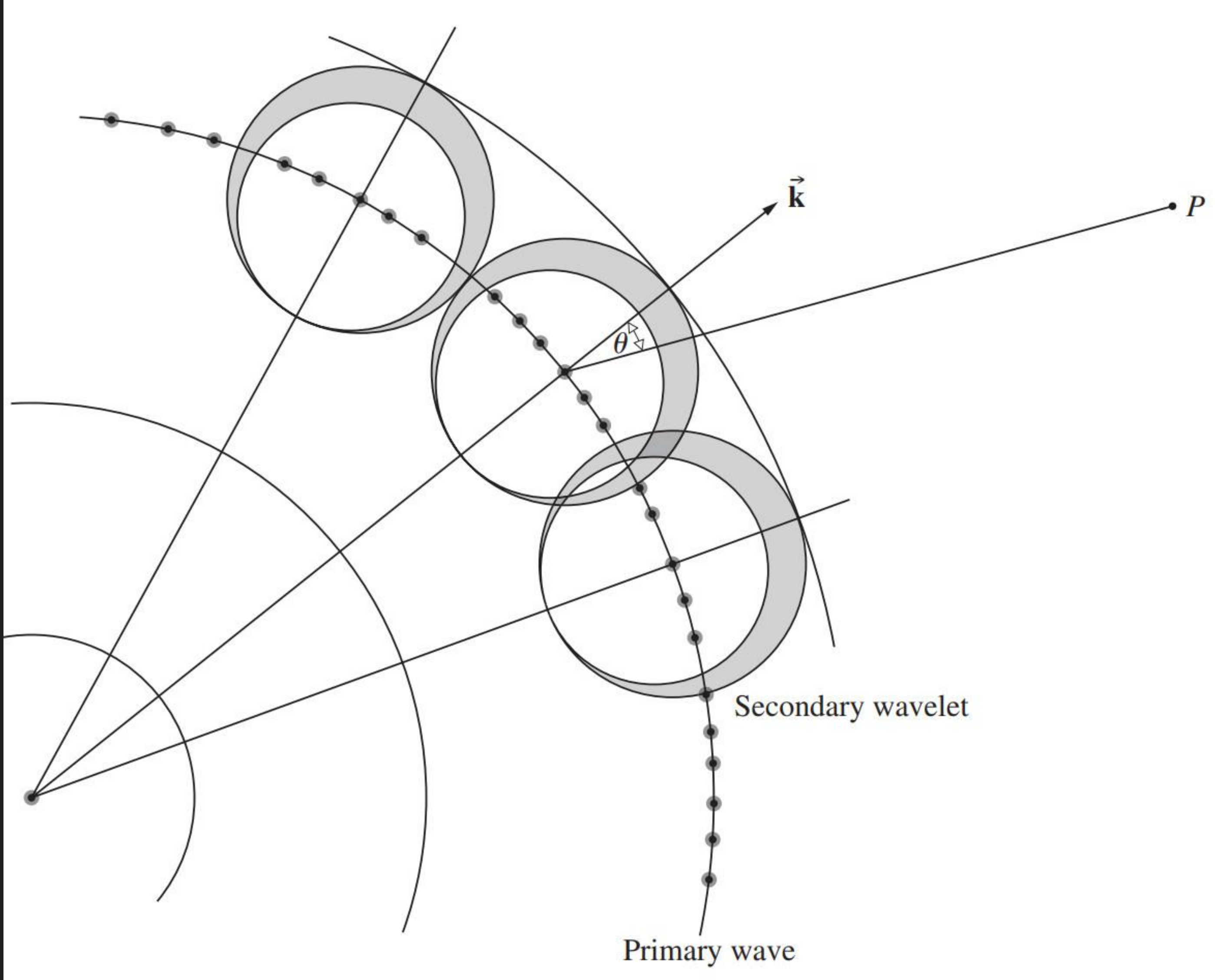
Rectangular aperture I



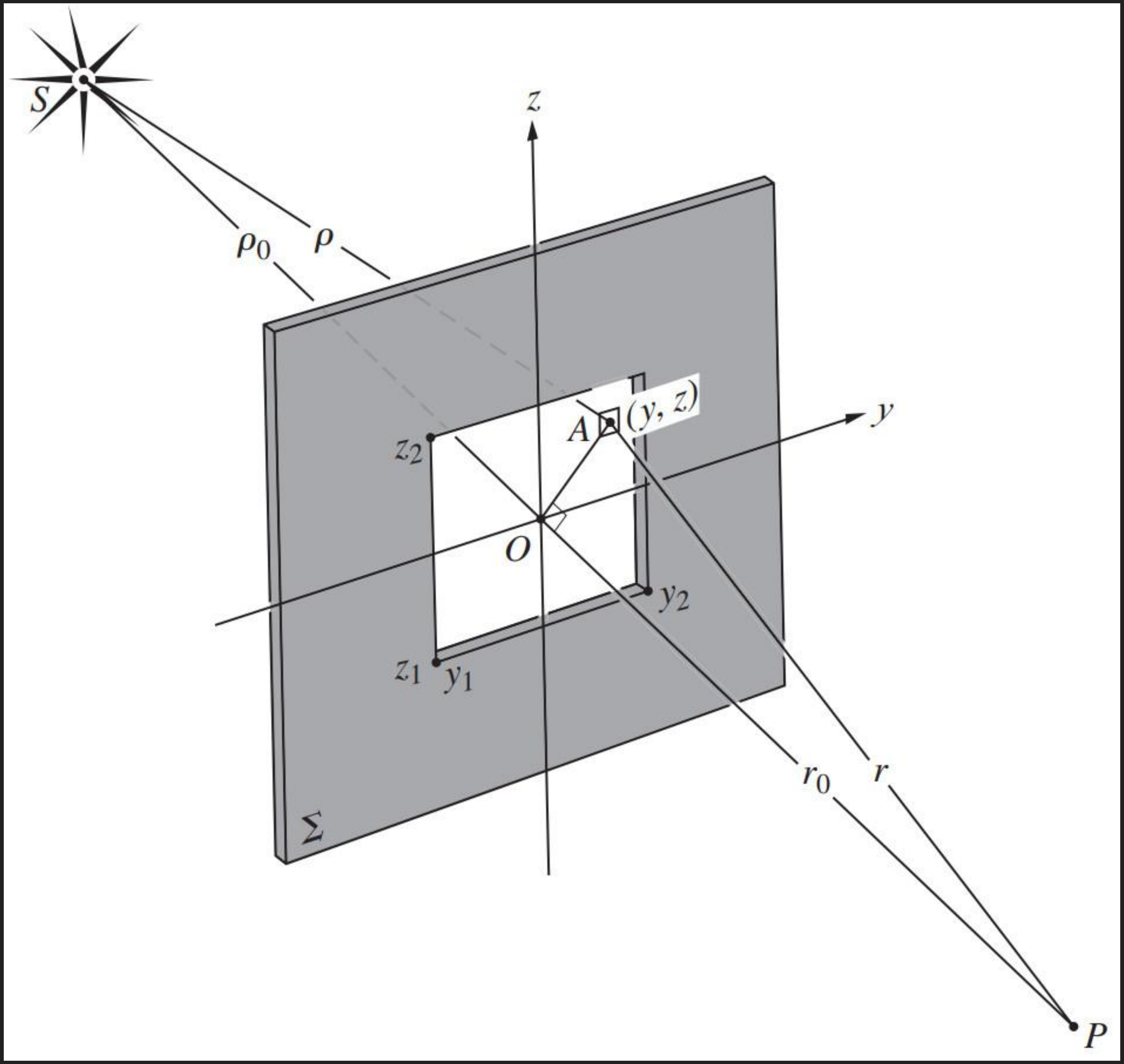
Square aperture



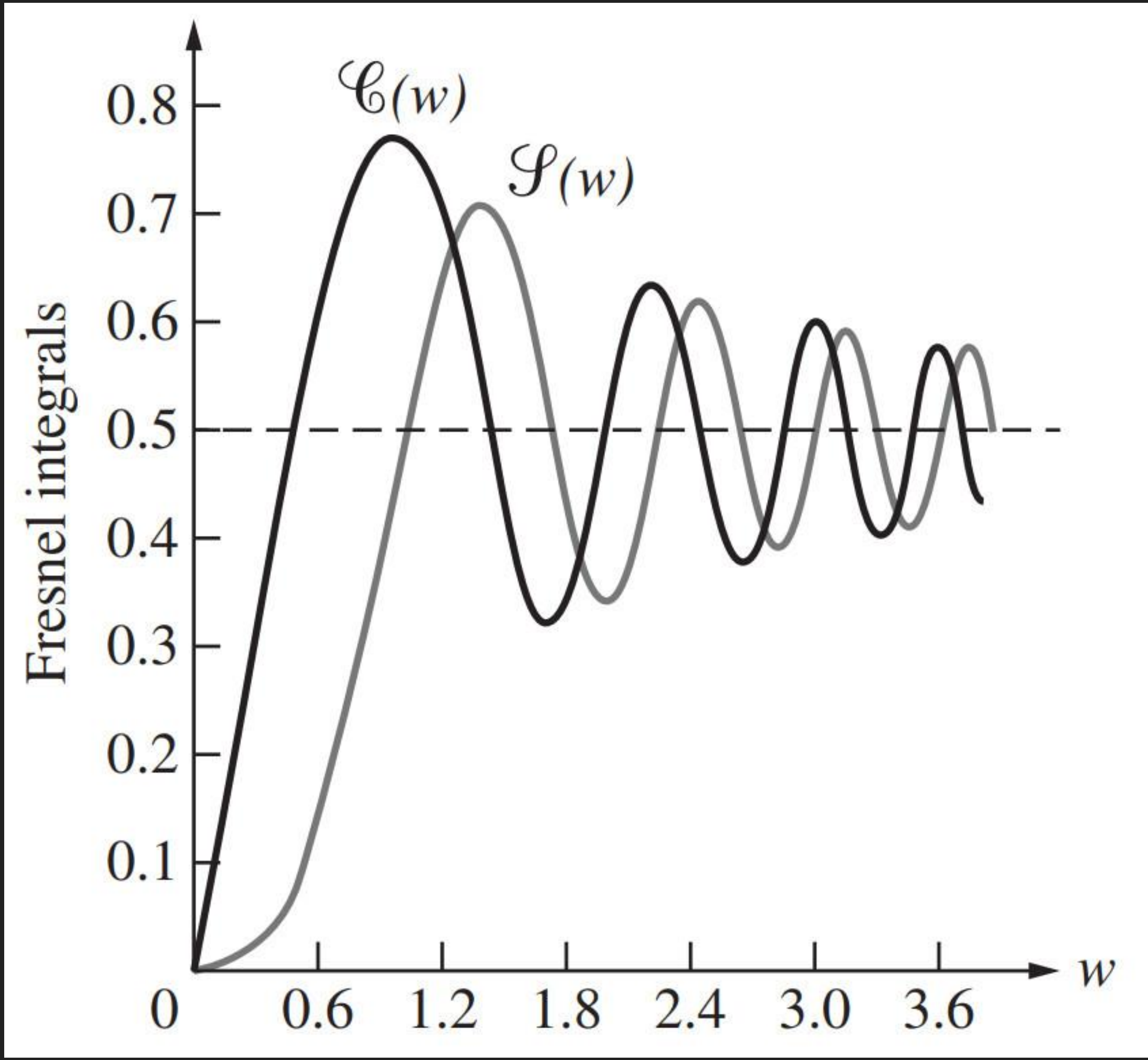
Obliquity factor



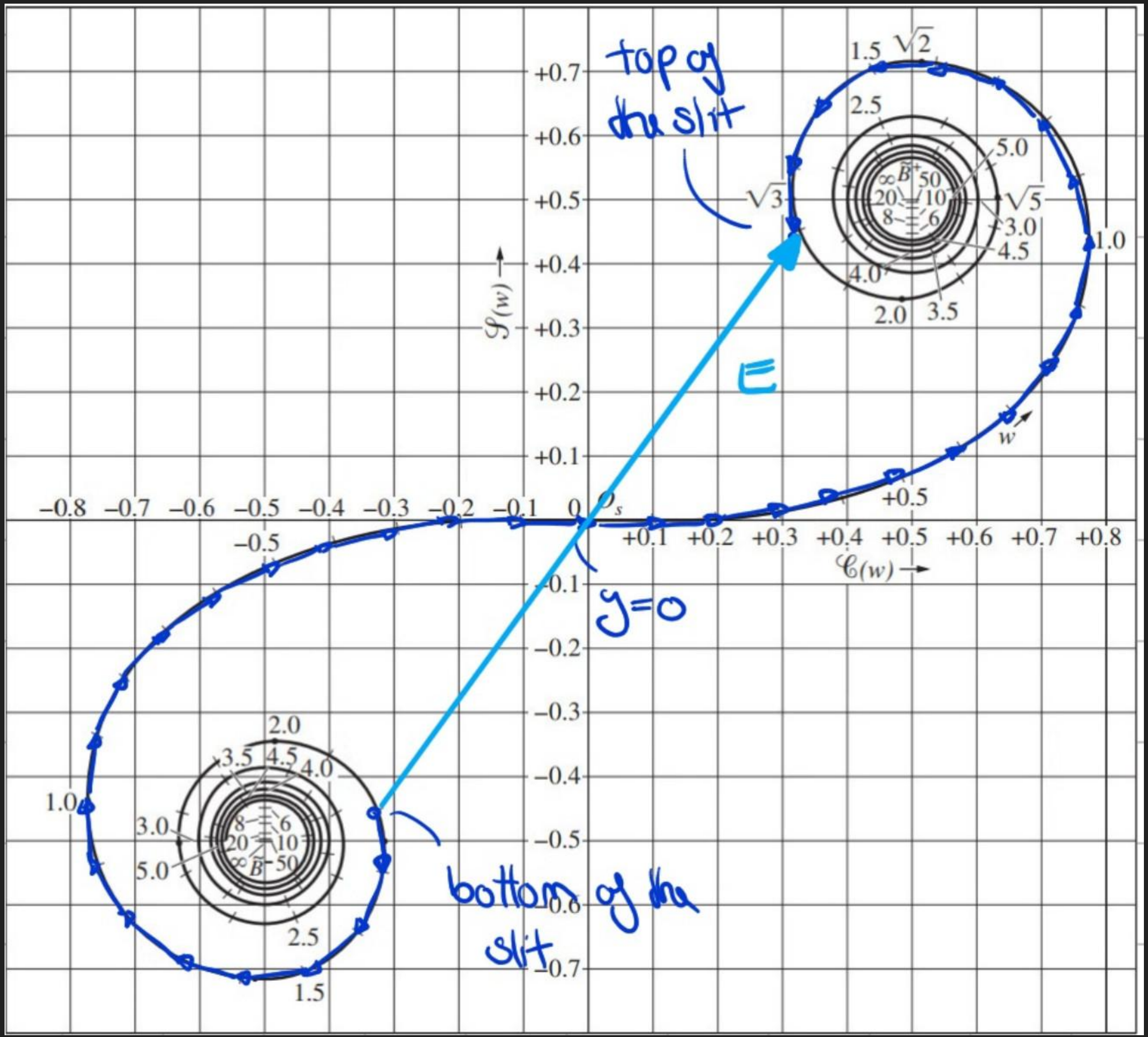
Rectangular aperture II



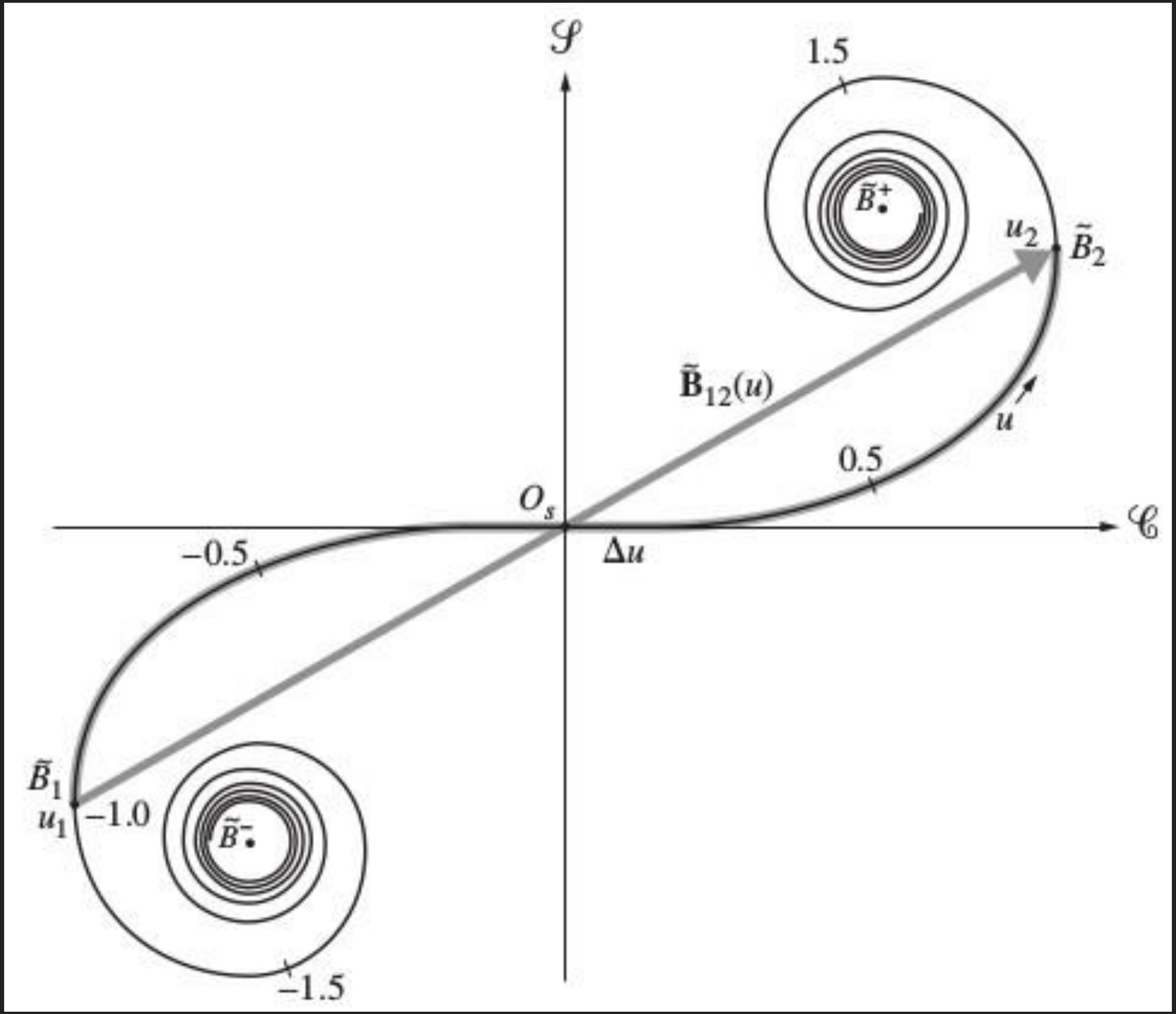
Fresnel integrals



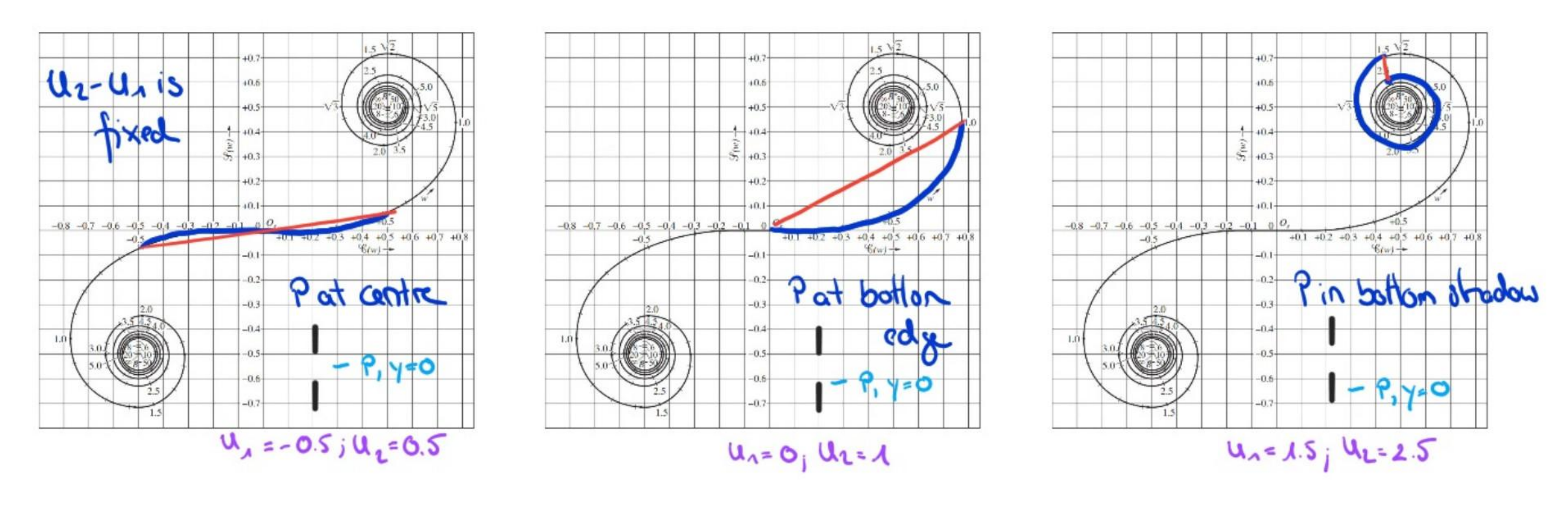
Cornu spiral I



