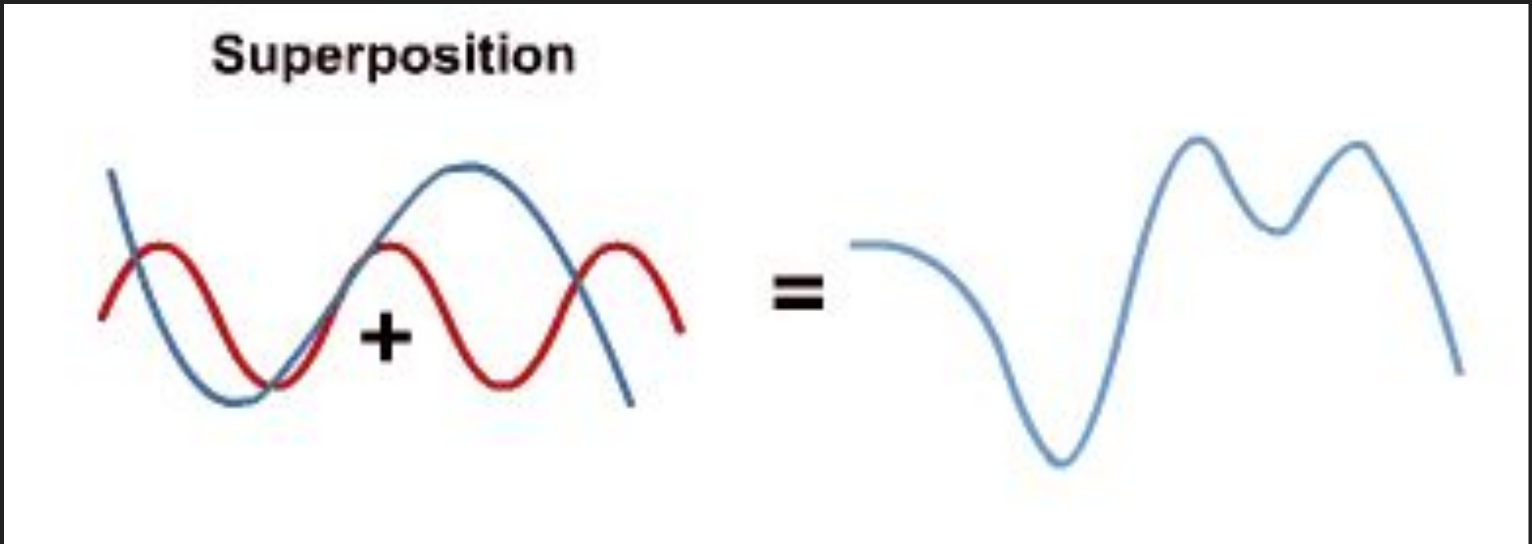
PHYS 434 Optics

Lecture 10: Wave superposition
Reading: 7.1, 7.2



Admin

- Third problem set will be available on myCourses website tonight:
  - Grader: Yang
  - Due date: Wednesday, Feb 13 (beginning of class)

- Groups for Demo #2 will be available online tonight. Dr. Lepo will email instructions on how to proceed.

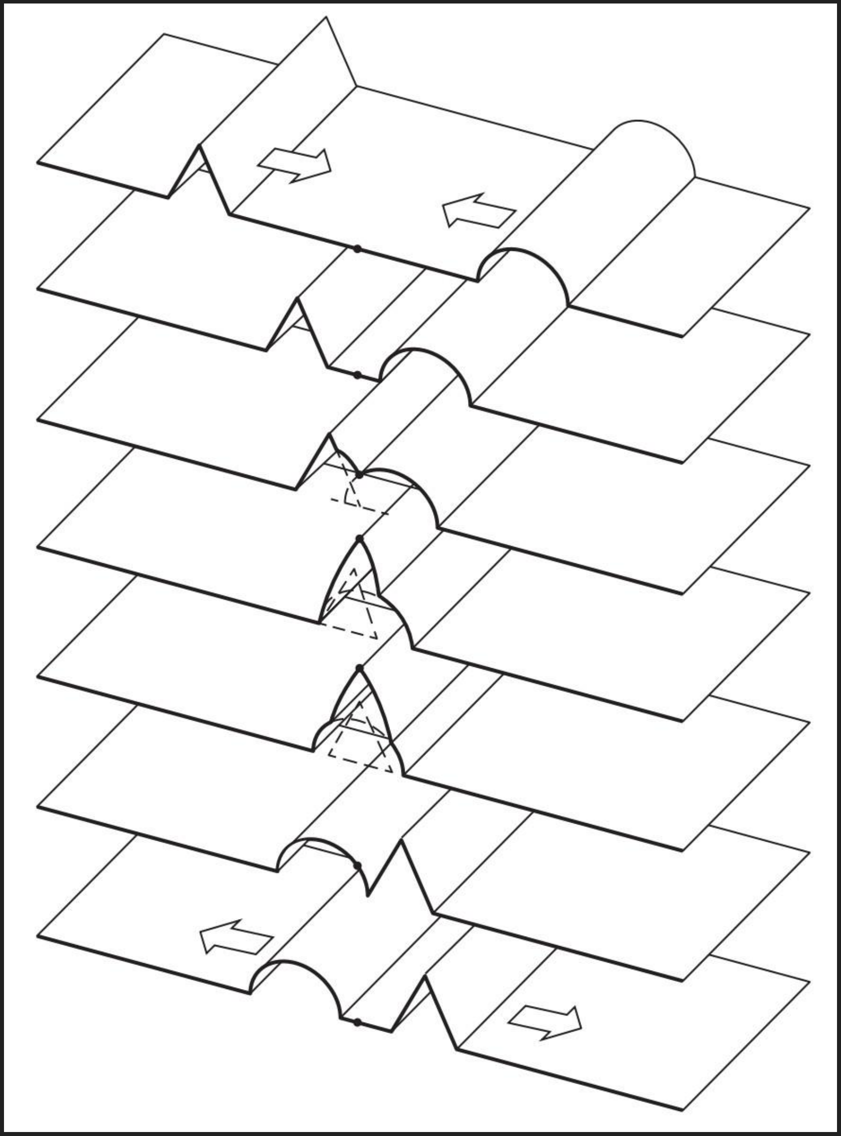
Summary Lecture 9

- So far, we have considered the ideal conditions of Gaussian optics. The first-order theory was based on the paraxial approximation.

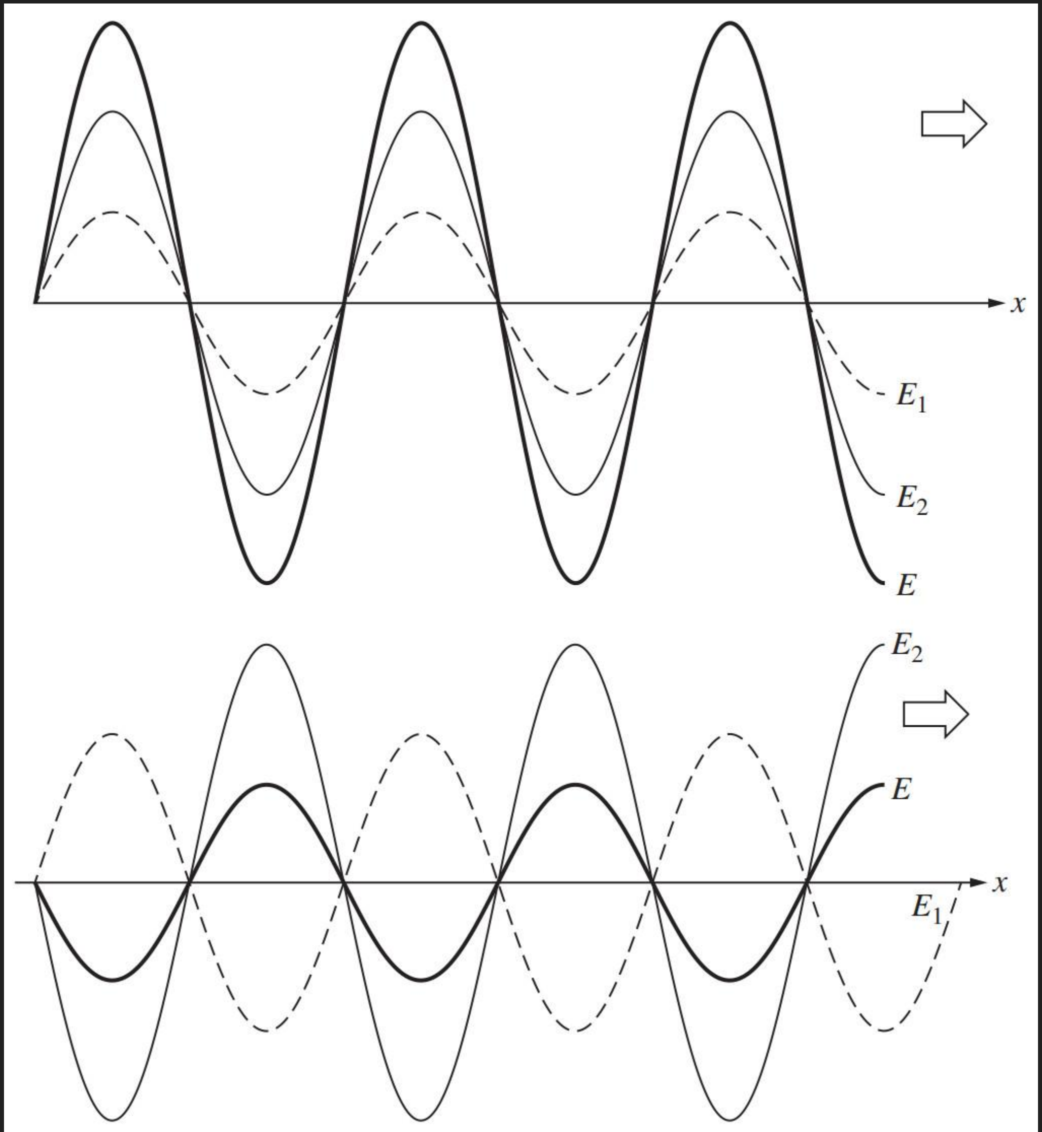
- Real system diverge from this and show aberrations. Monochromatic/Seidel aberrations: spherical aberration, coma, astigmatism, field curvature, distortion.