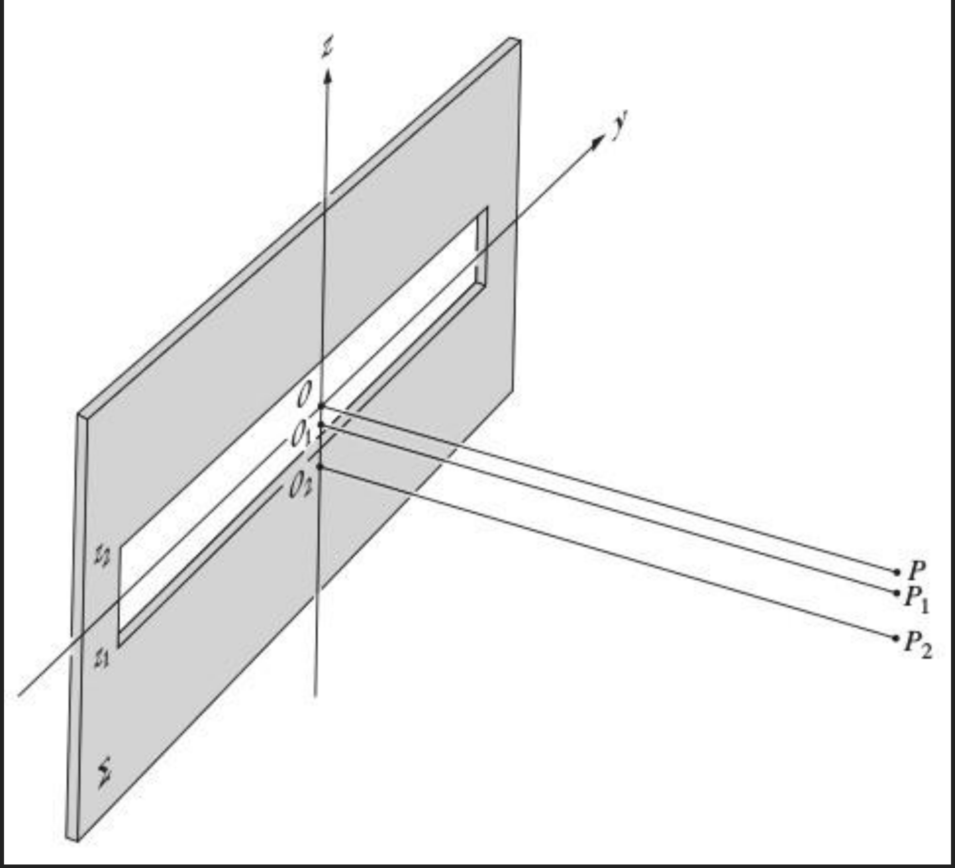
Cornu spiral II

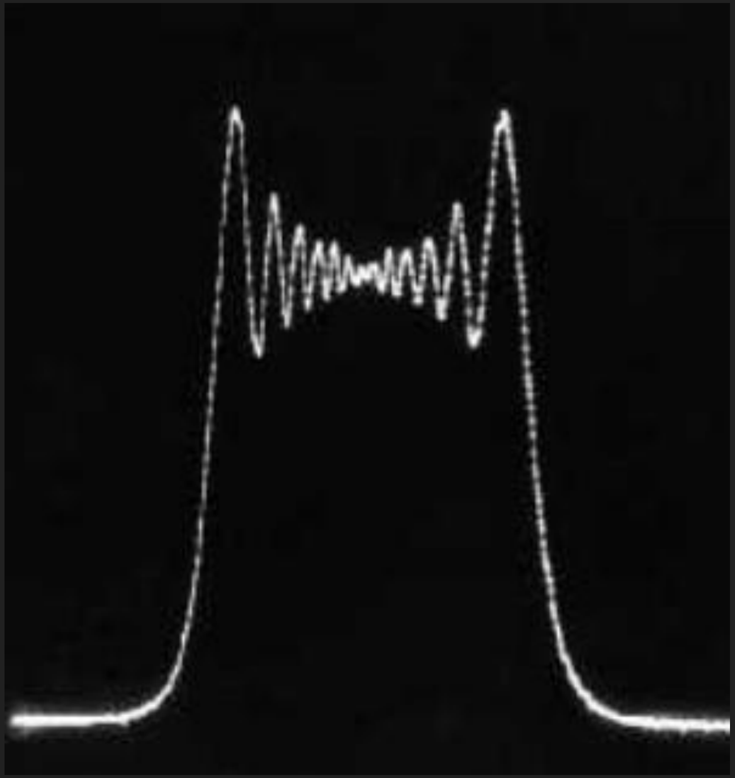


Cornu spiral III

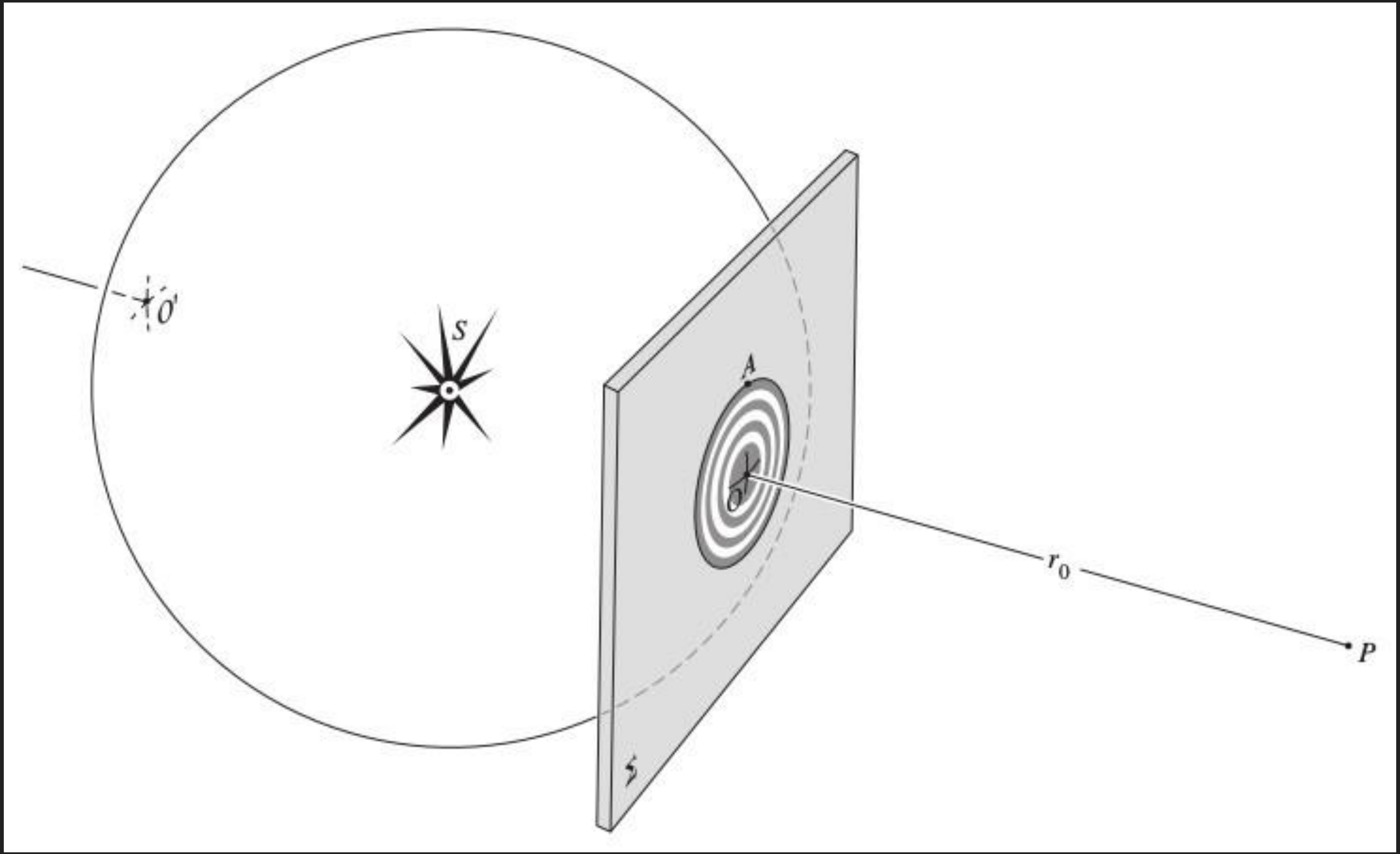


Slit

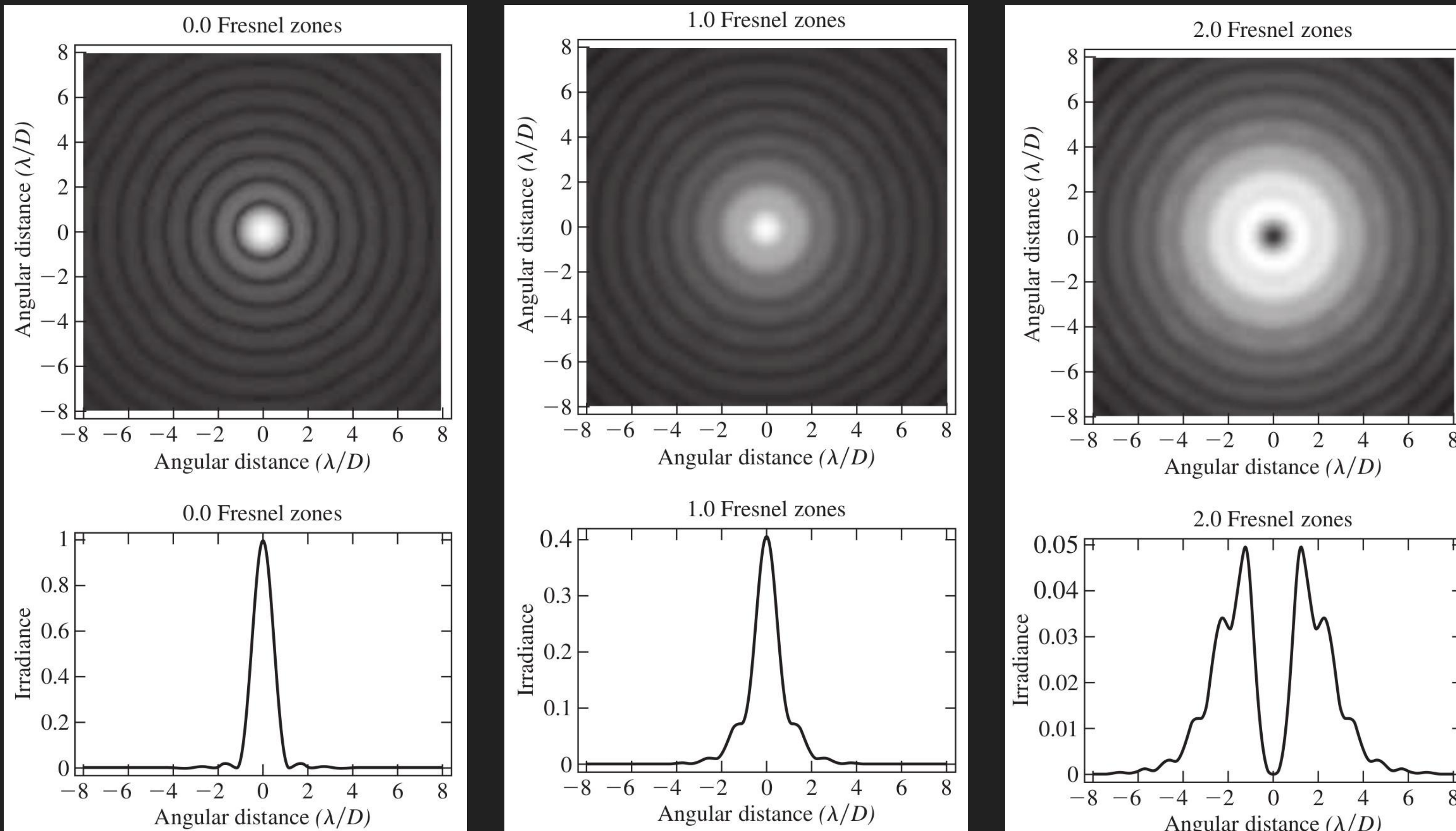




Circular aperture



Fresnel zones



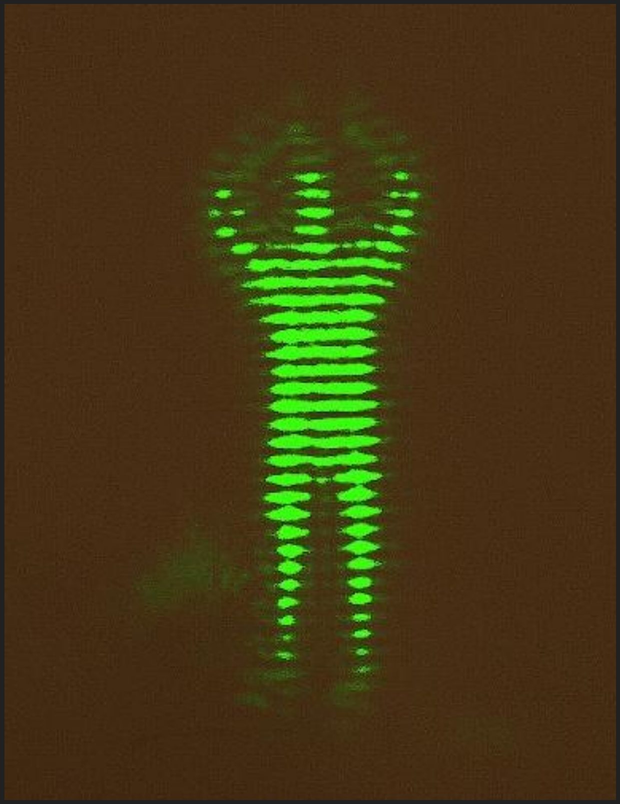
Summary Lecture 20

- 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.

PHYS 434 Optics

Lecture 21: Fourier Transforms / Optics

Reading: 11.1 - 11.3



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 require-ments 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.
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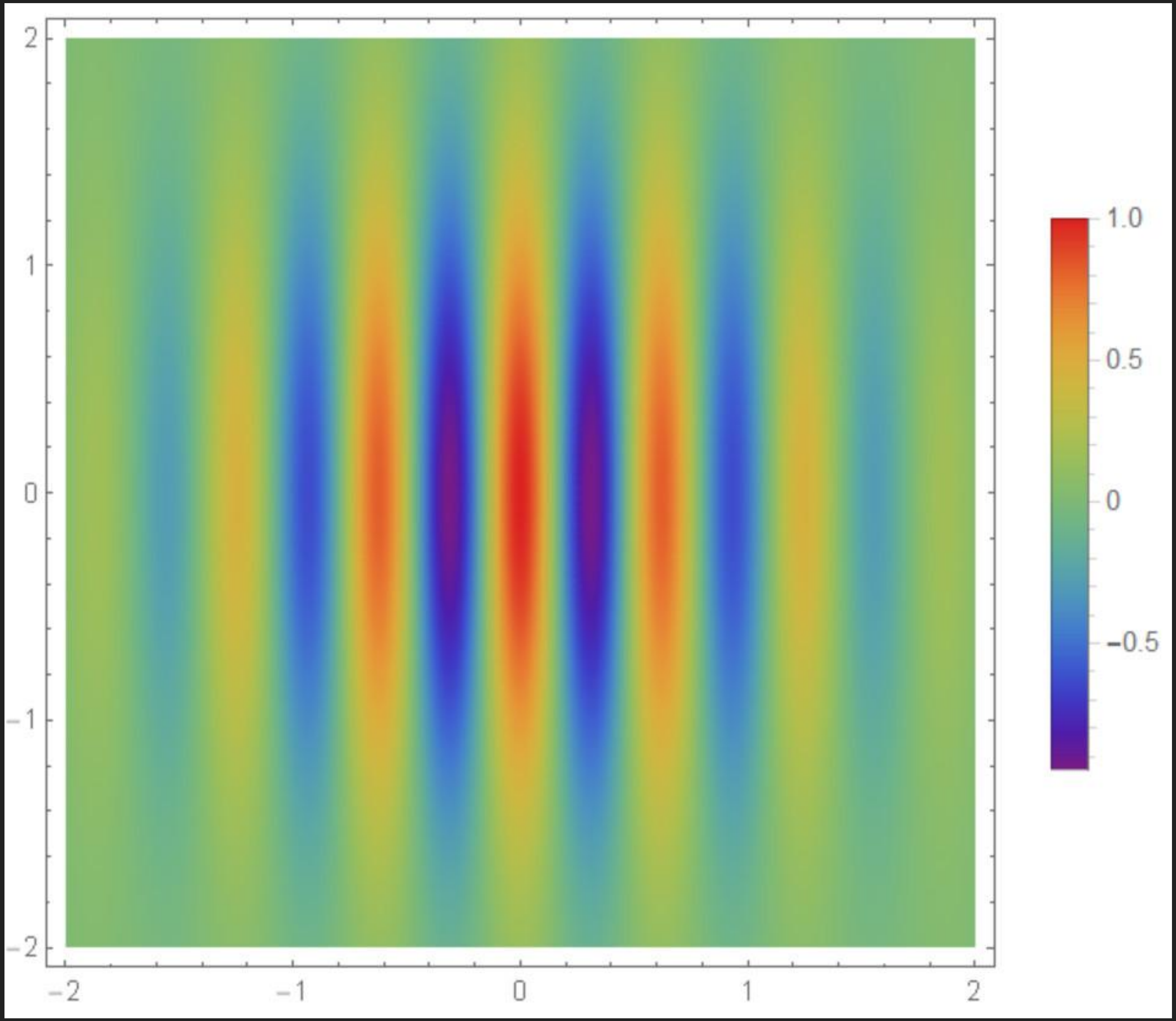
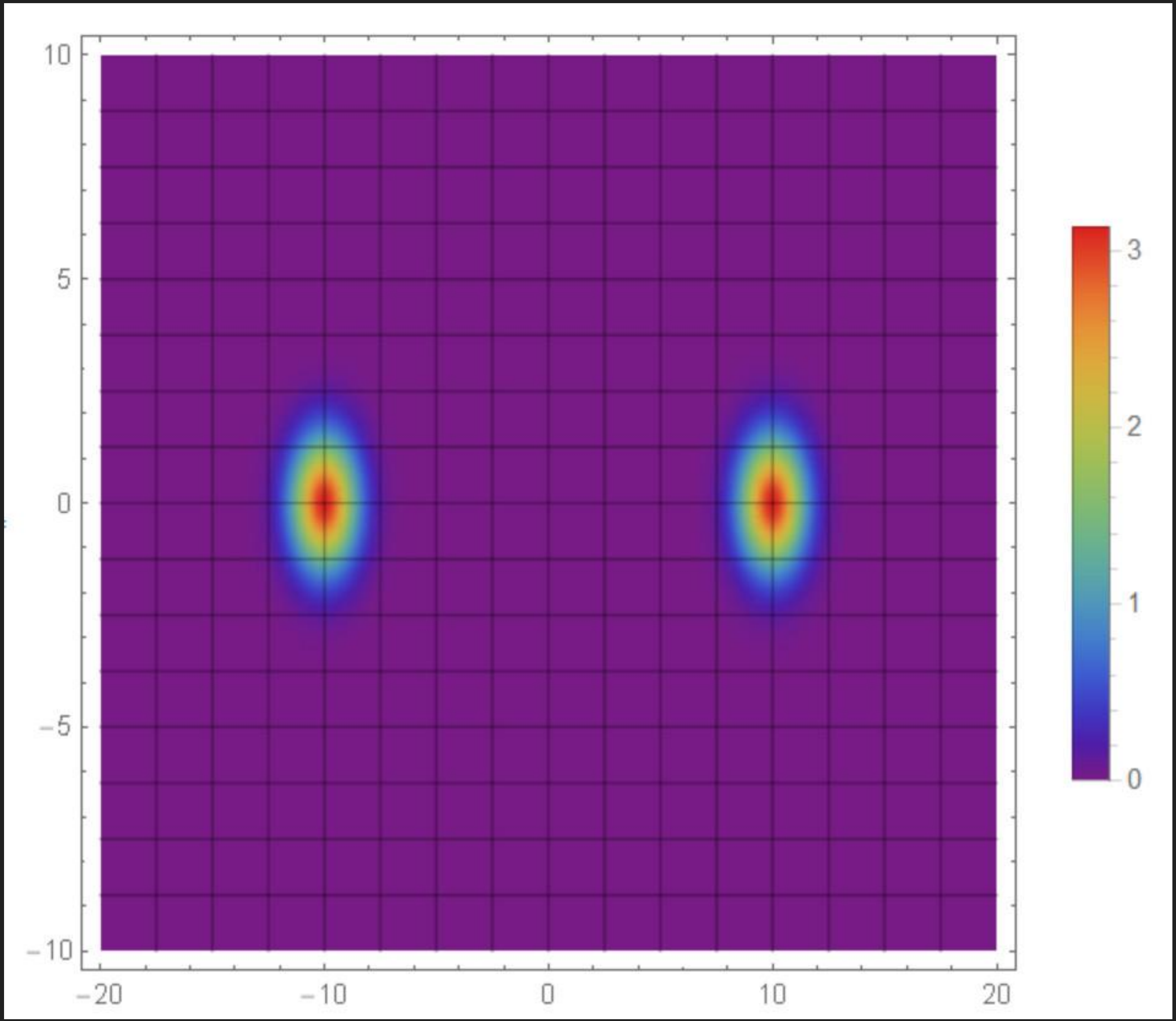
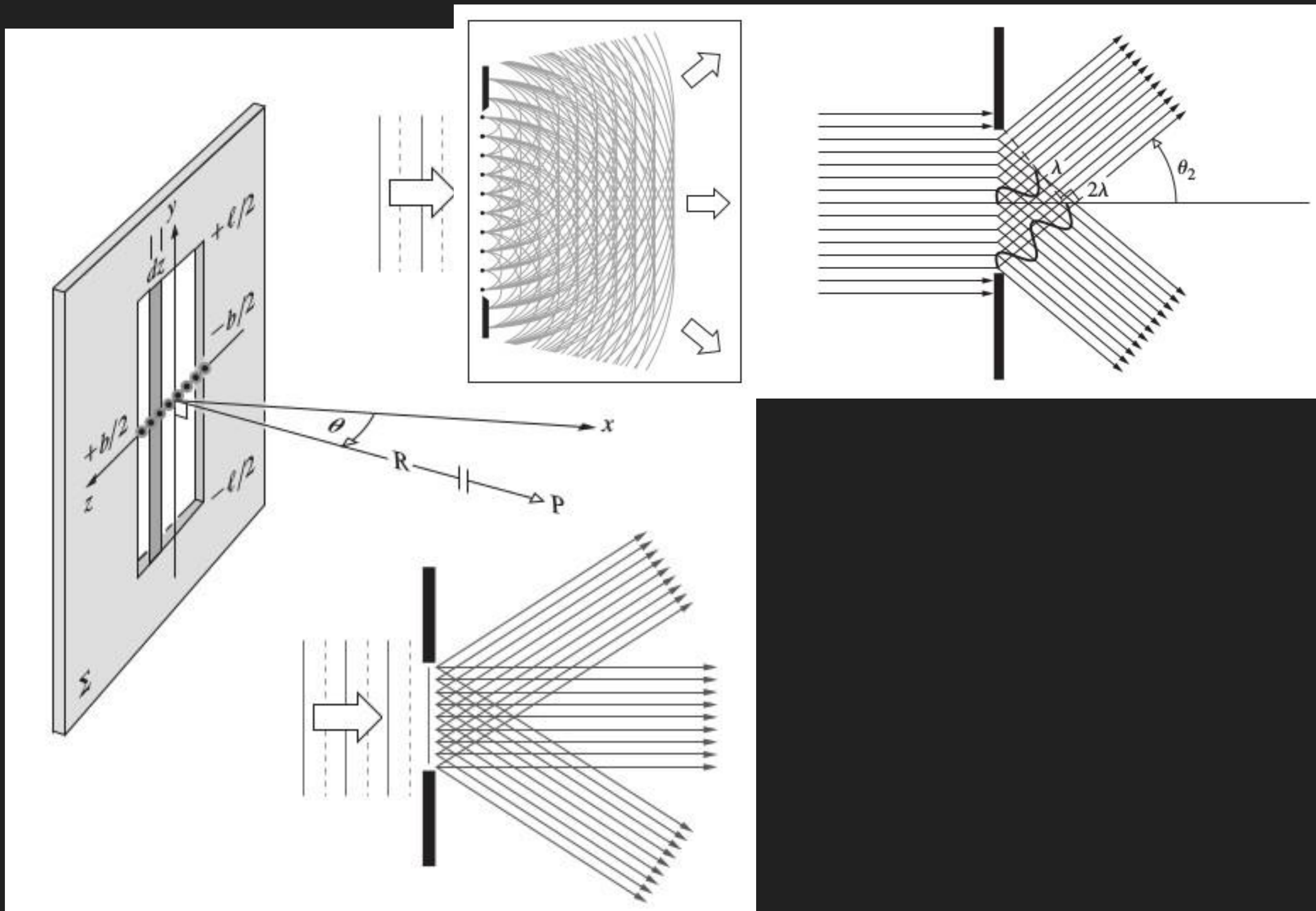
2D Signal