- Additionally, chromatic aberrations are present that originate from the density dependence of n and f.

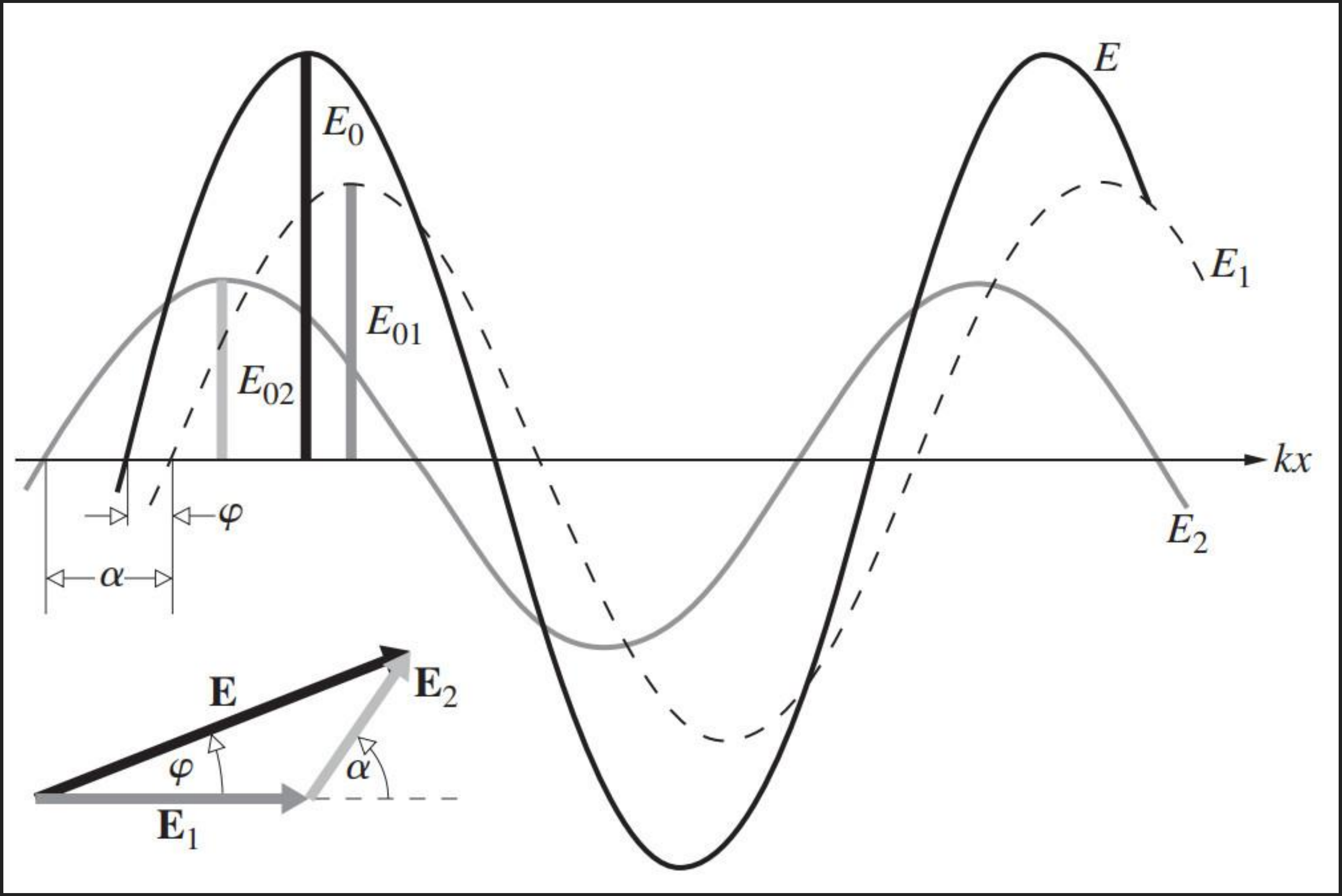
Superposition



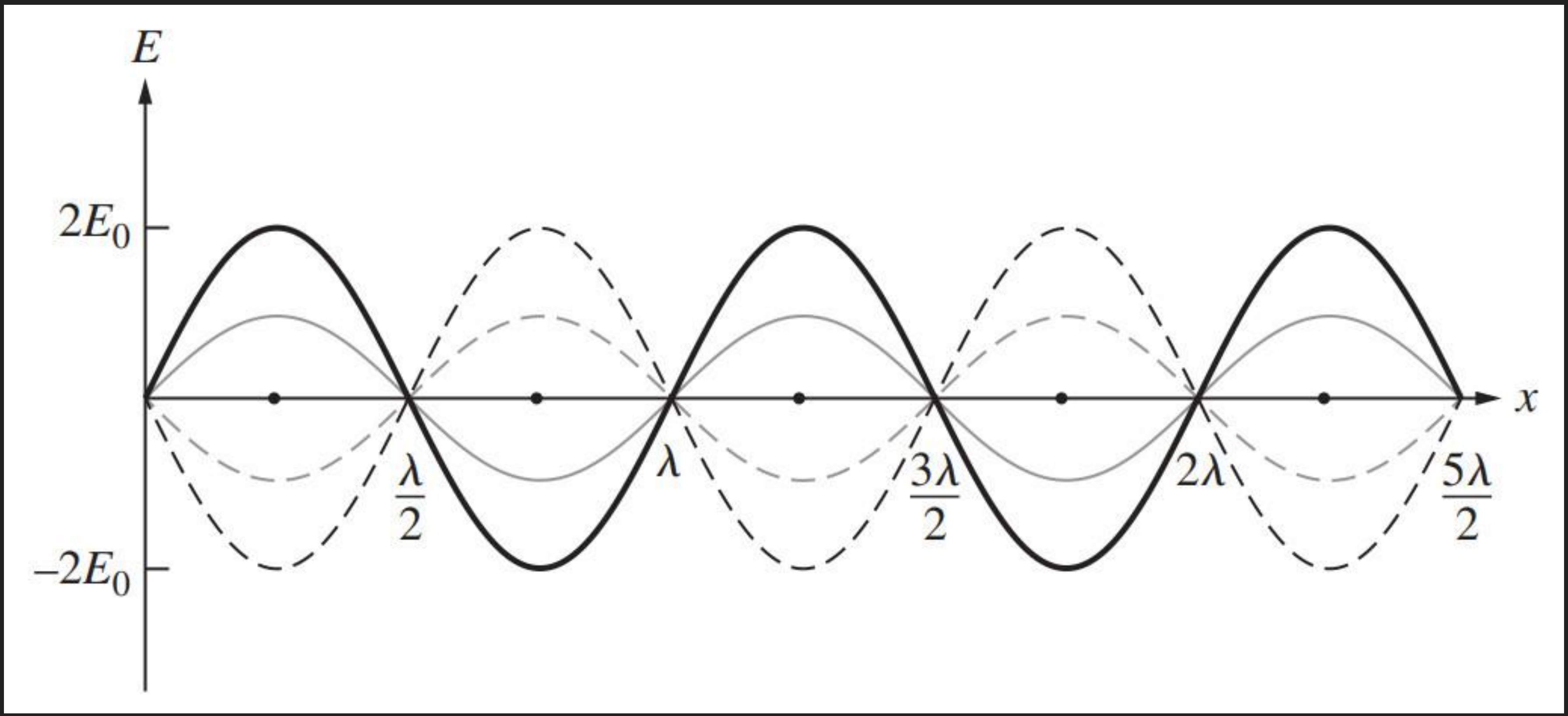
Interference term



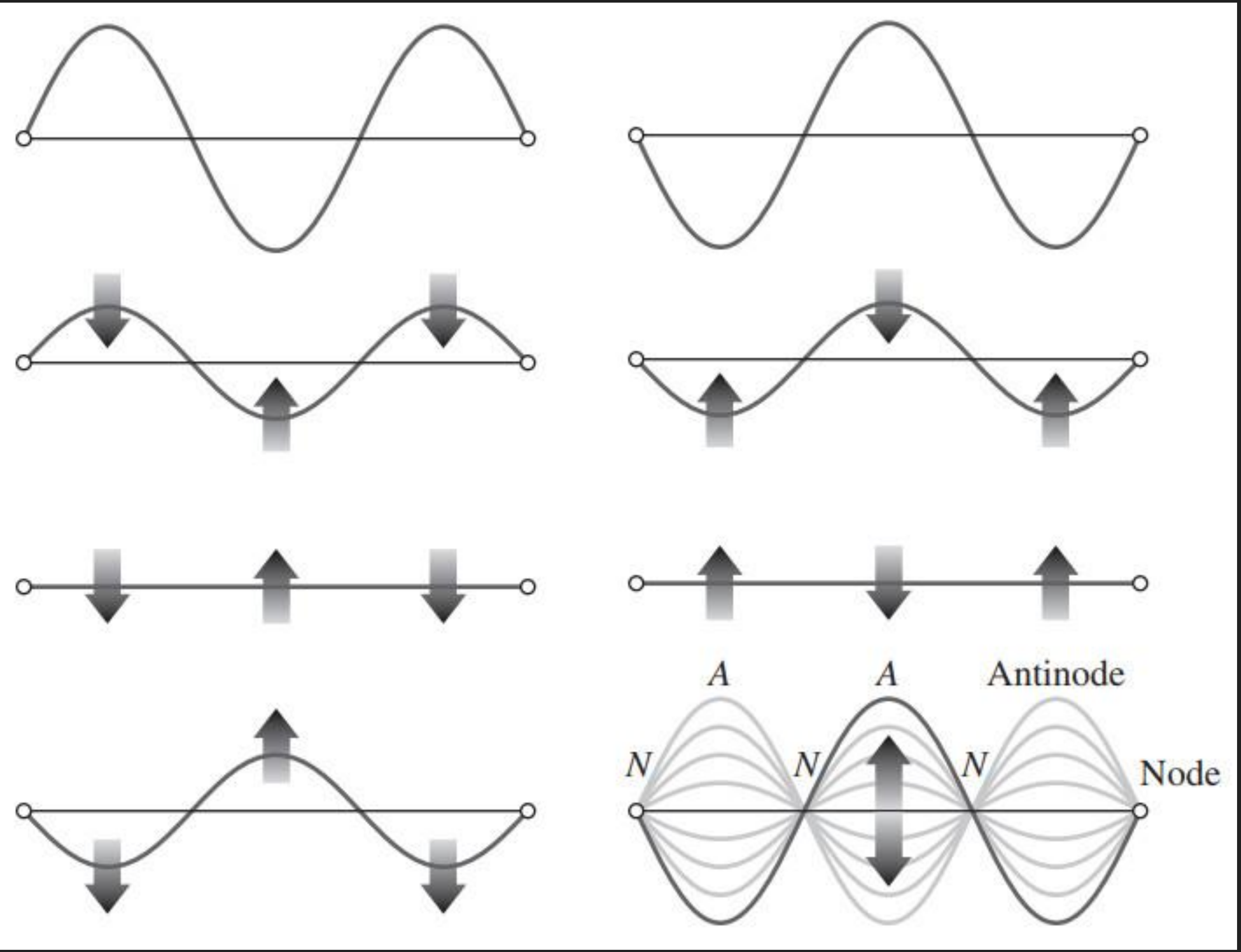
Phasor addition



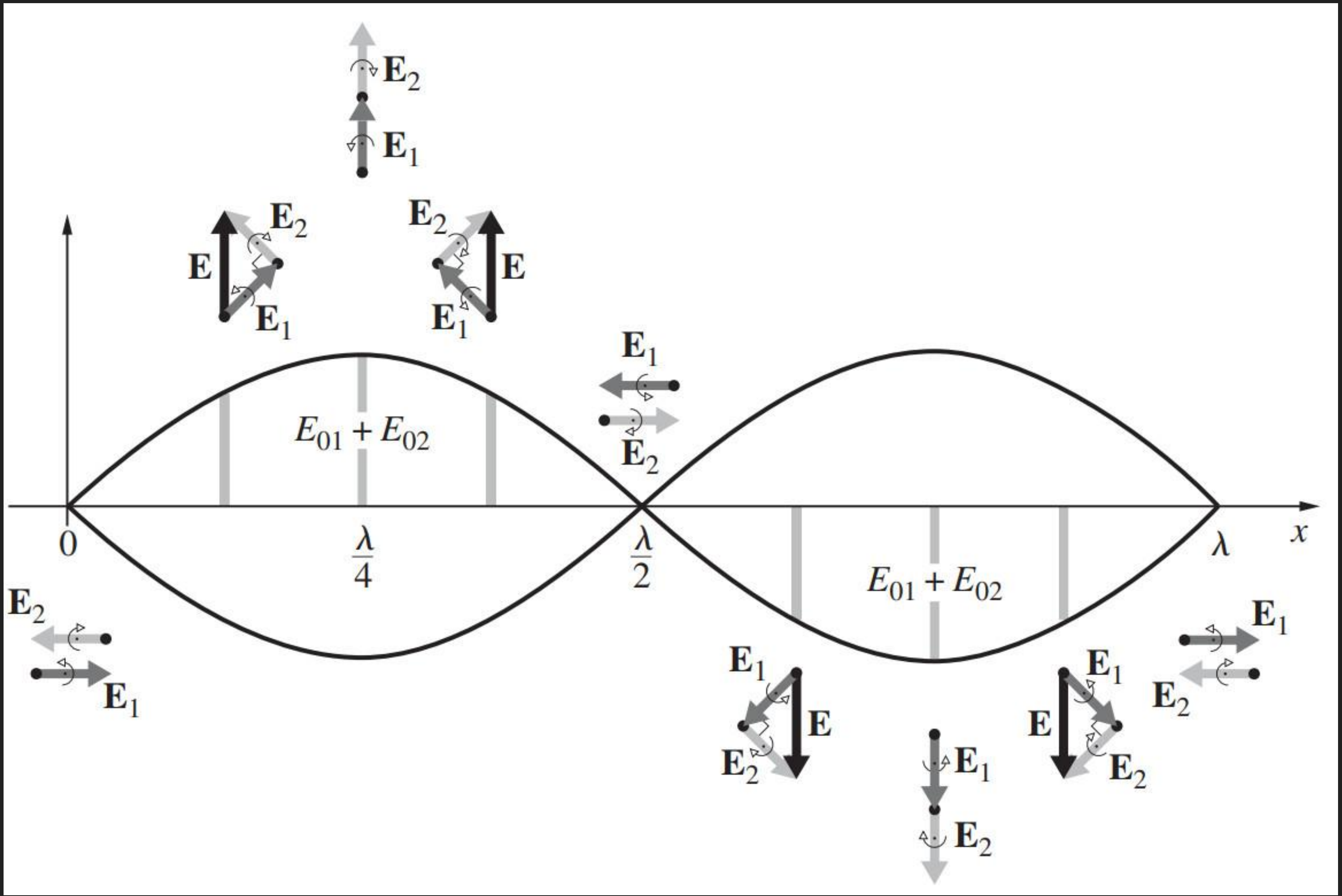
Standing waves I



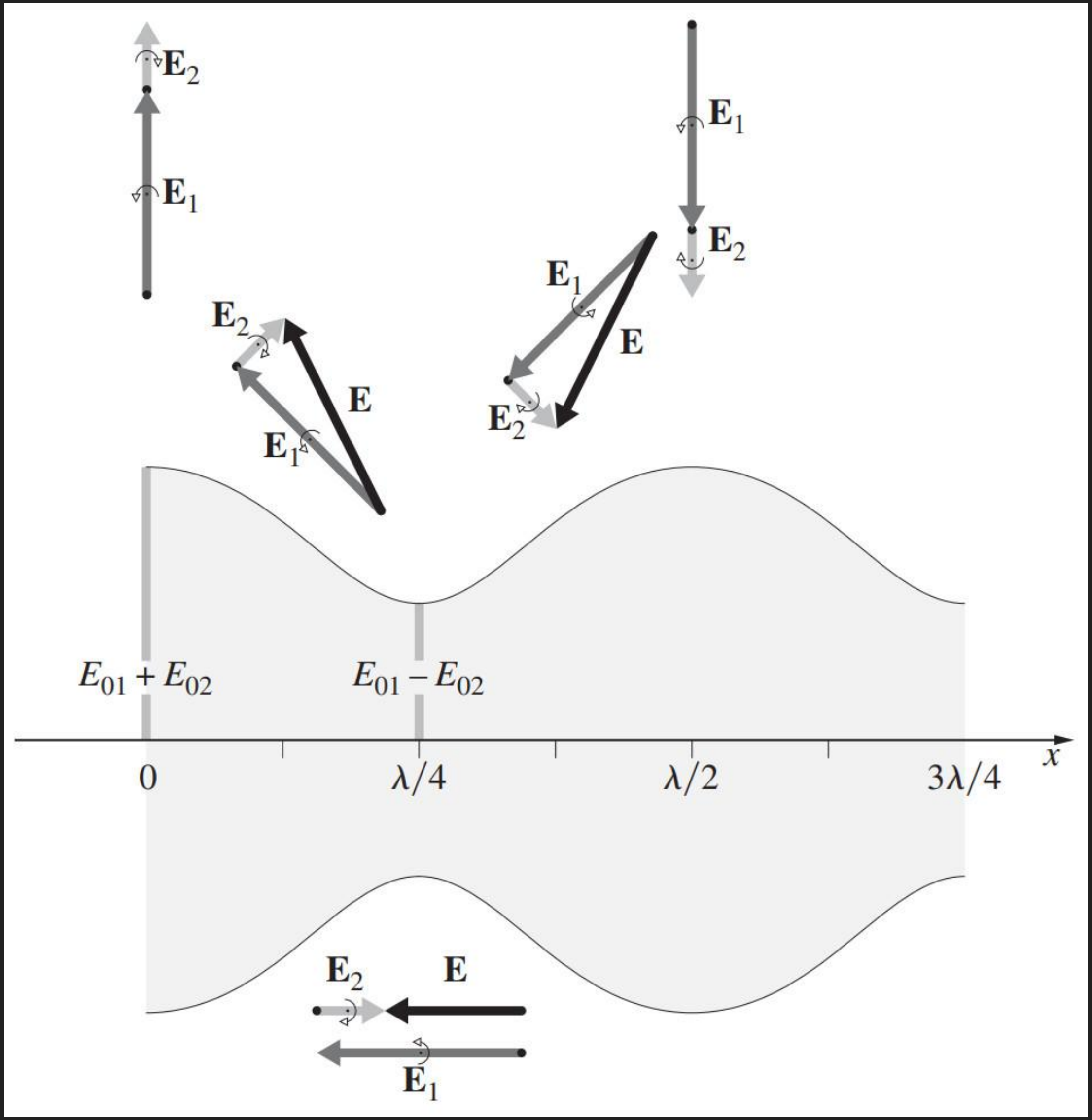
Standing waves II



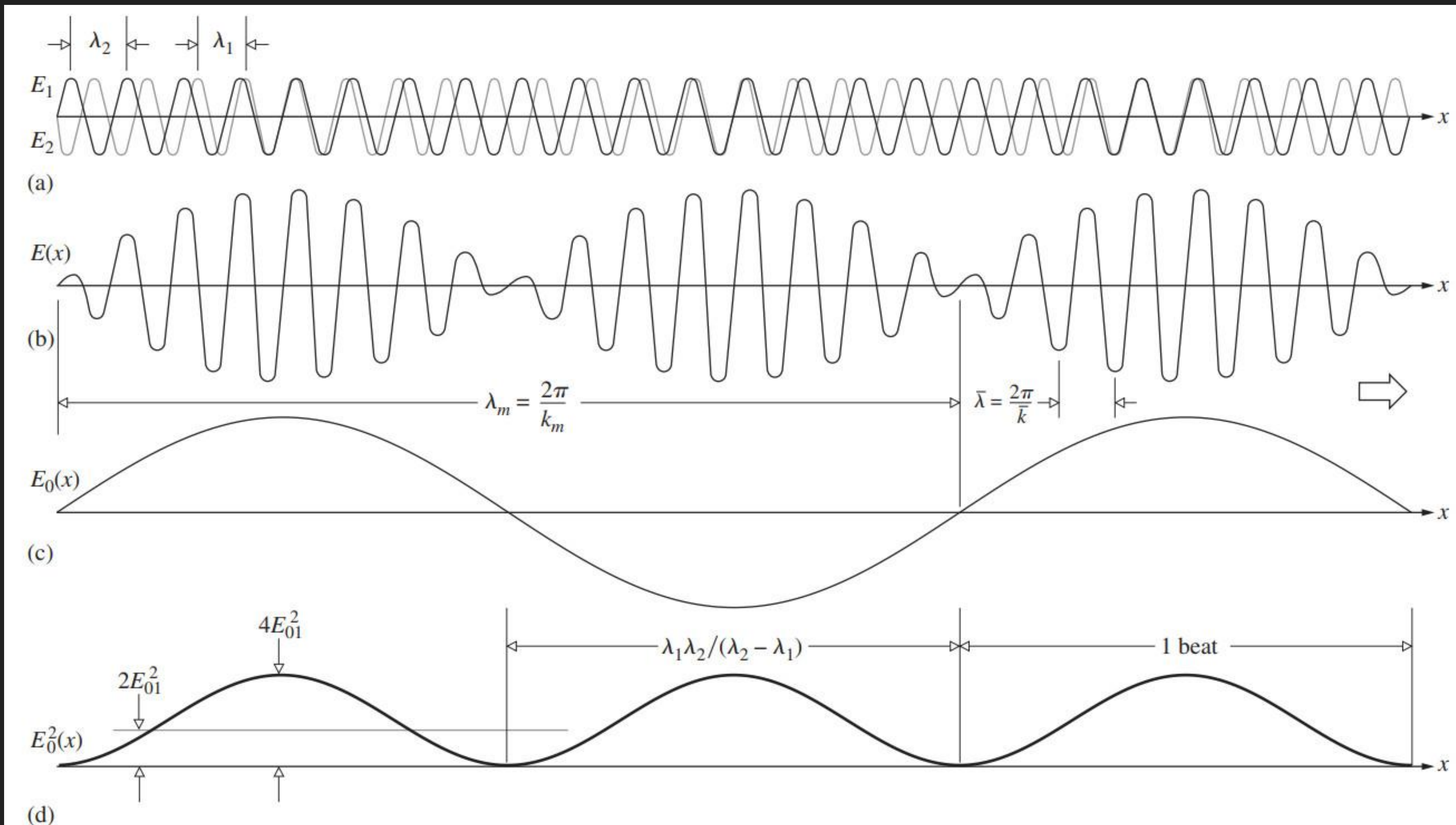
Standing waves III



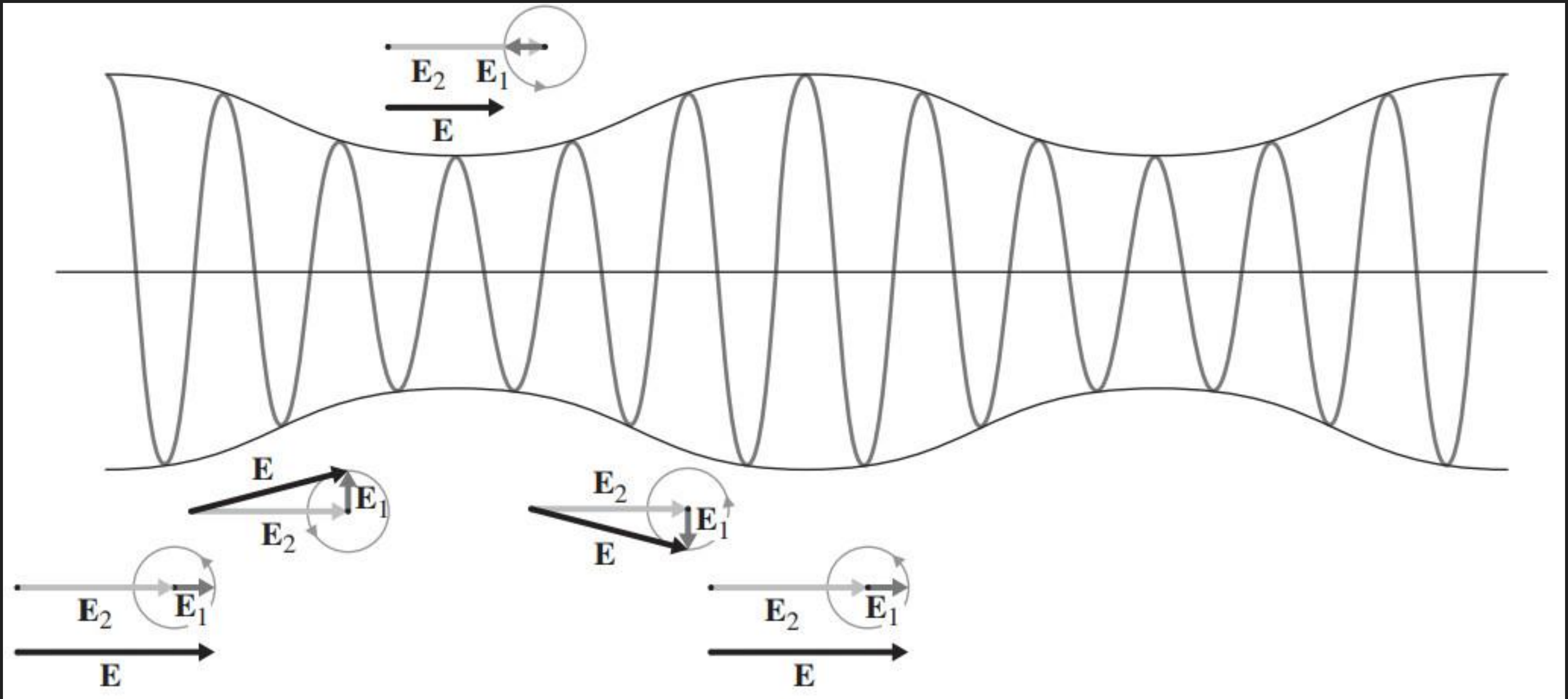
Standing waves IV



Beating and carrier wave I



Beating and carrier wave II



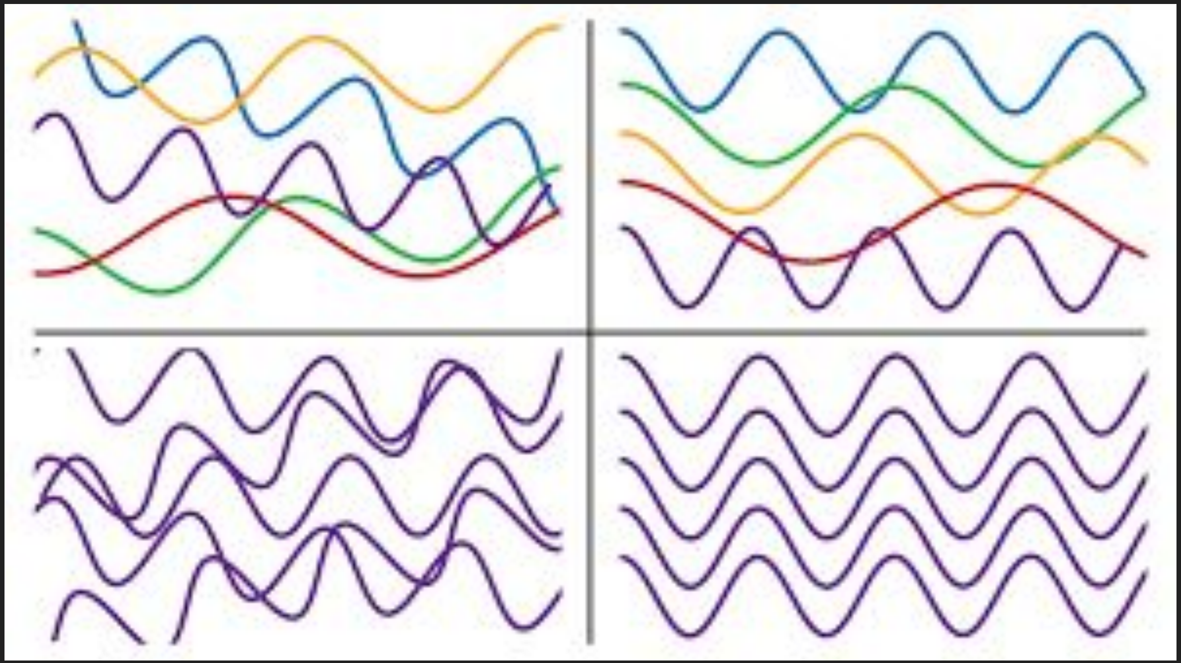
Summary Lecture 10

- For many effects in Optics, the wave-like nature of light cannot be neglected. Phenomena like polari-sation, interference and diffraction all rely on the the superposition principle.
- When two travelling waves of same frequency move through each other, they generate a standing wave, that is characterised by nodes and antinodes.
- The addition of two waves of different frequency results in a disturbance that is product of a travelling carrier wave (v) and a modulated envelope (v_g).