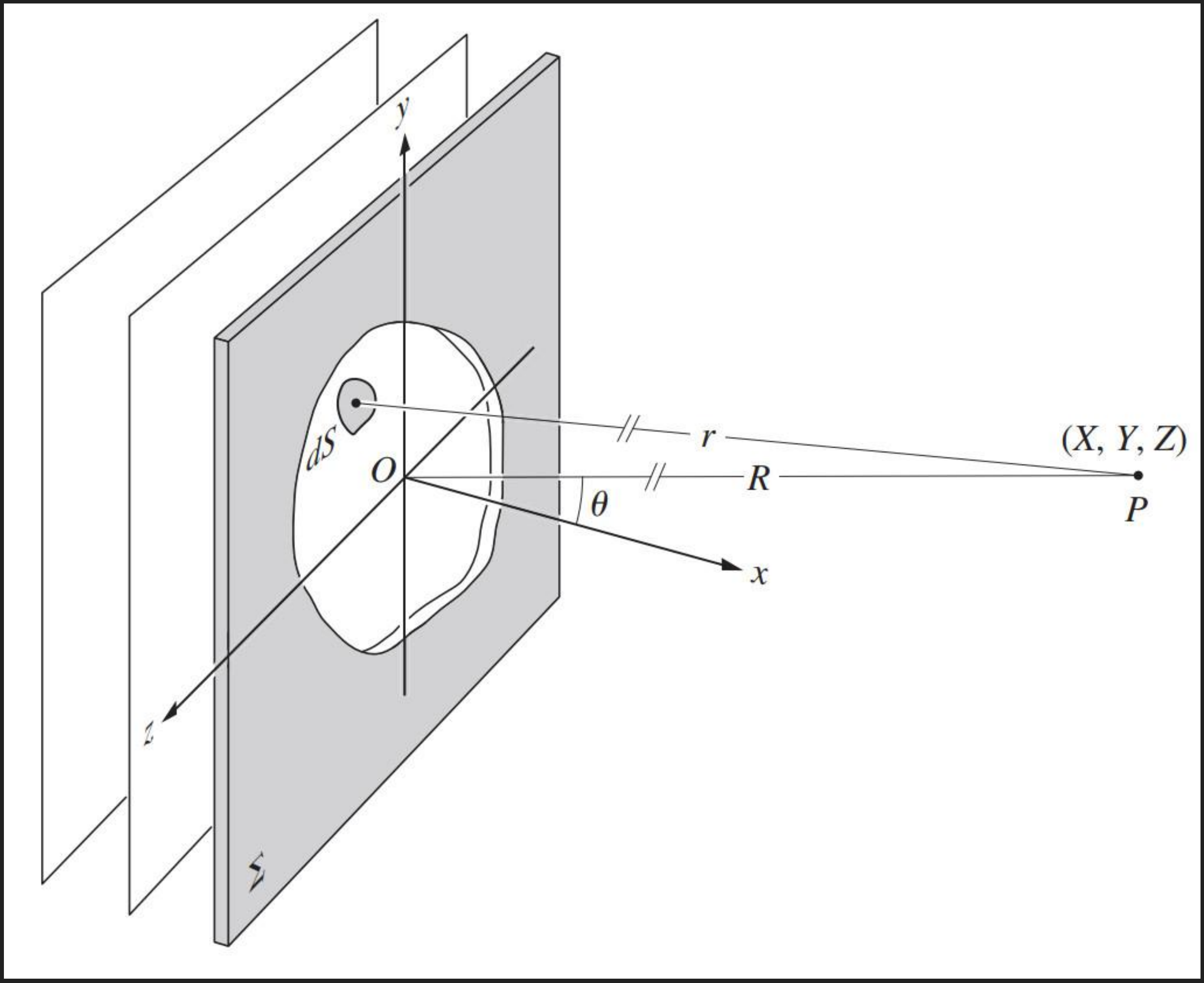
2D Fourier transform



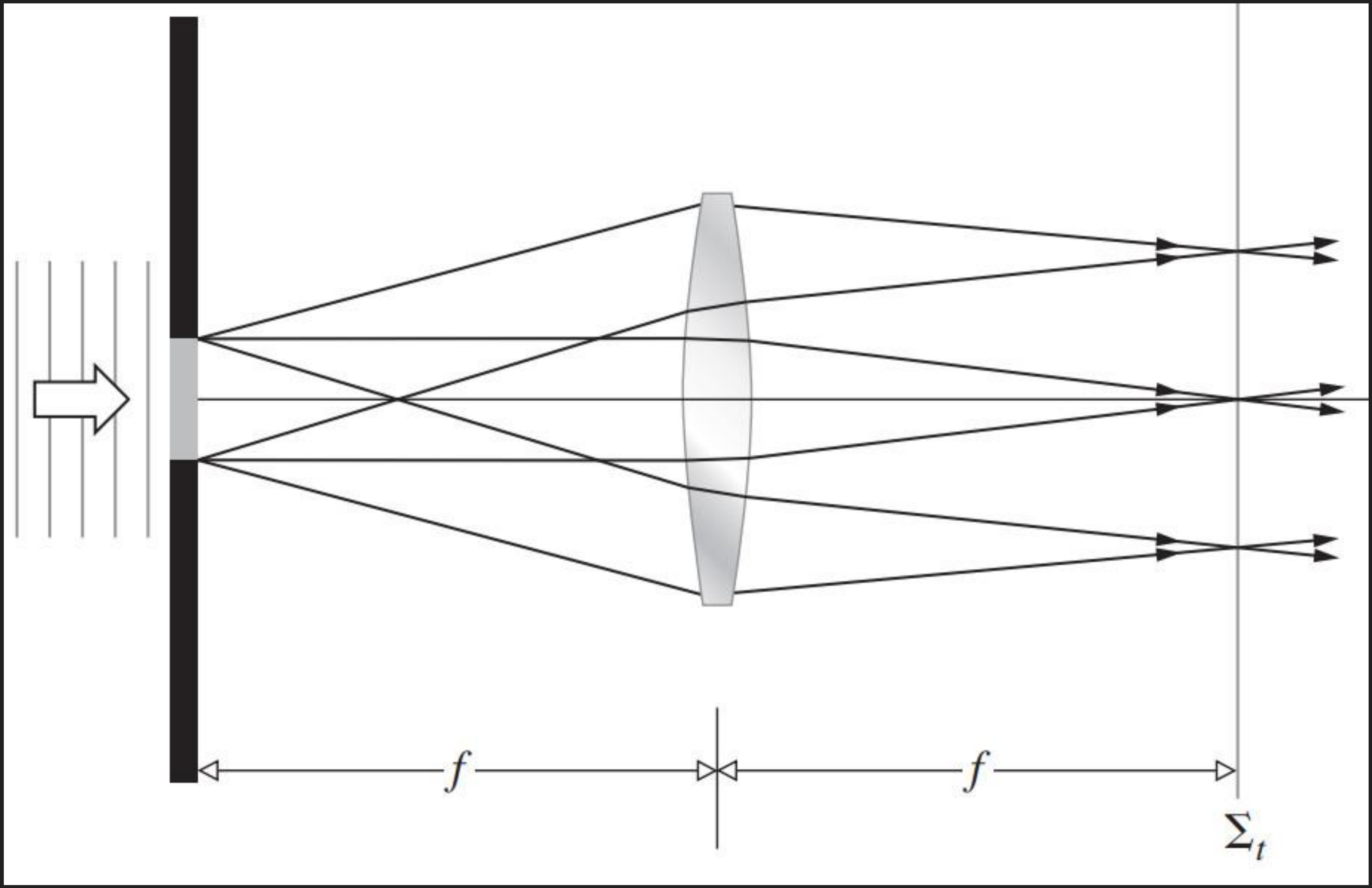
Fraunhofer diffraction I



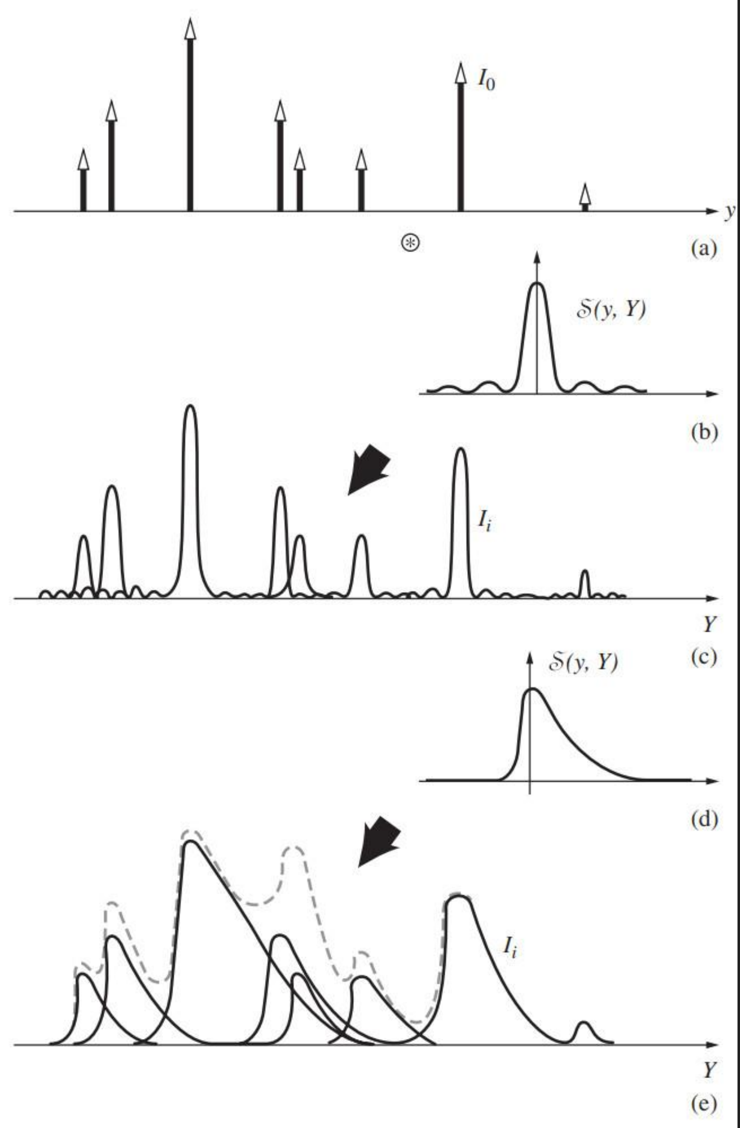
Fraunhofer diffraction II



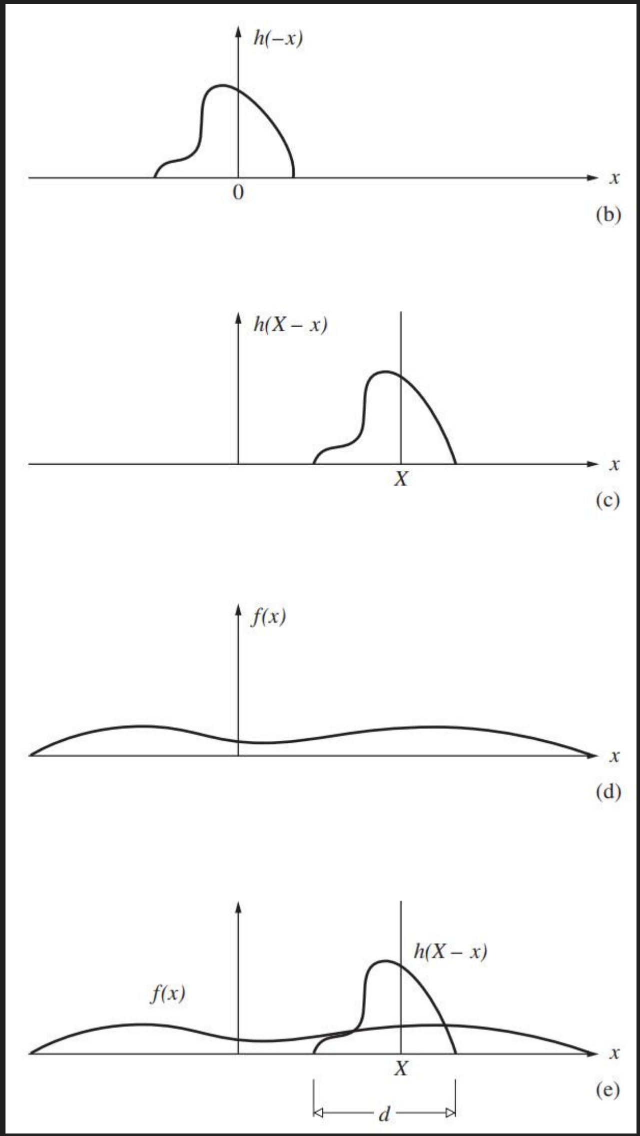
Lens as a Fourier transformer

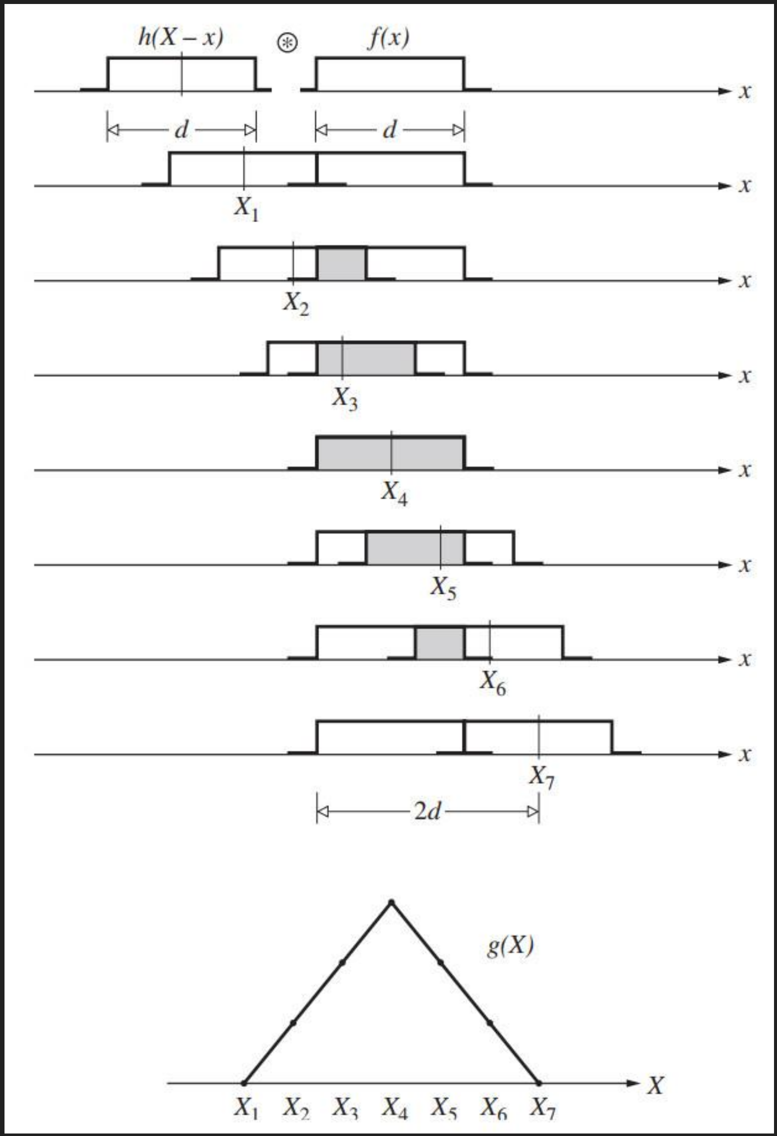


Convolution



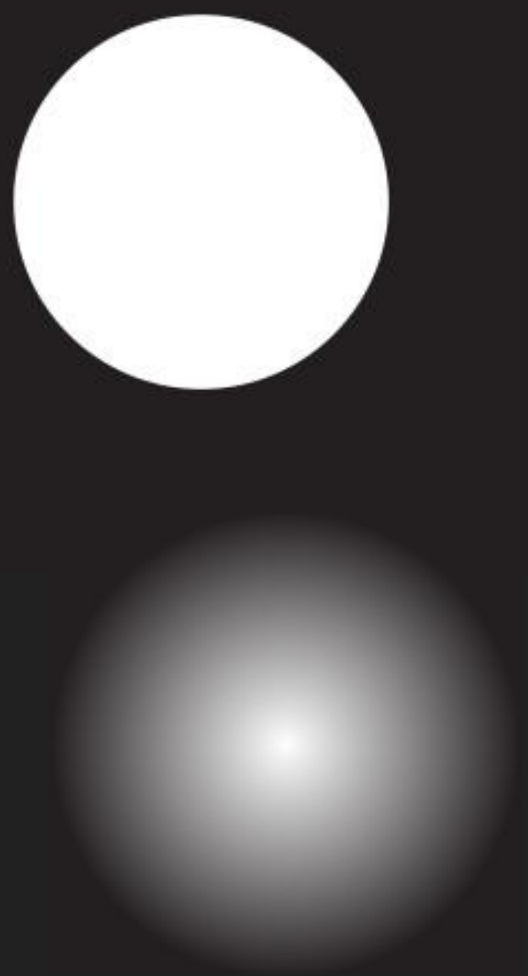
Convolution integral

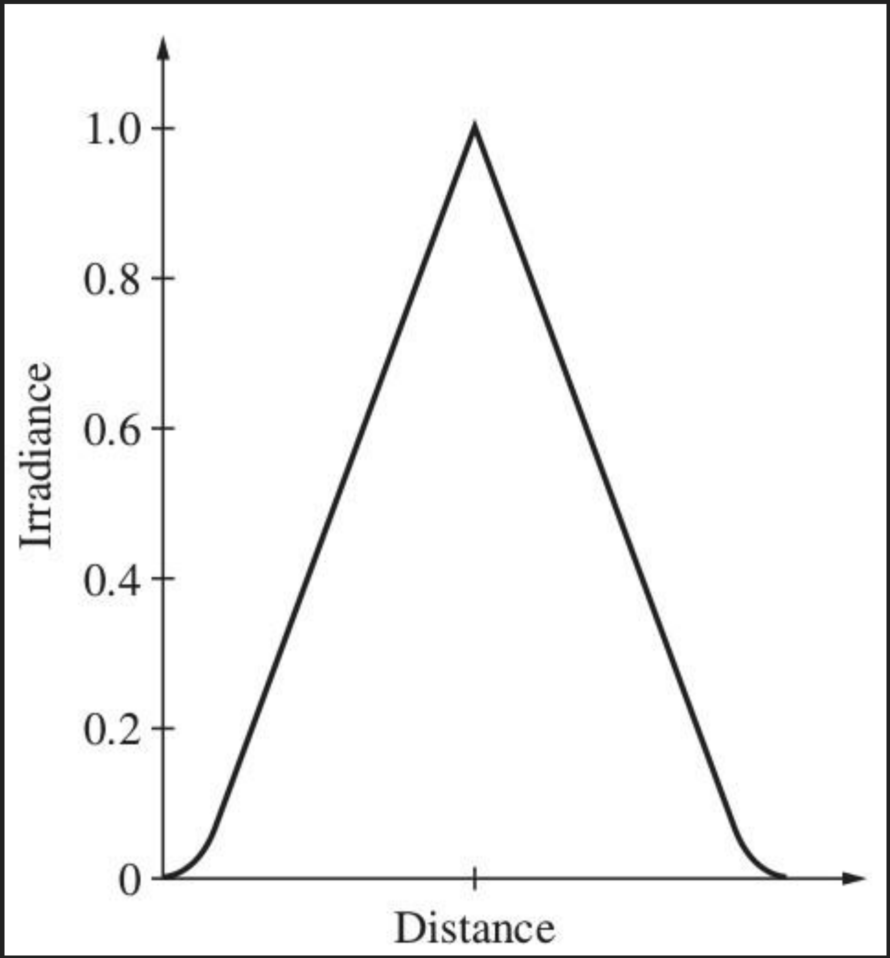