PHYS 434 Optics

Lecture 11: Fourier Series, Coherence

Reading: 7.3, 7.4



Summary Lecture 10

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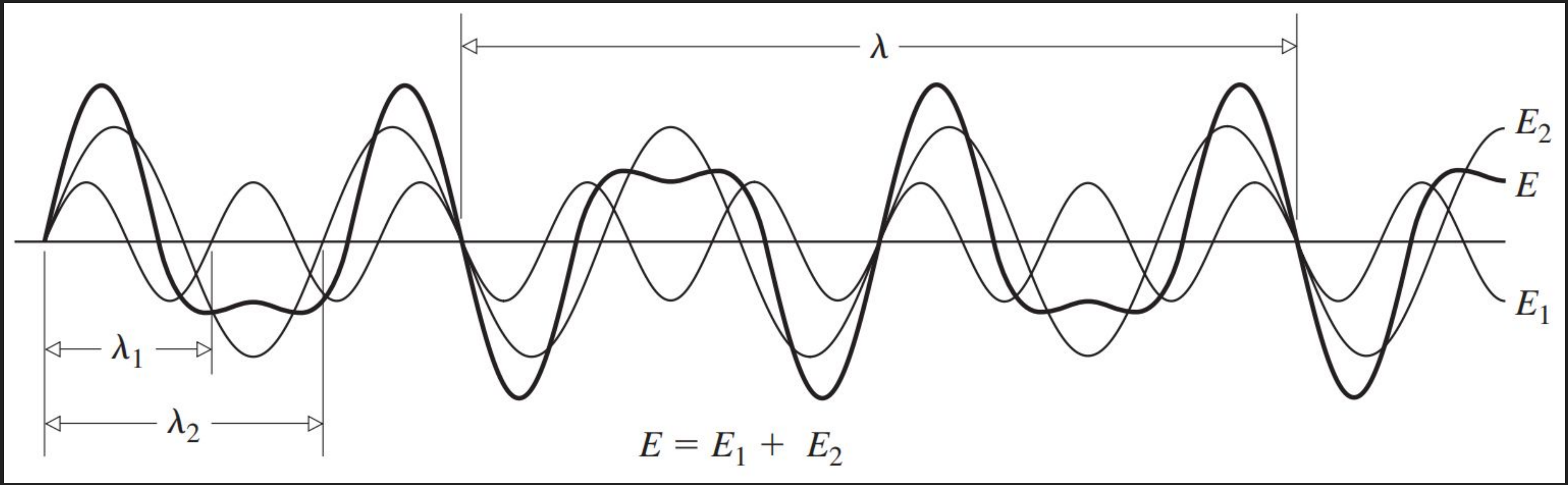
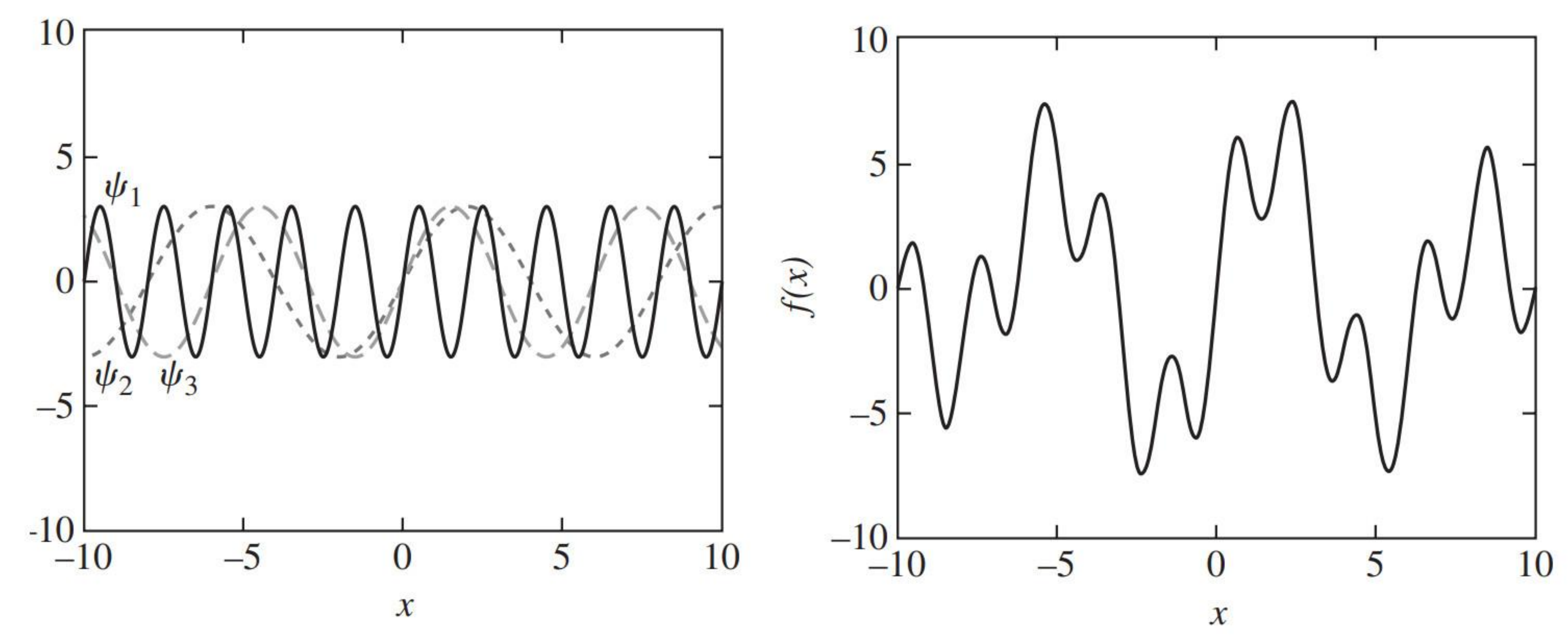
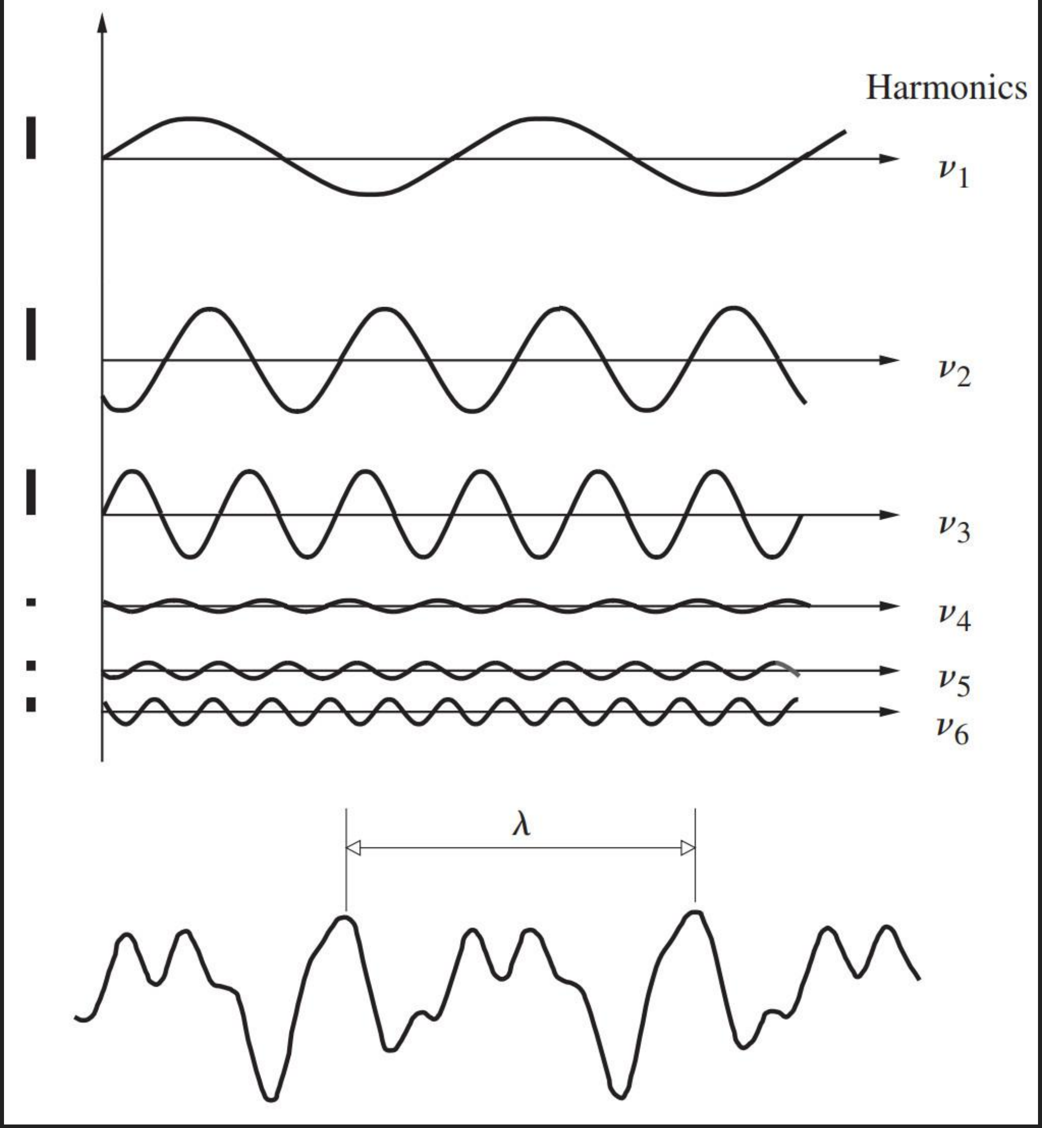
Anharmonic waves I



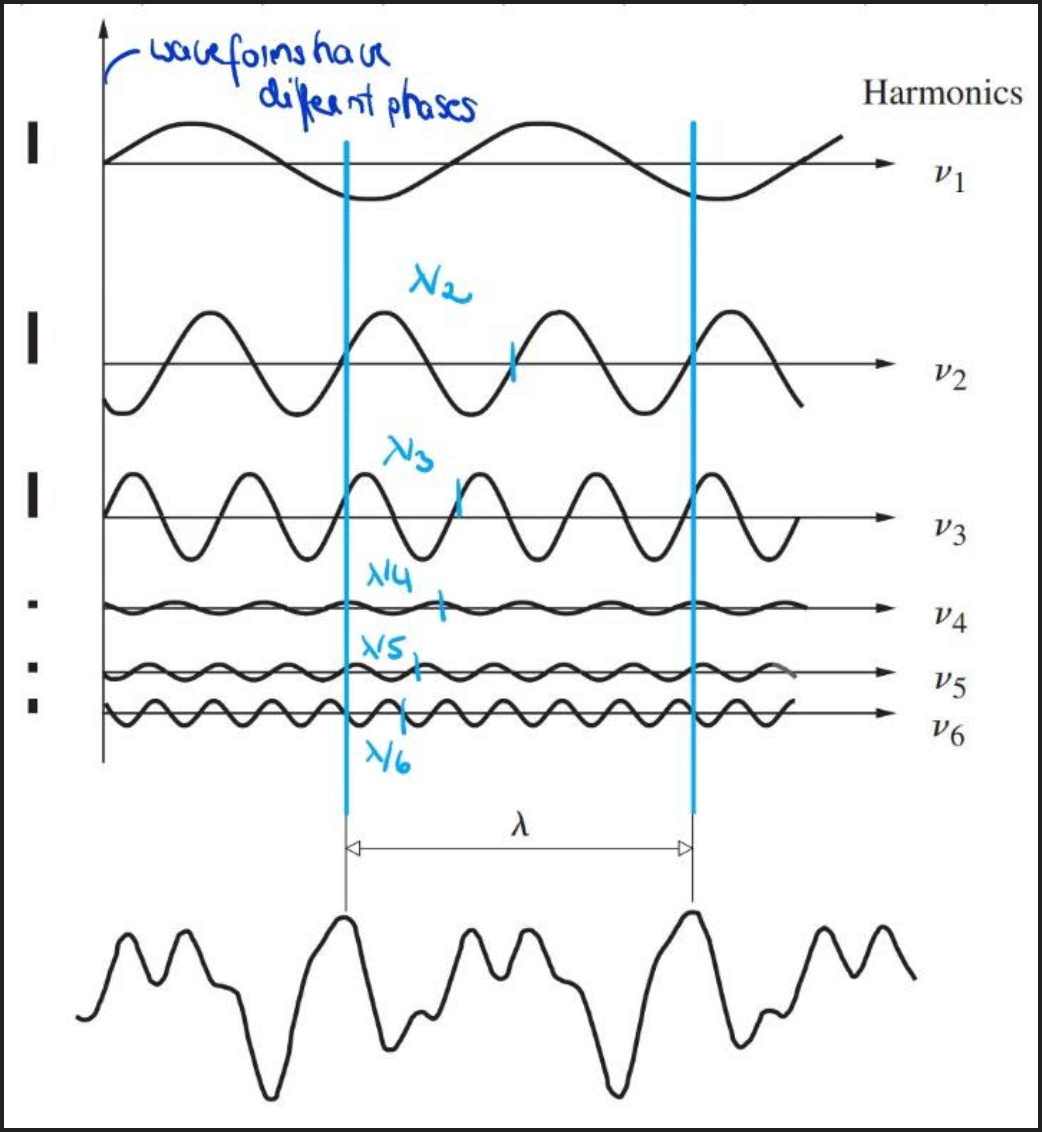
Anharmonic waves II



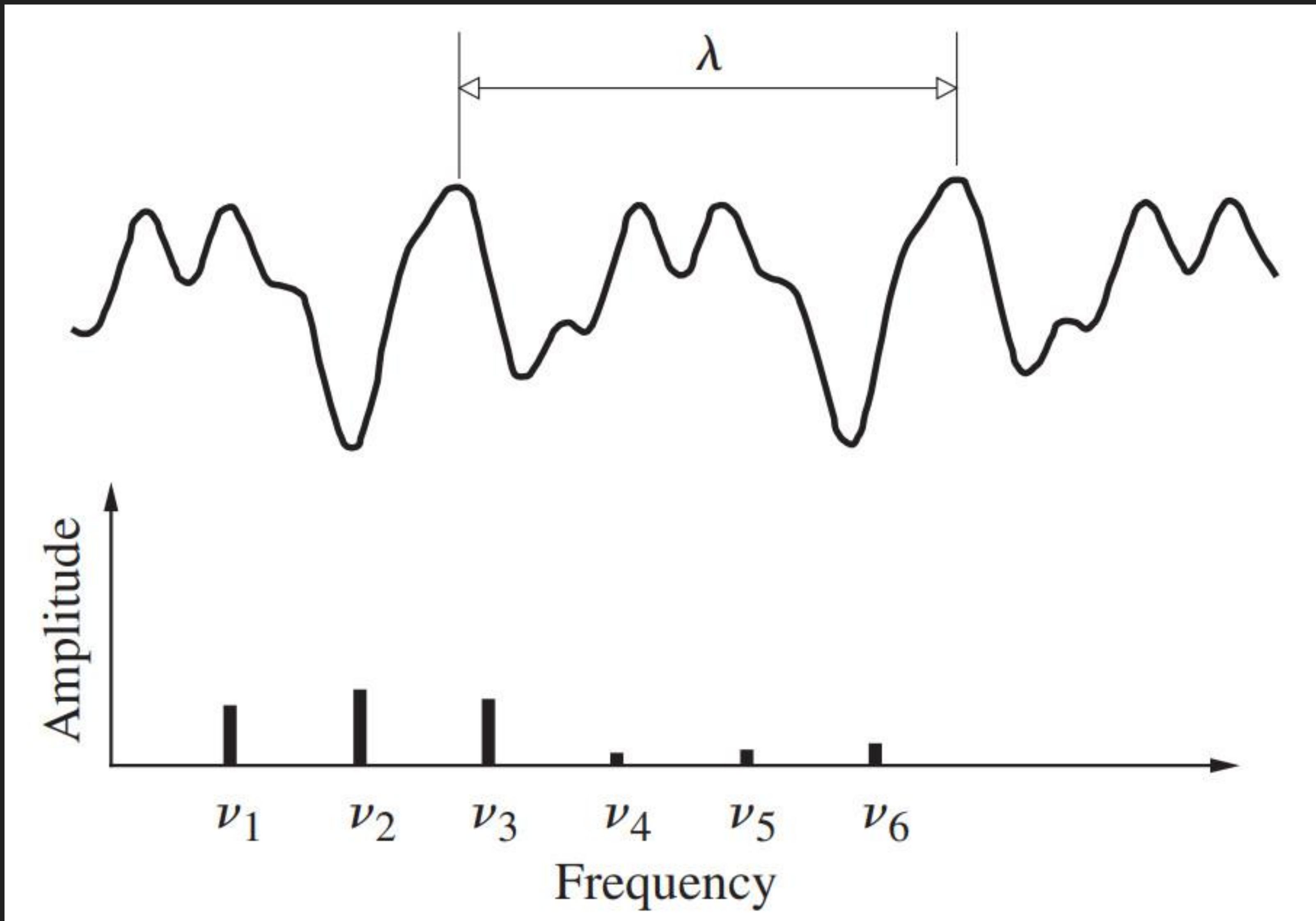
Fundamental wavelength



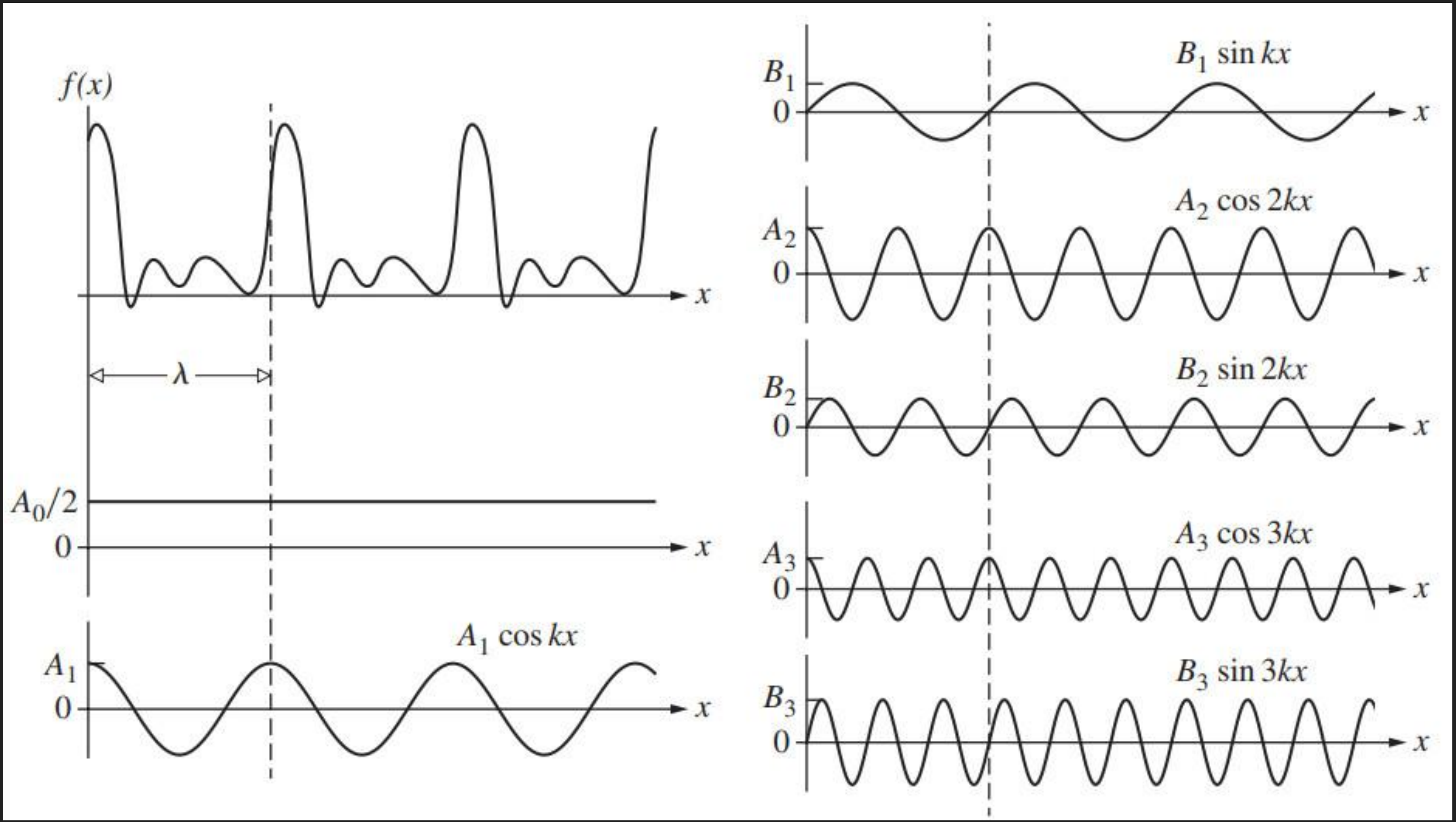
Fundamental wavelength



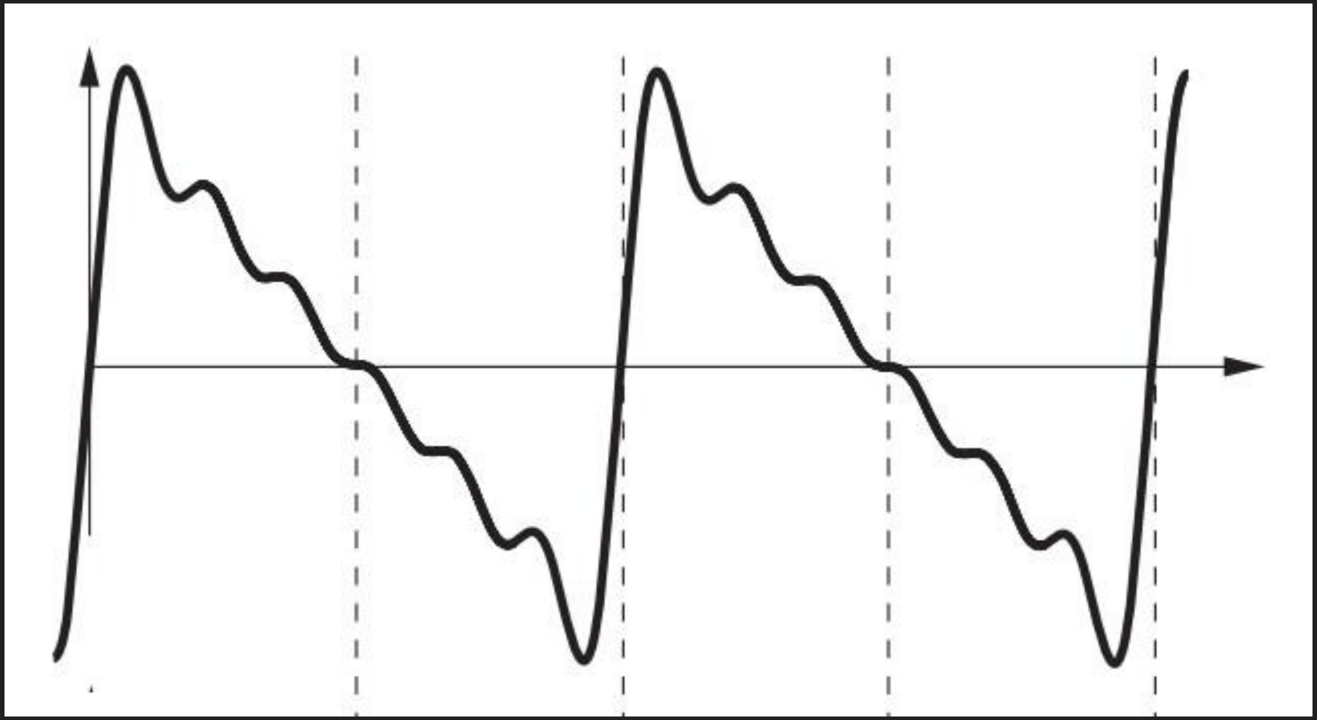
Frequency spectrum



Fourier decomposition



Serrated ‘saw tooth’