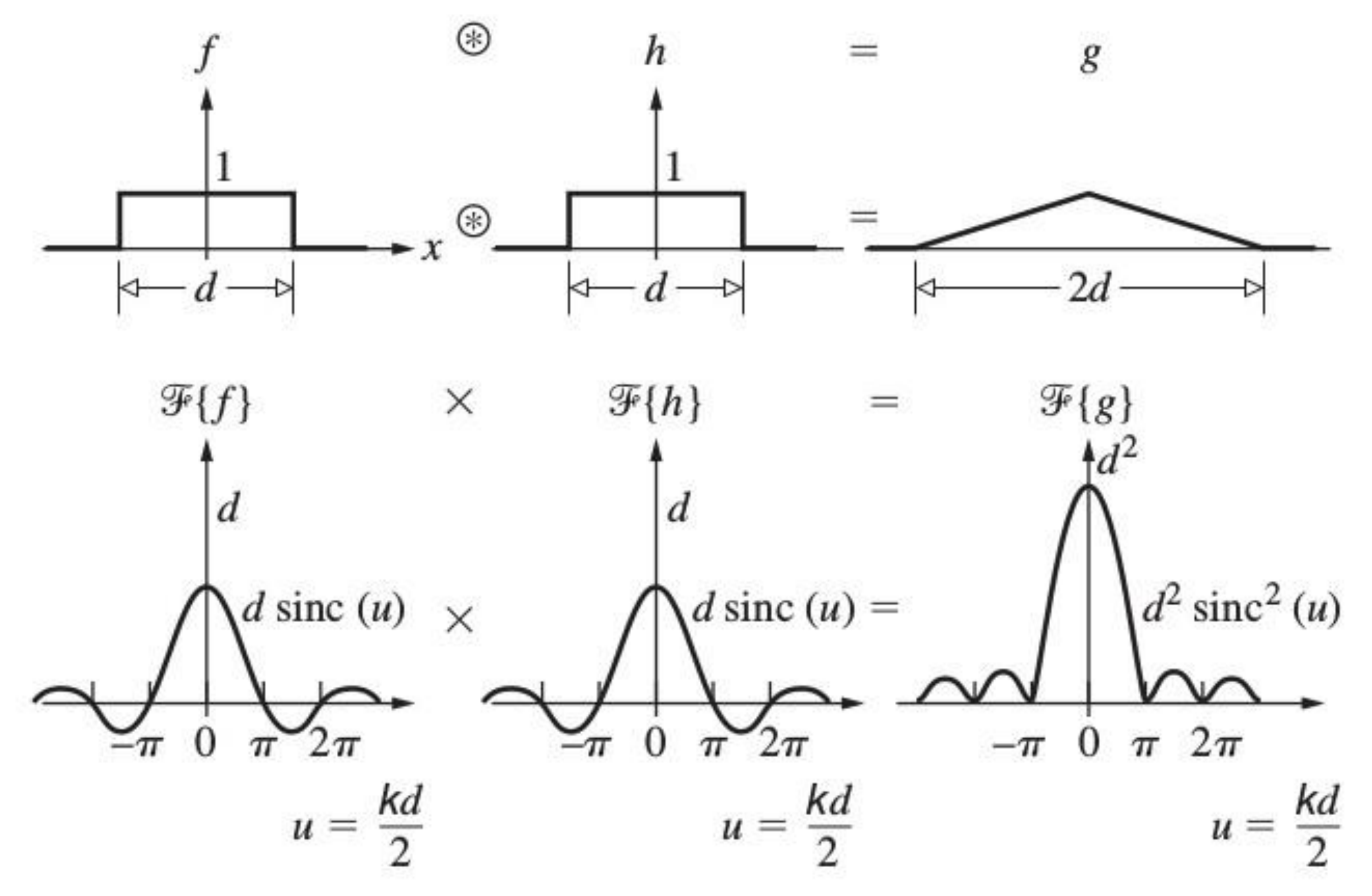
Convolution of a circle I

Convolution of a circle II

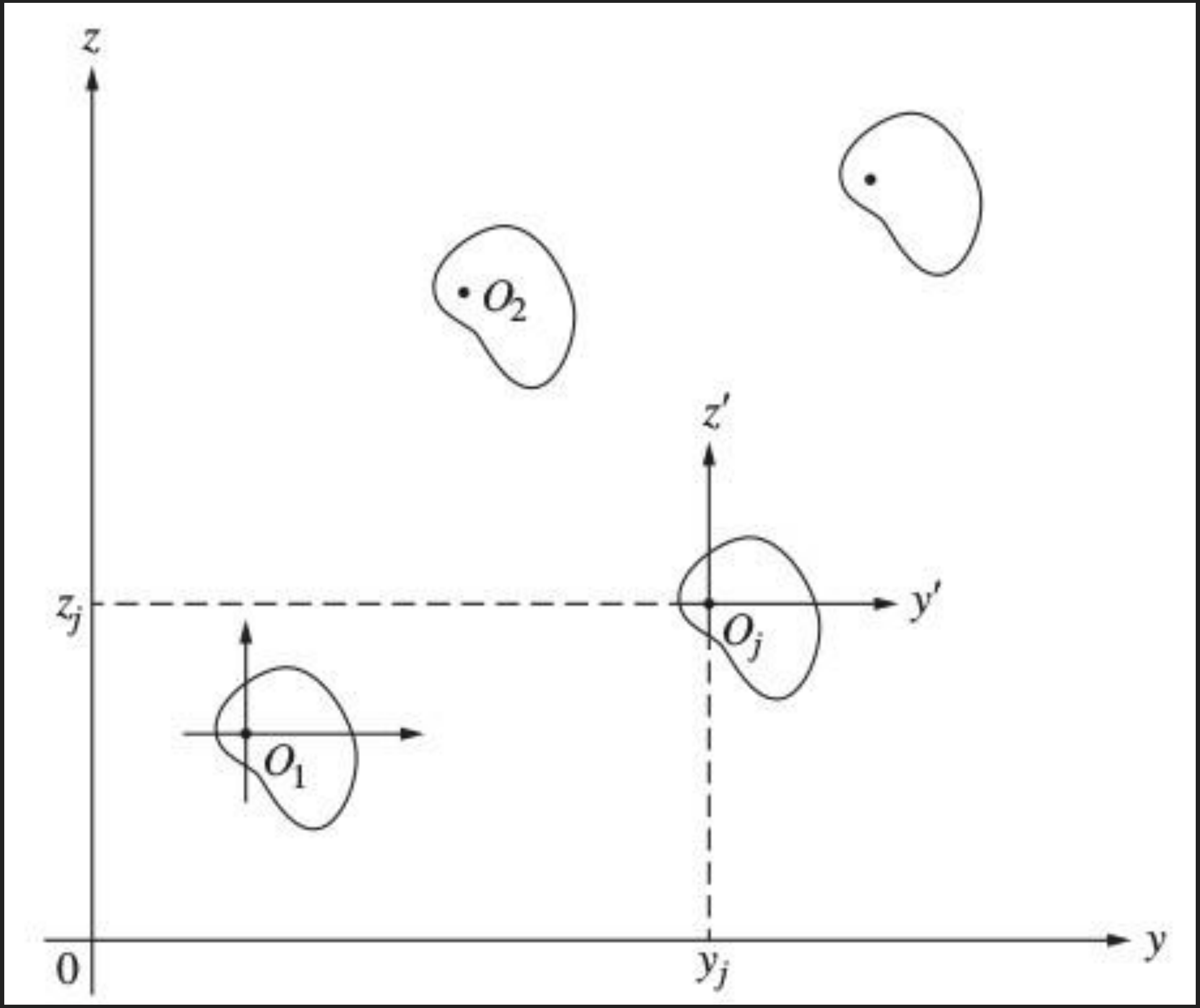




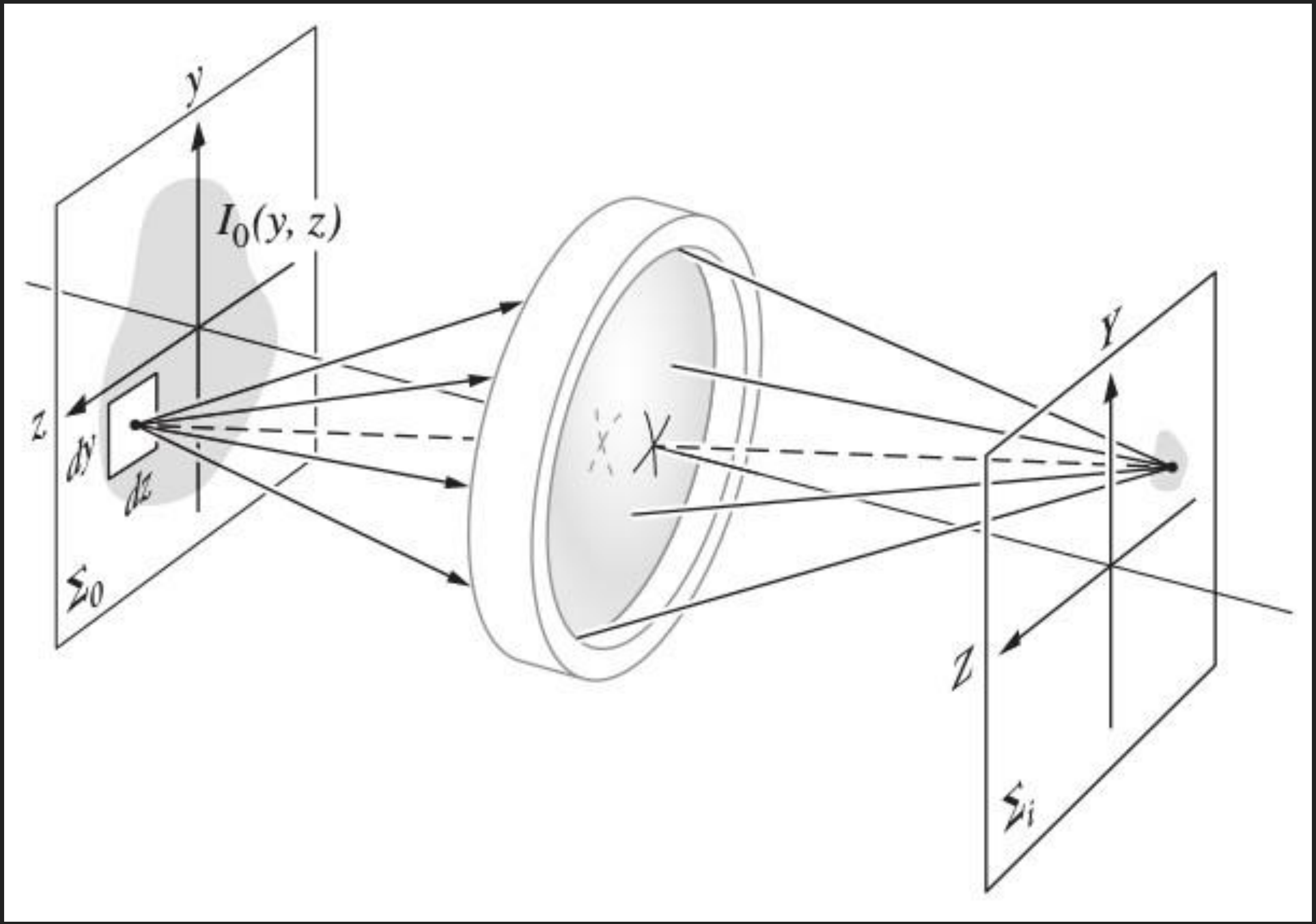
Convolution theorem



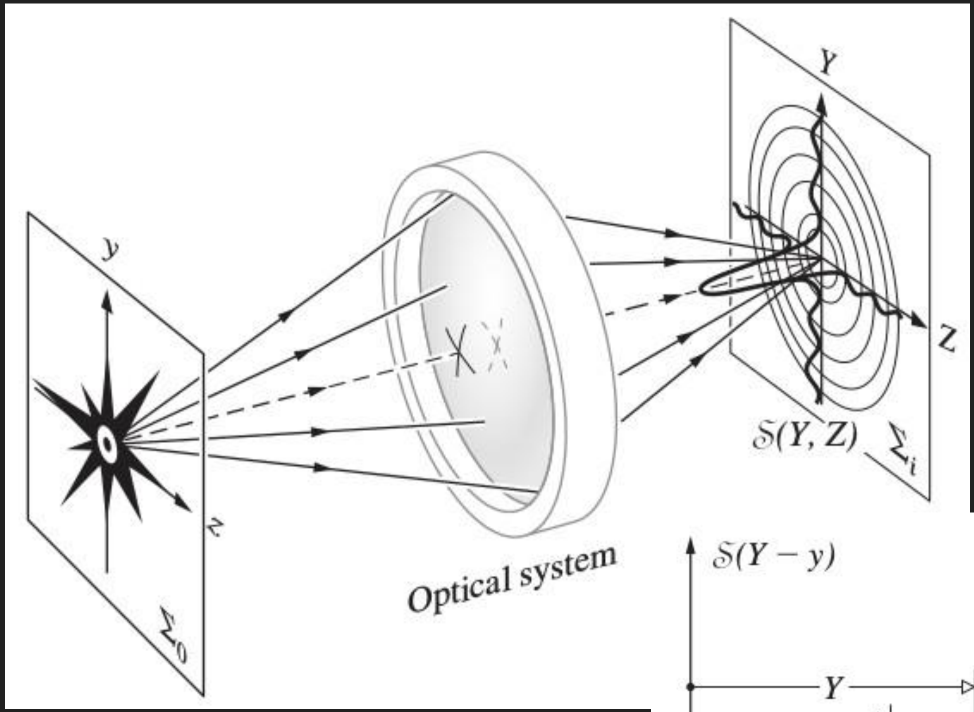
Array theorem

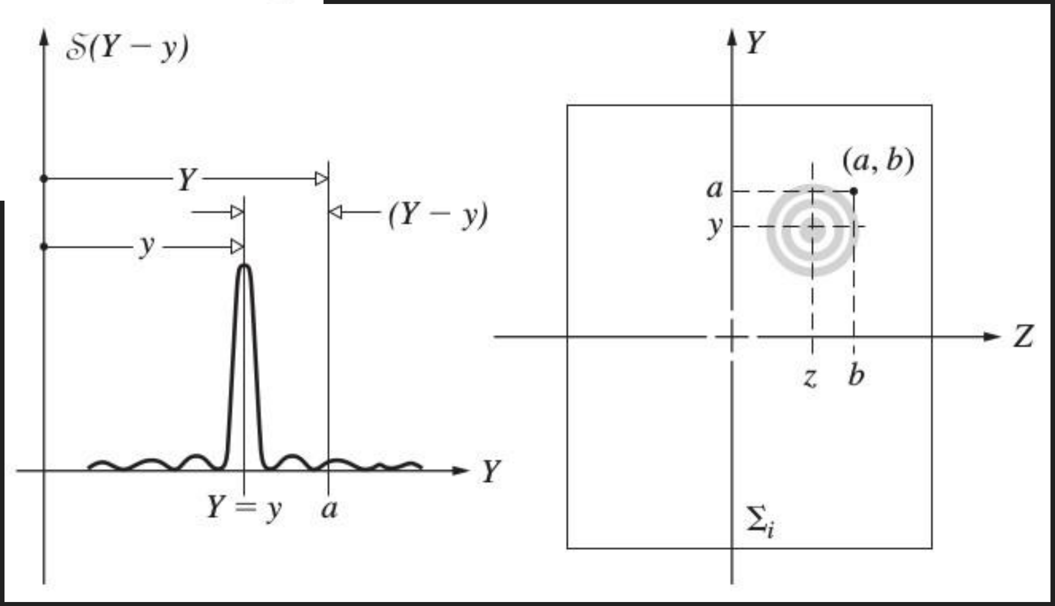


Imaging linear systems

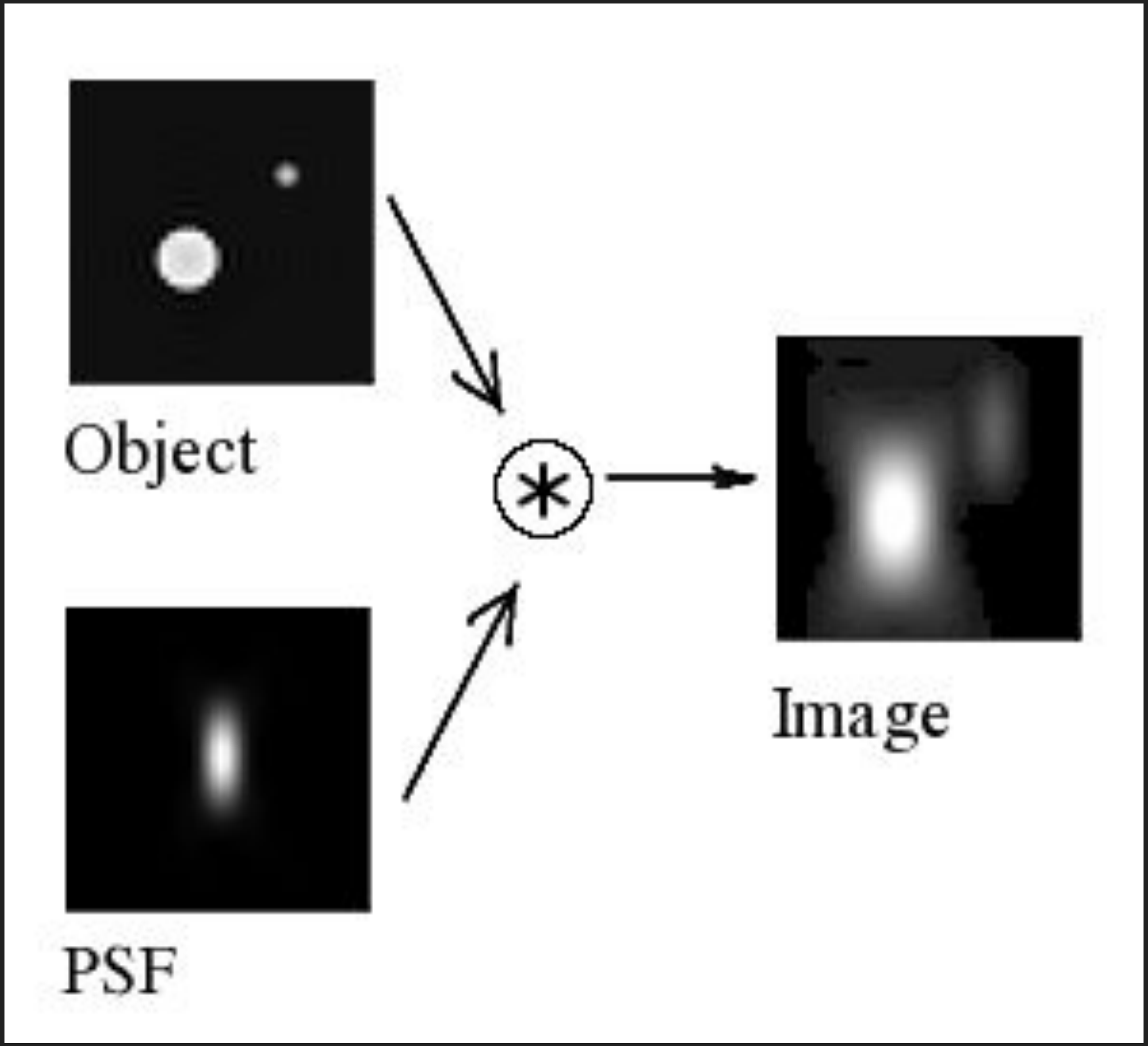


Point-spread function





Point-spread function II



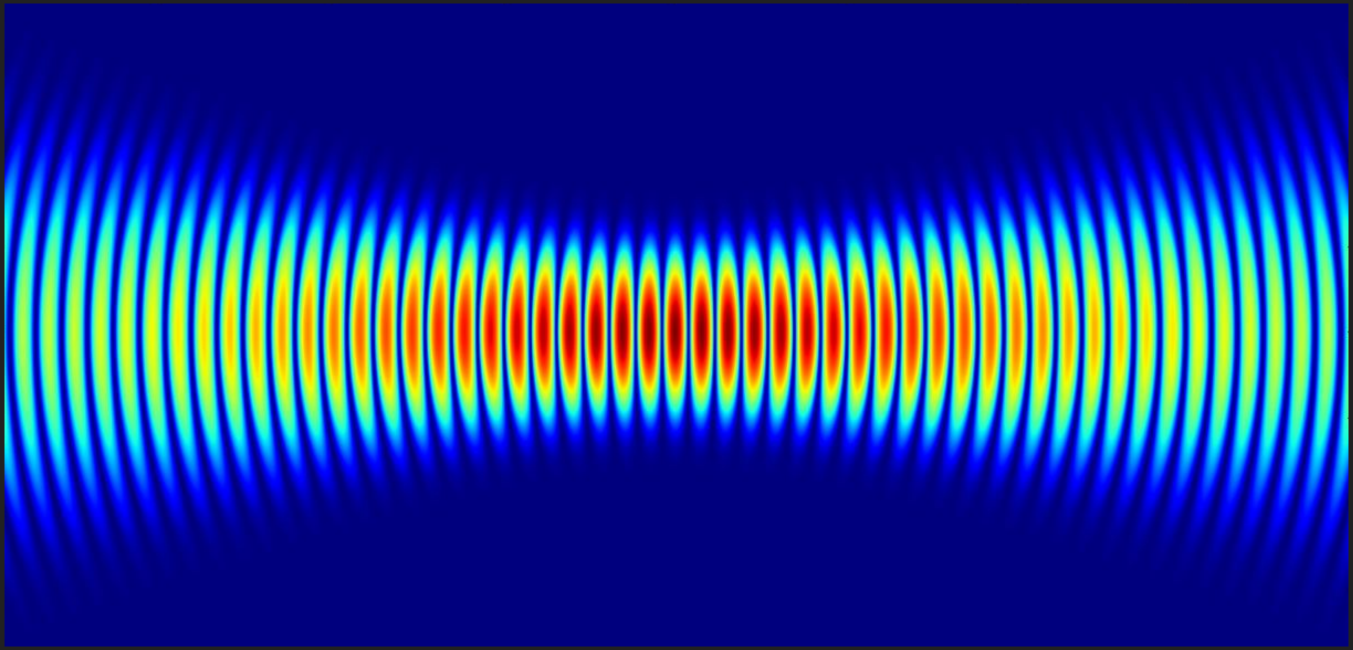
Summary Lecture 21

- 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.

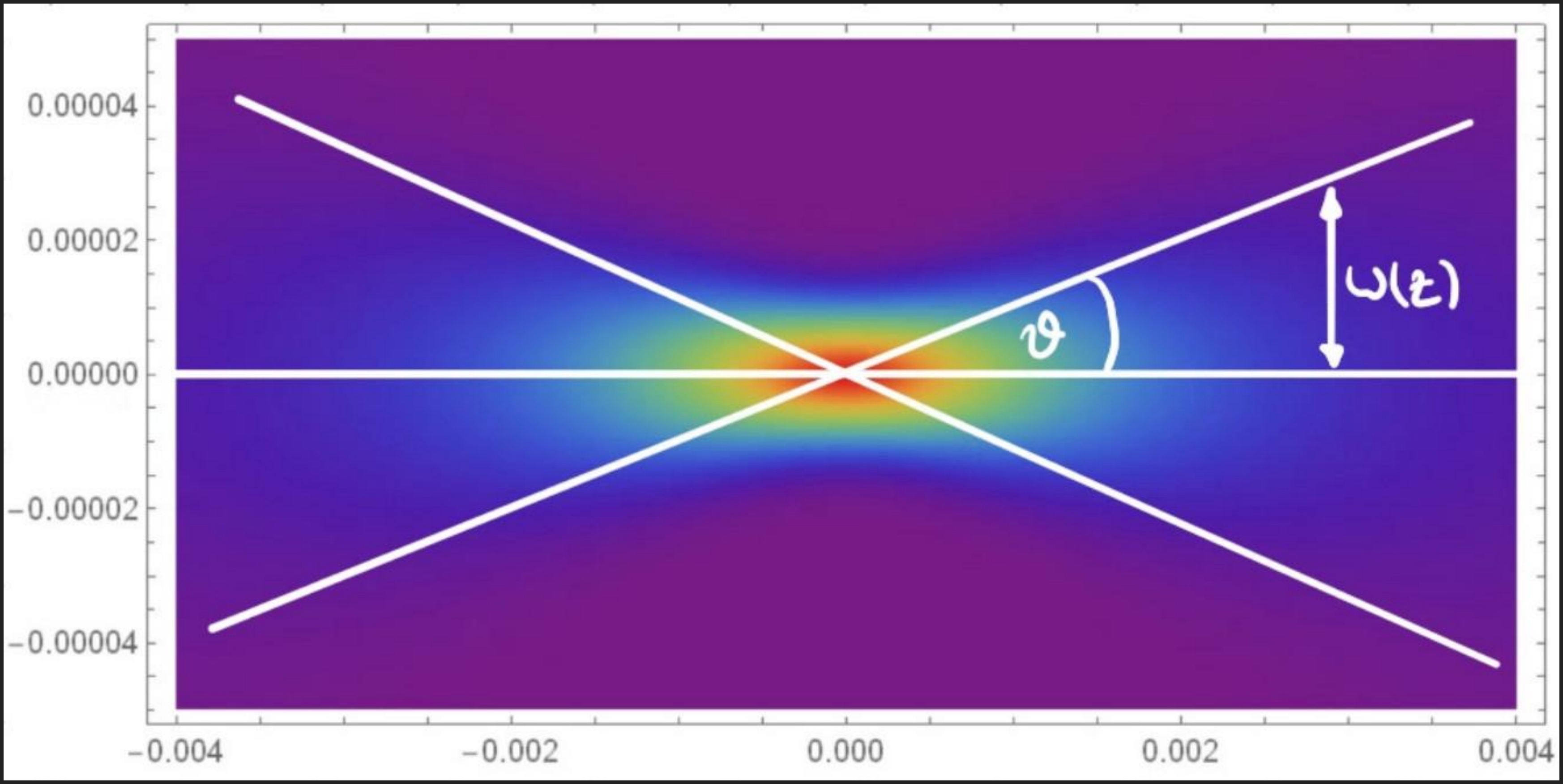
PHYS 434 Optics

Lecture 24: Gaussian Beams, Lens Transformations

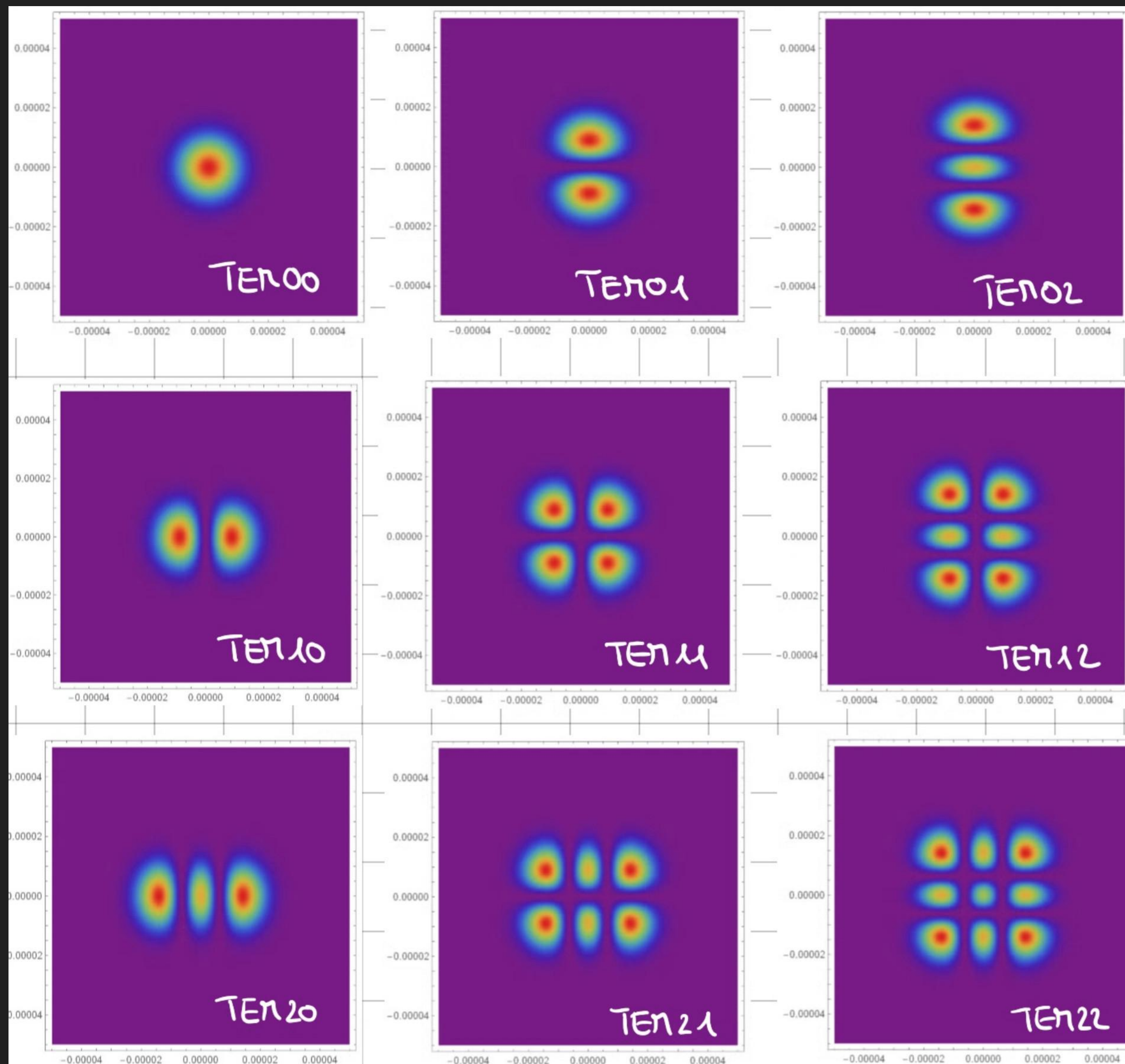
Reading: 13.1



Divergence angle



Higher-order modes



Summary Lecture 24

- 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

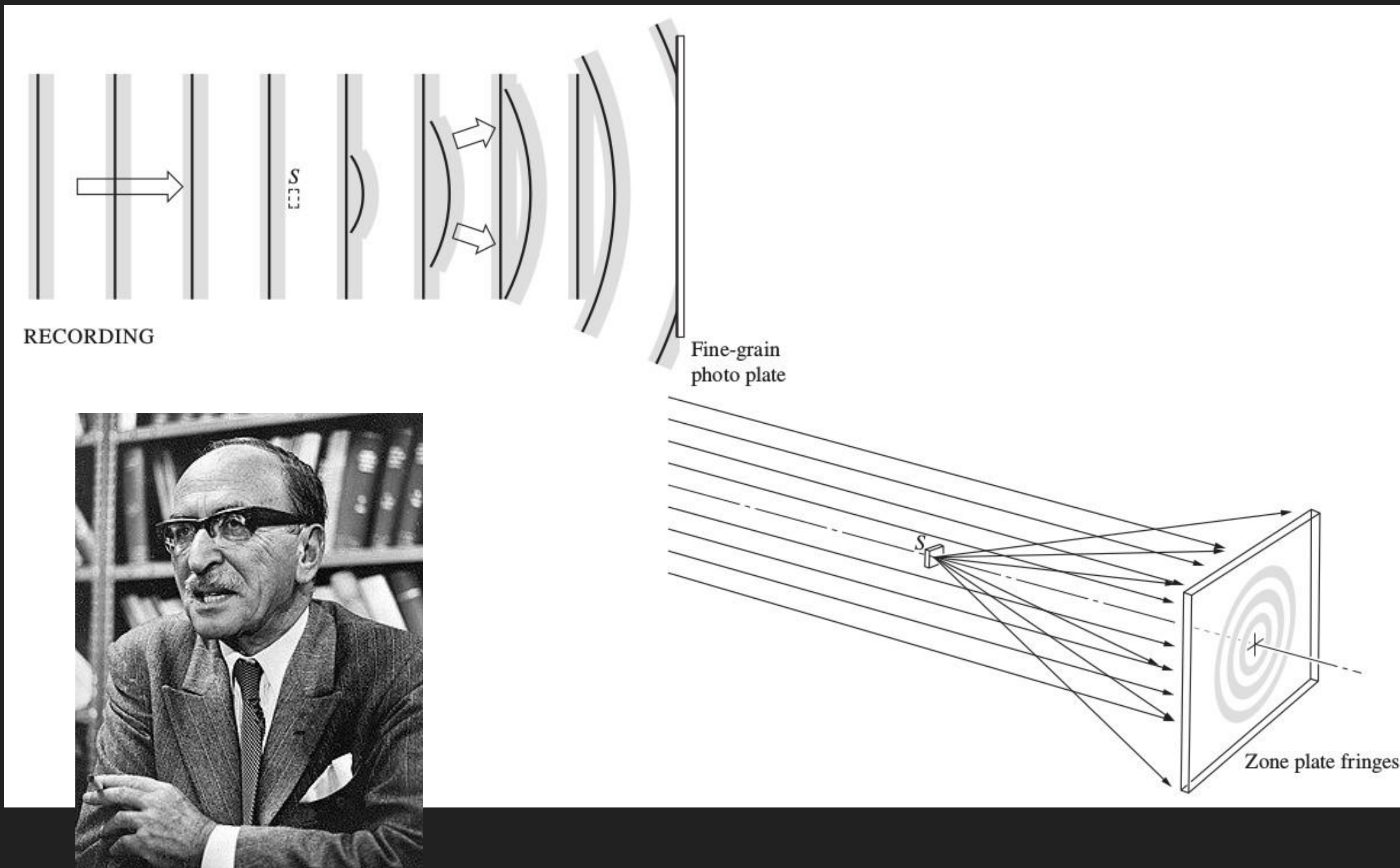
Admin

- 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.