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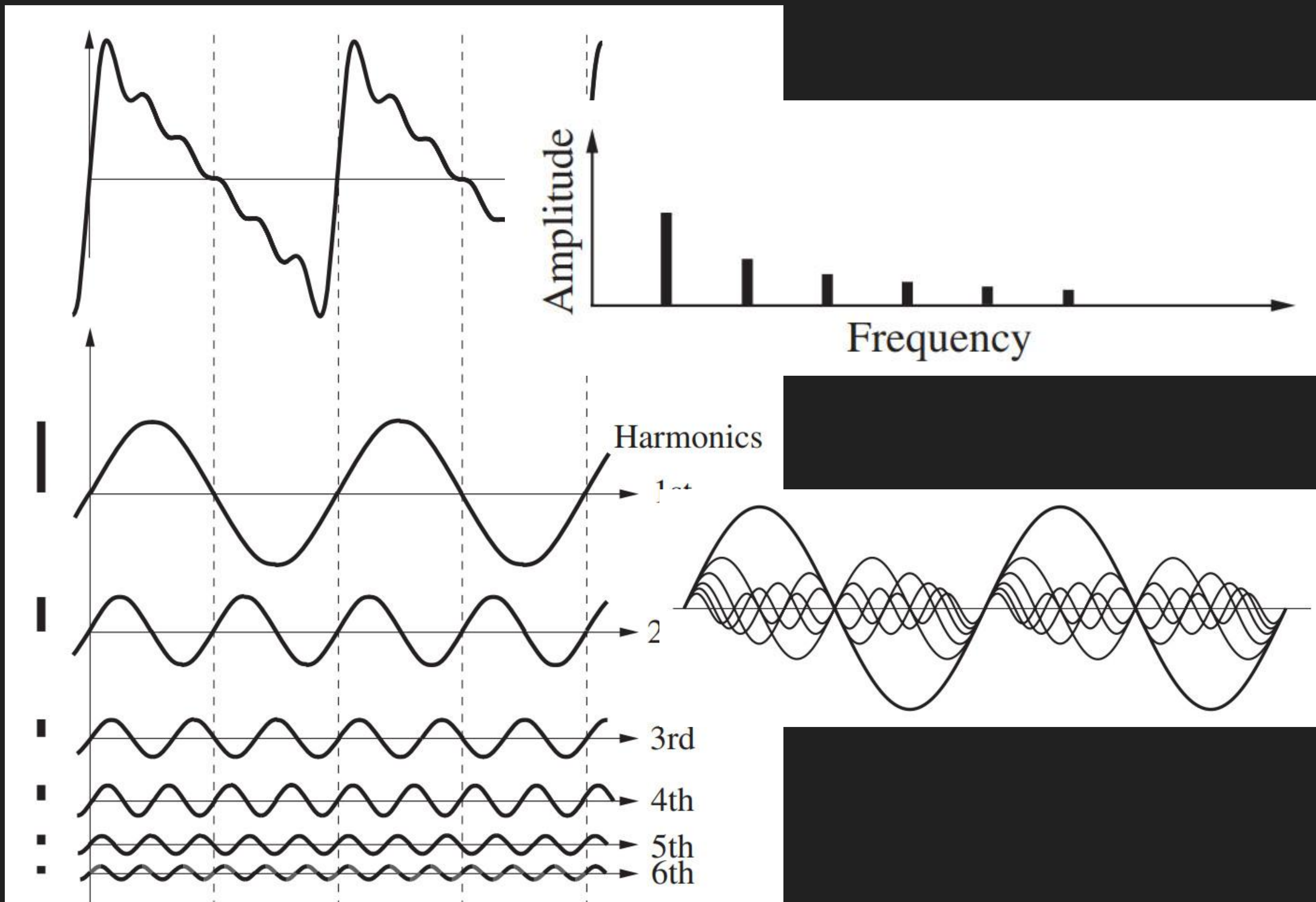
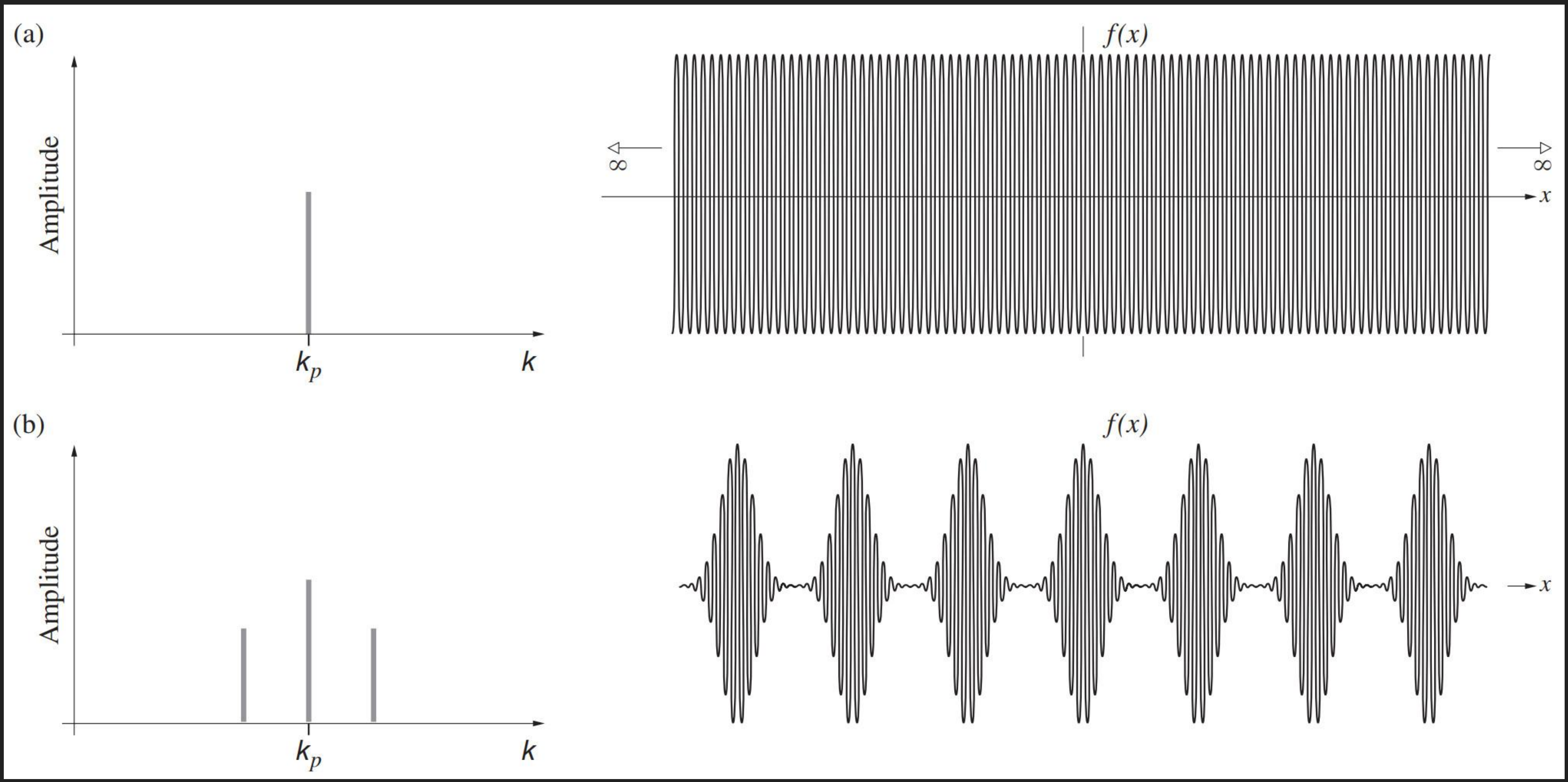