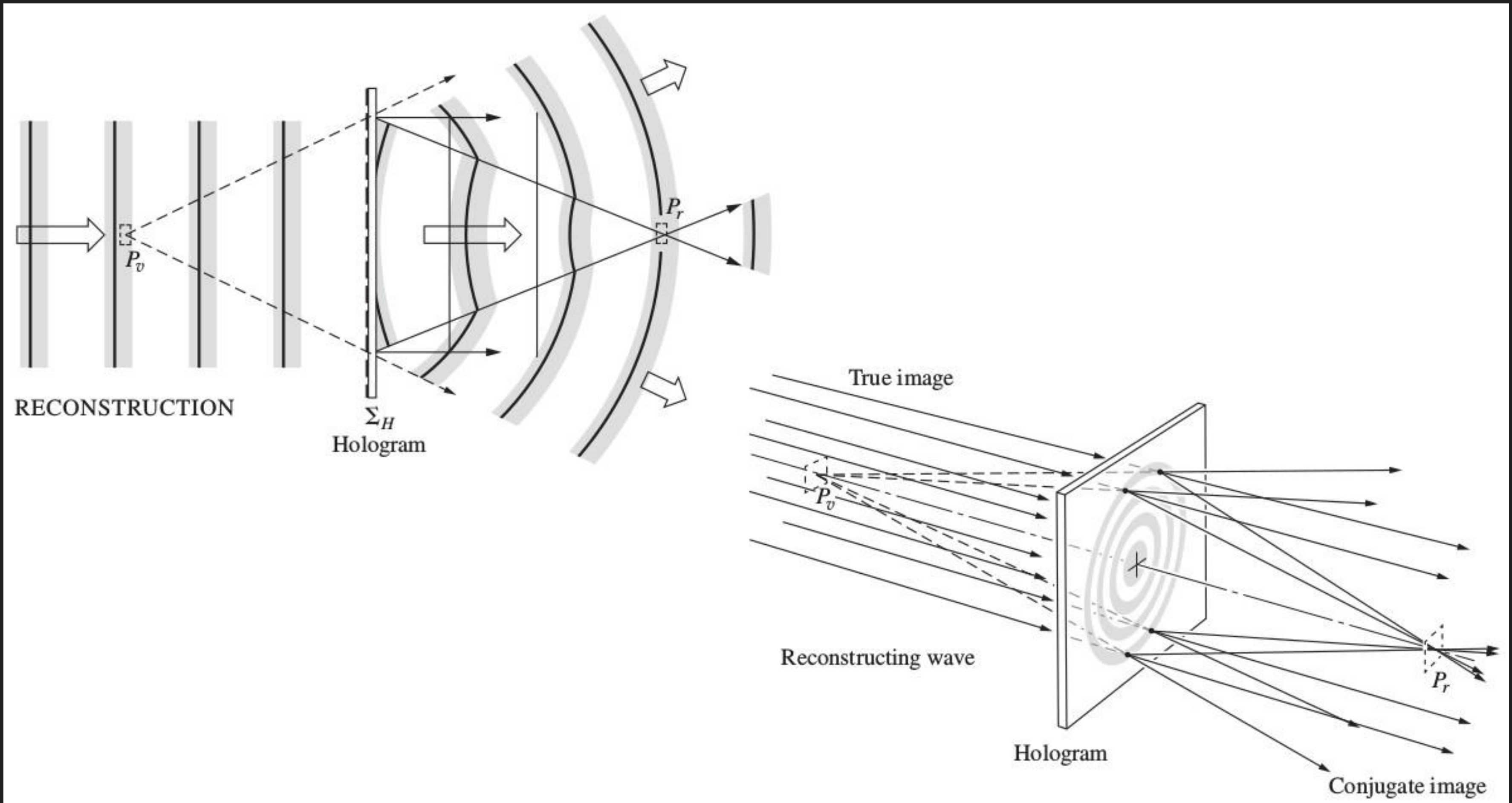
Summary Lecture 24

- 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).

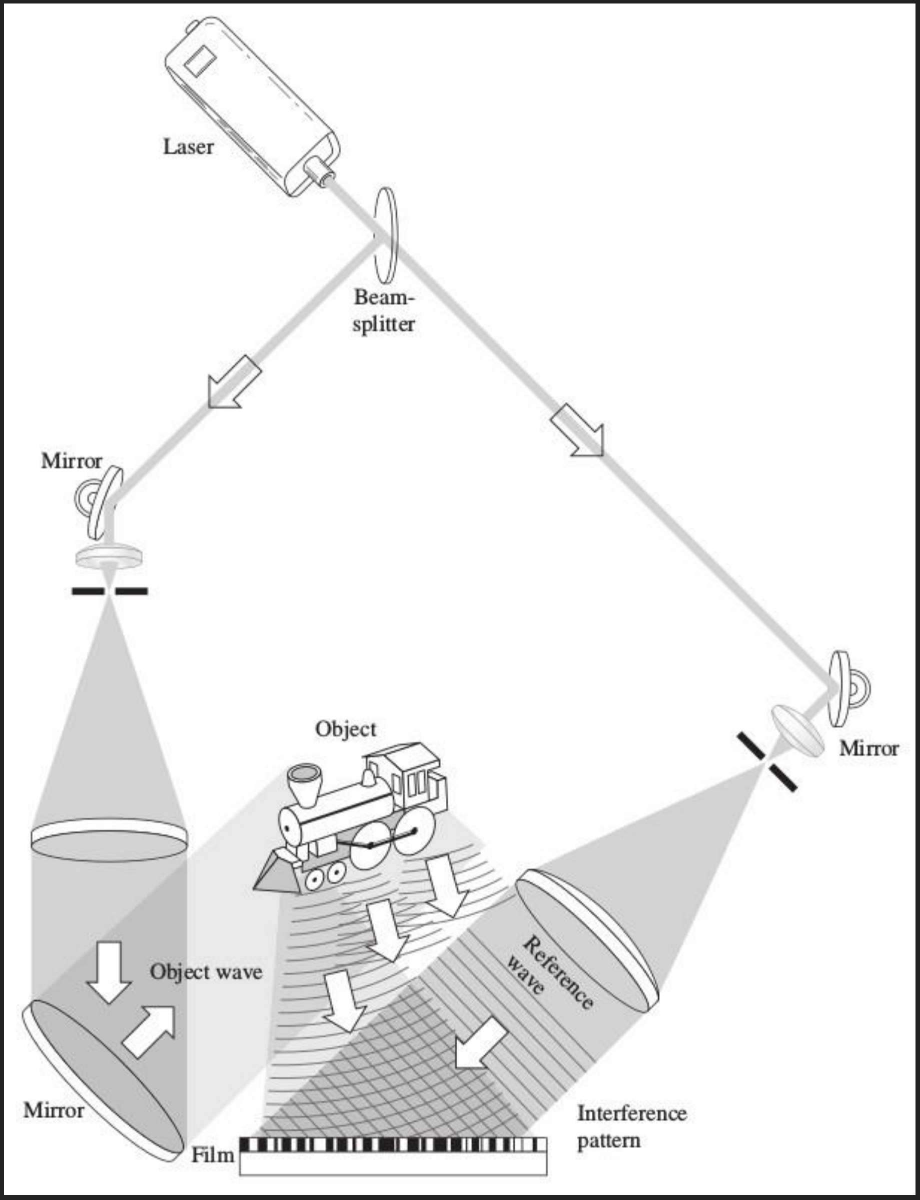
Initial holographic set-up I



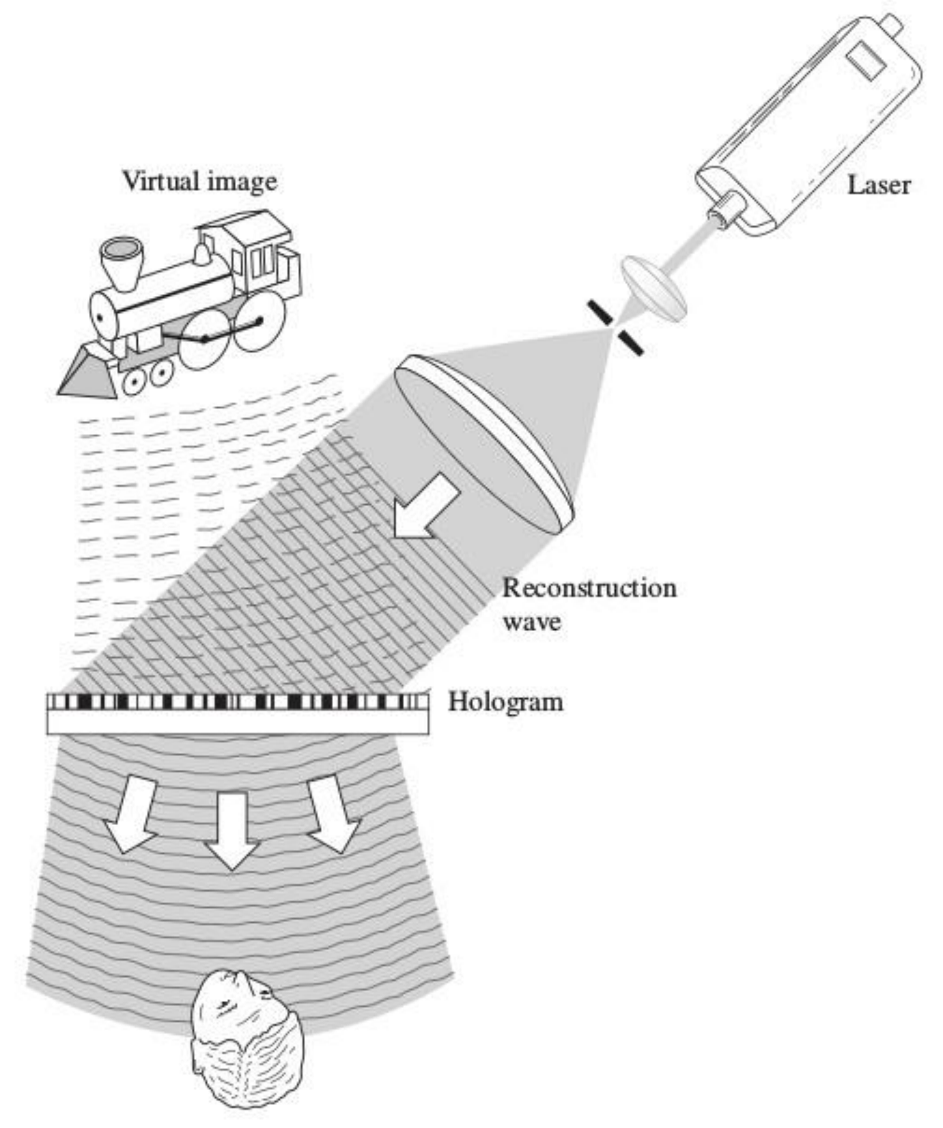
Initial holographic set-up II



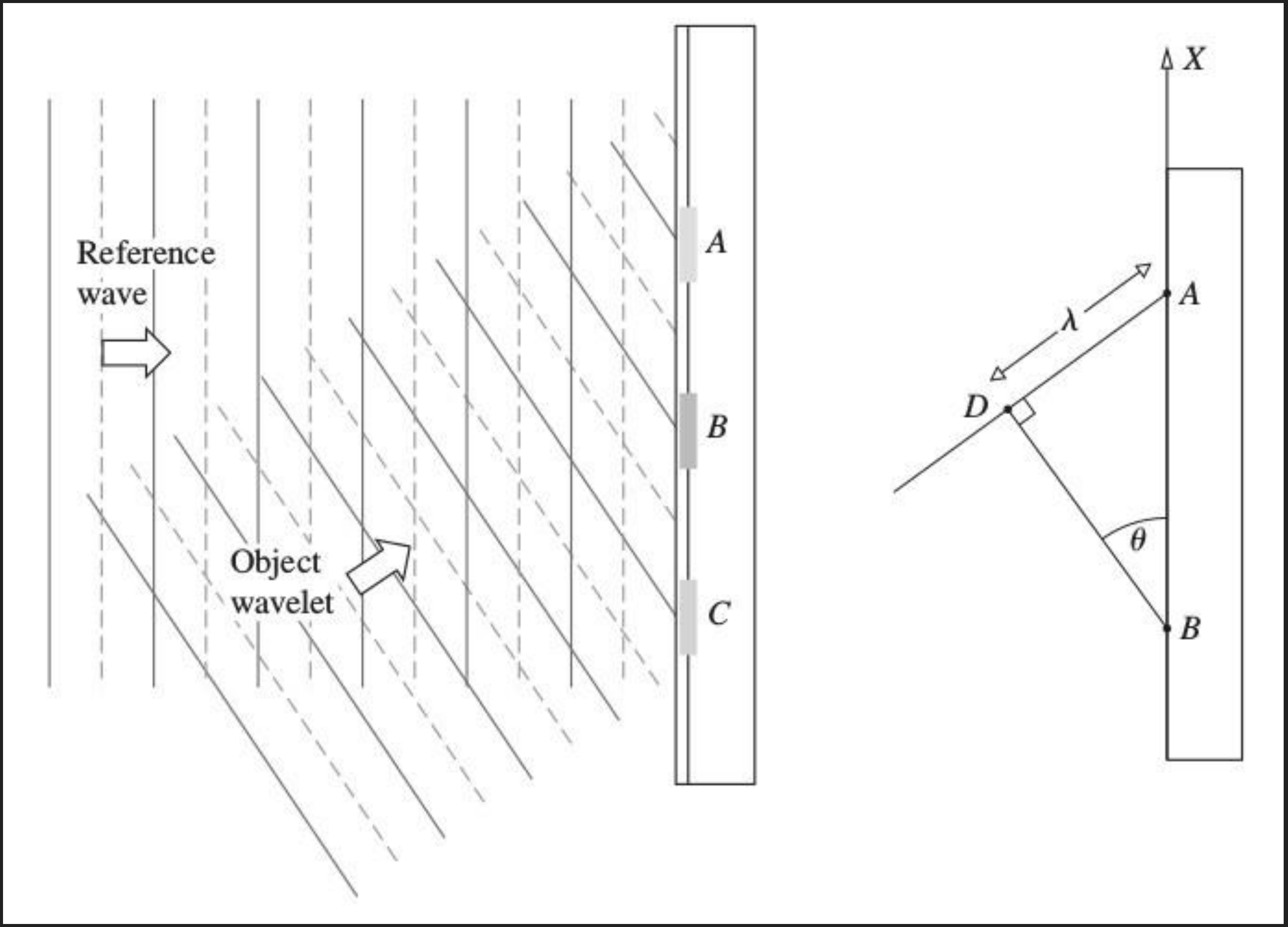
Transmission holography I



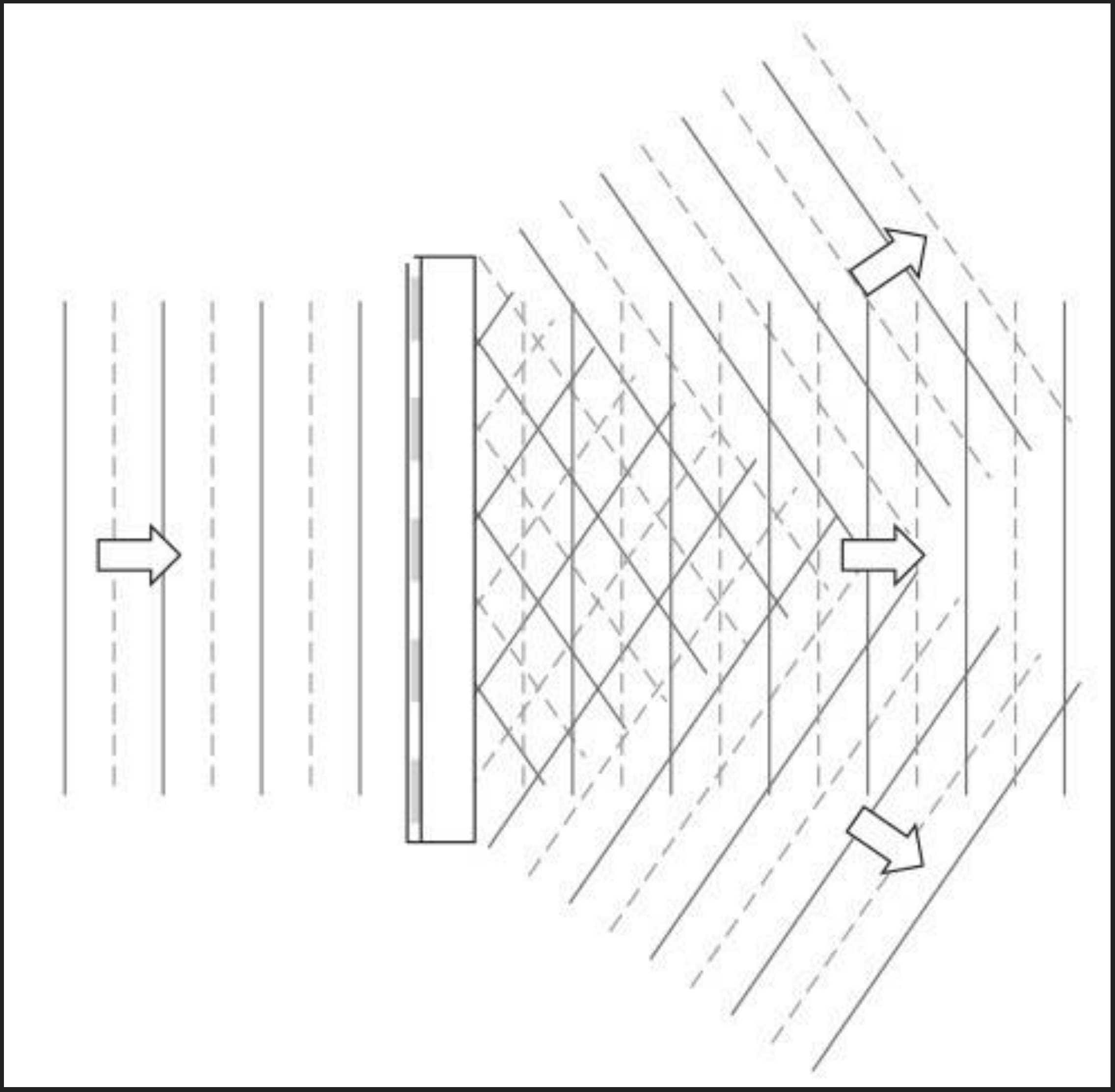
Transmission holography II



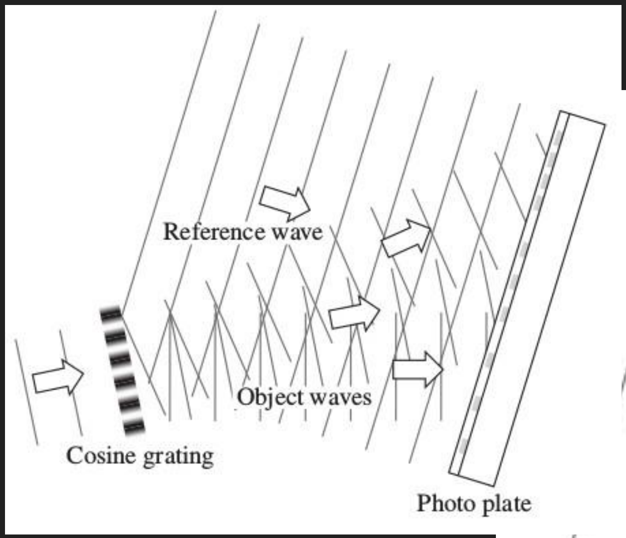
Characteristic fringe

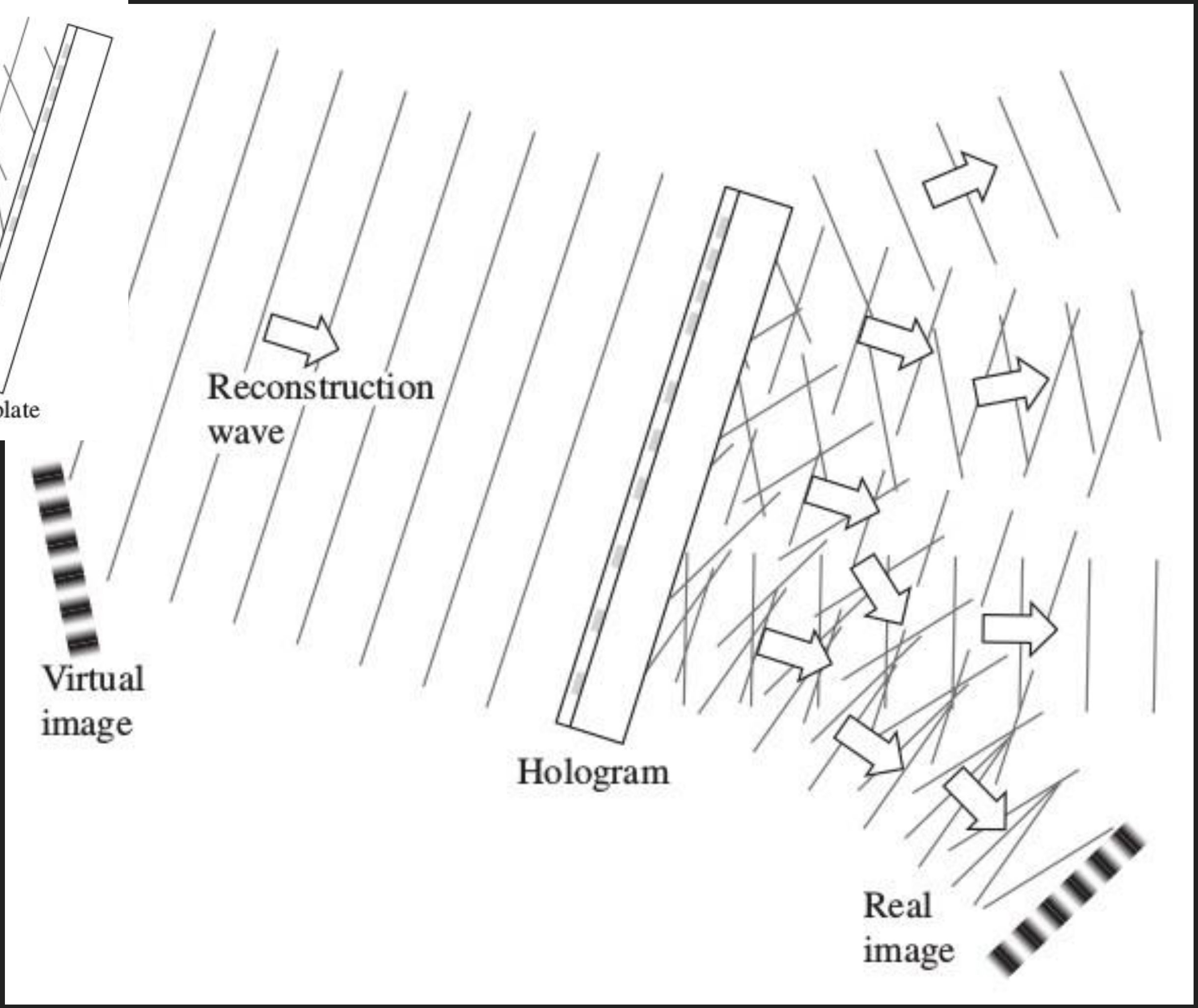


Diffraction / reconstruction I

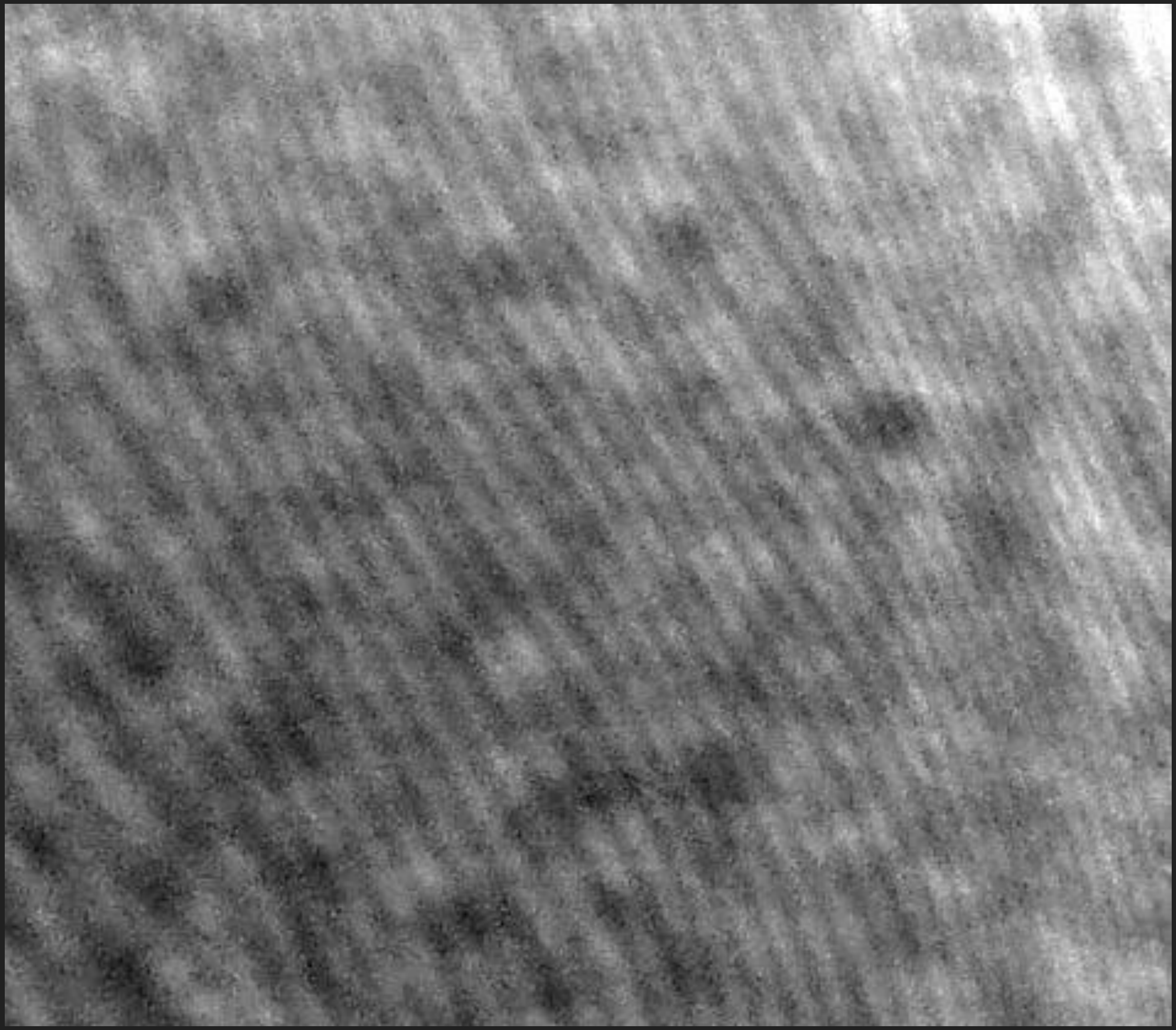


Diffraction / reconstruction II

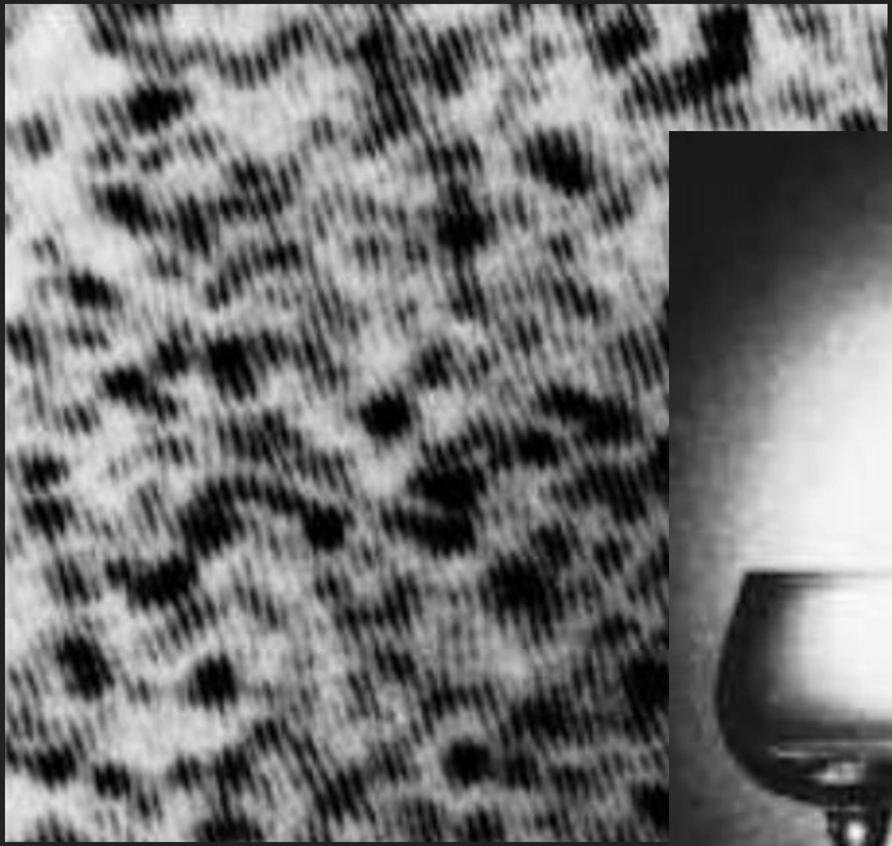




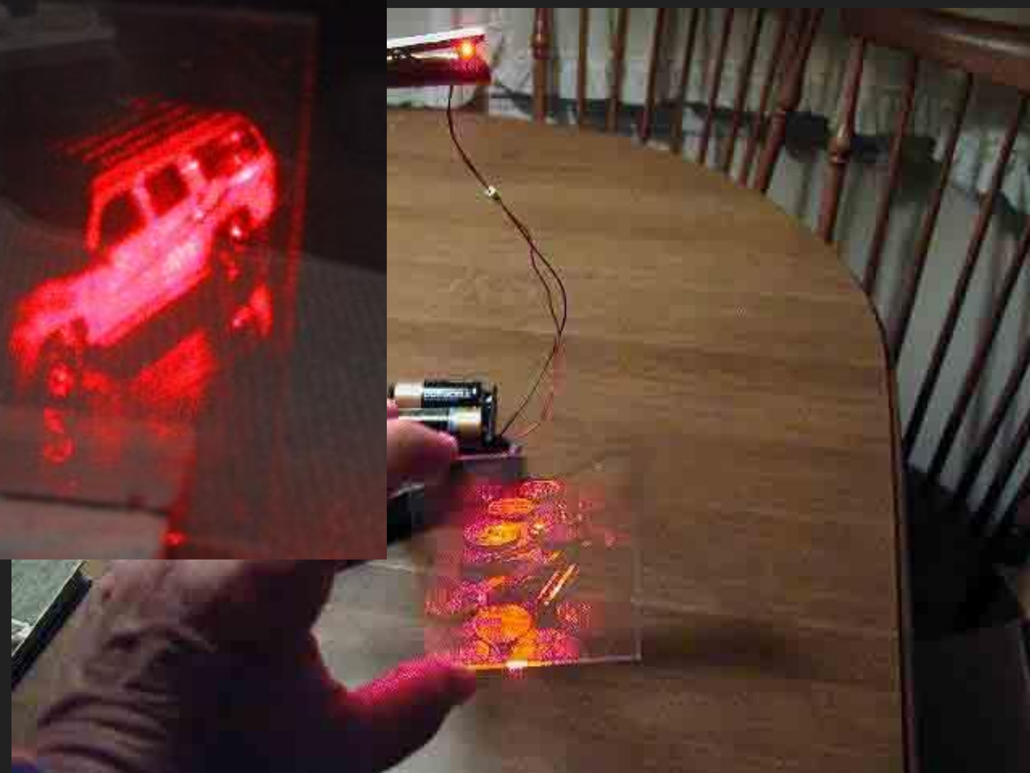
Holographic fringes I



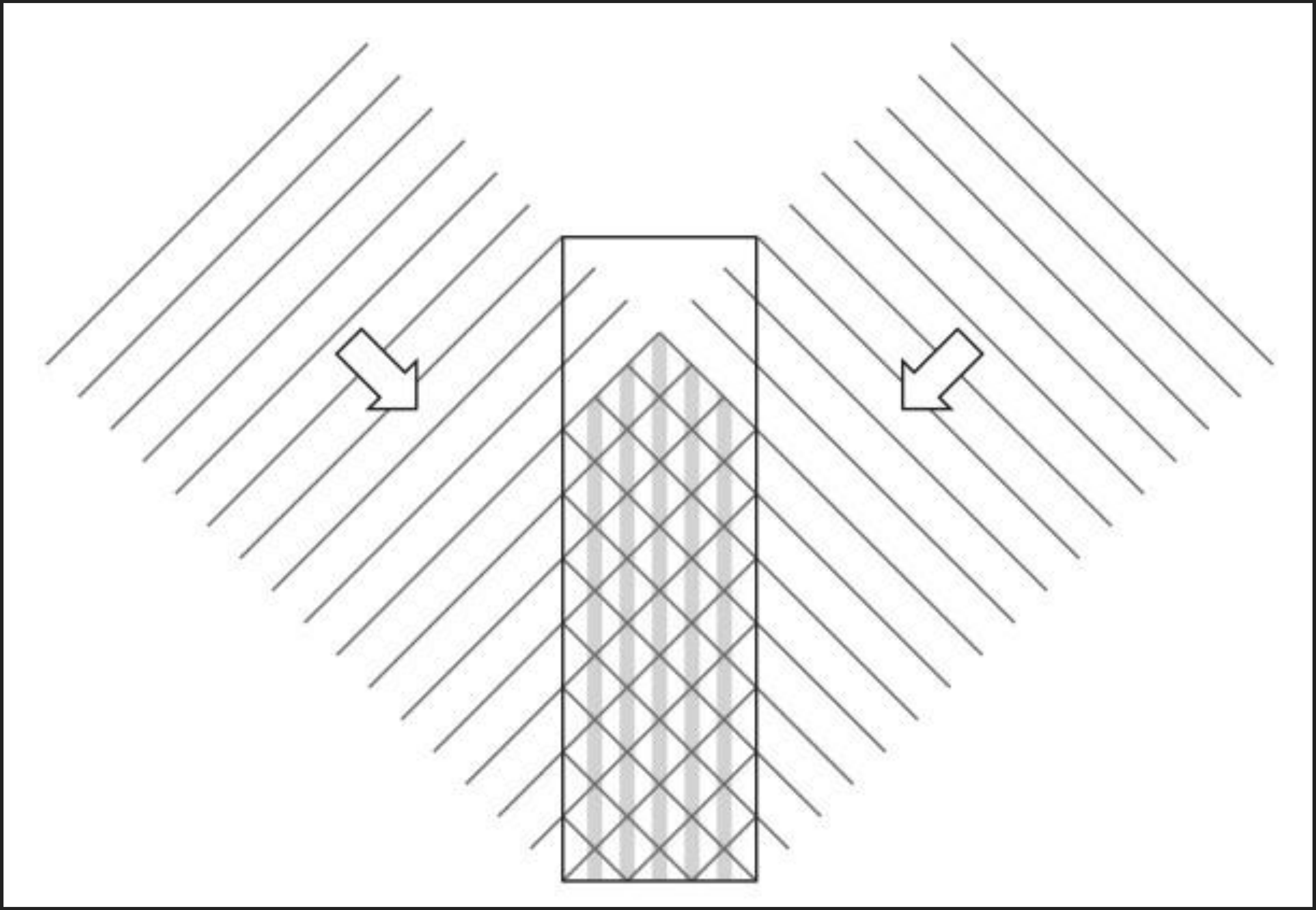
Holographic fringes II



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.