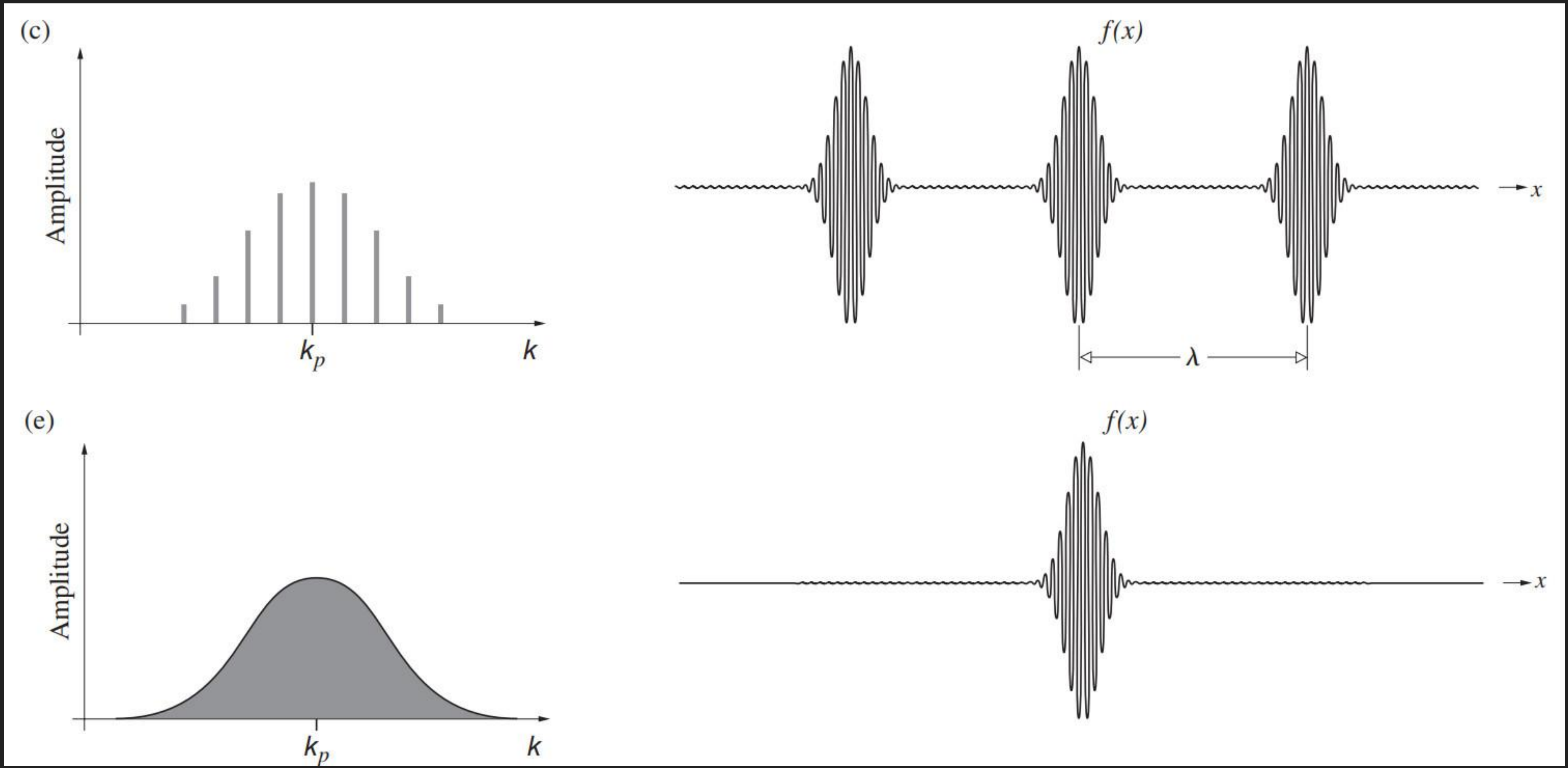


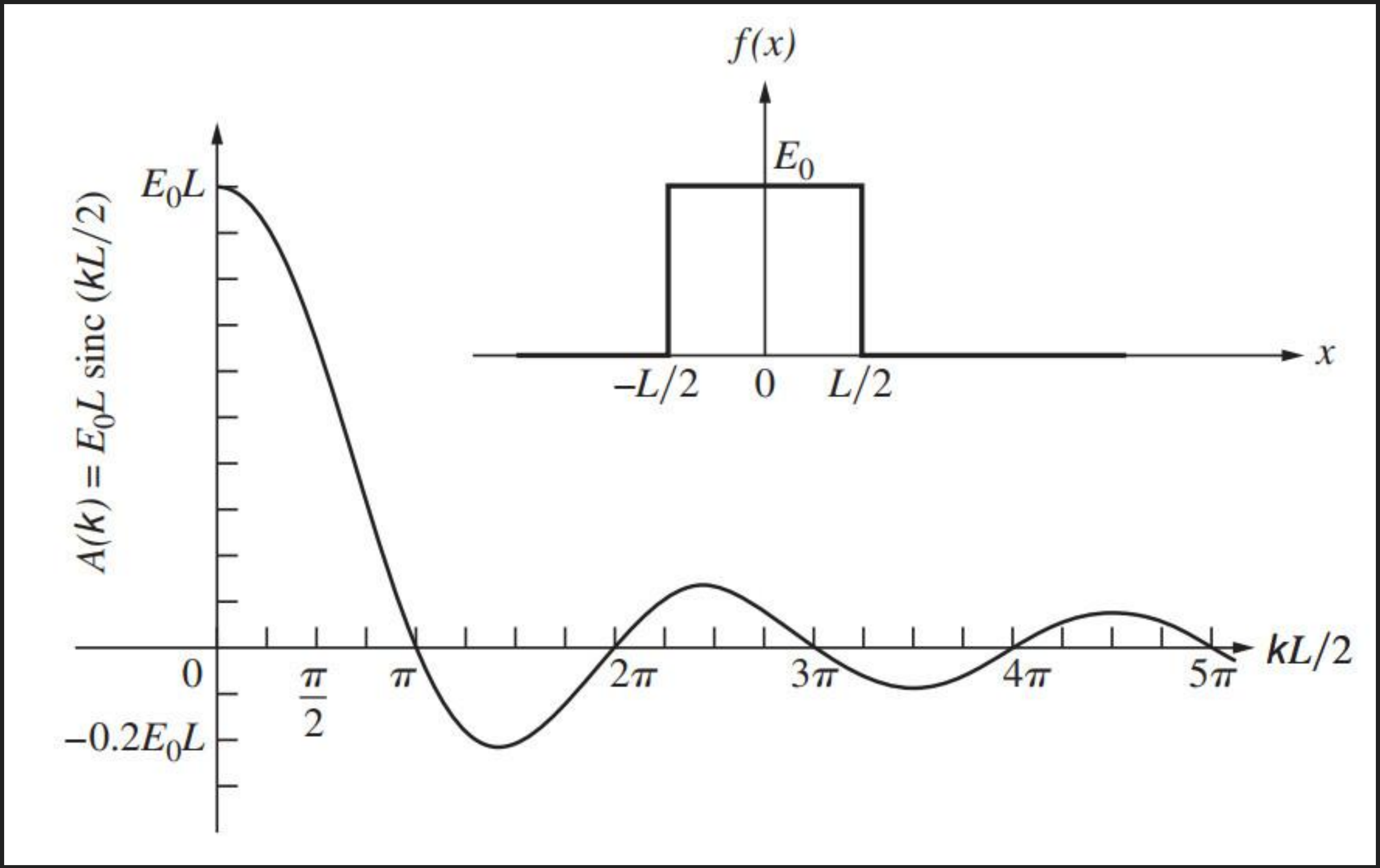
Non-period waves I



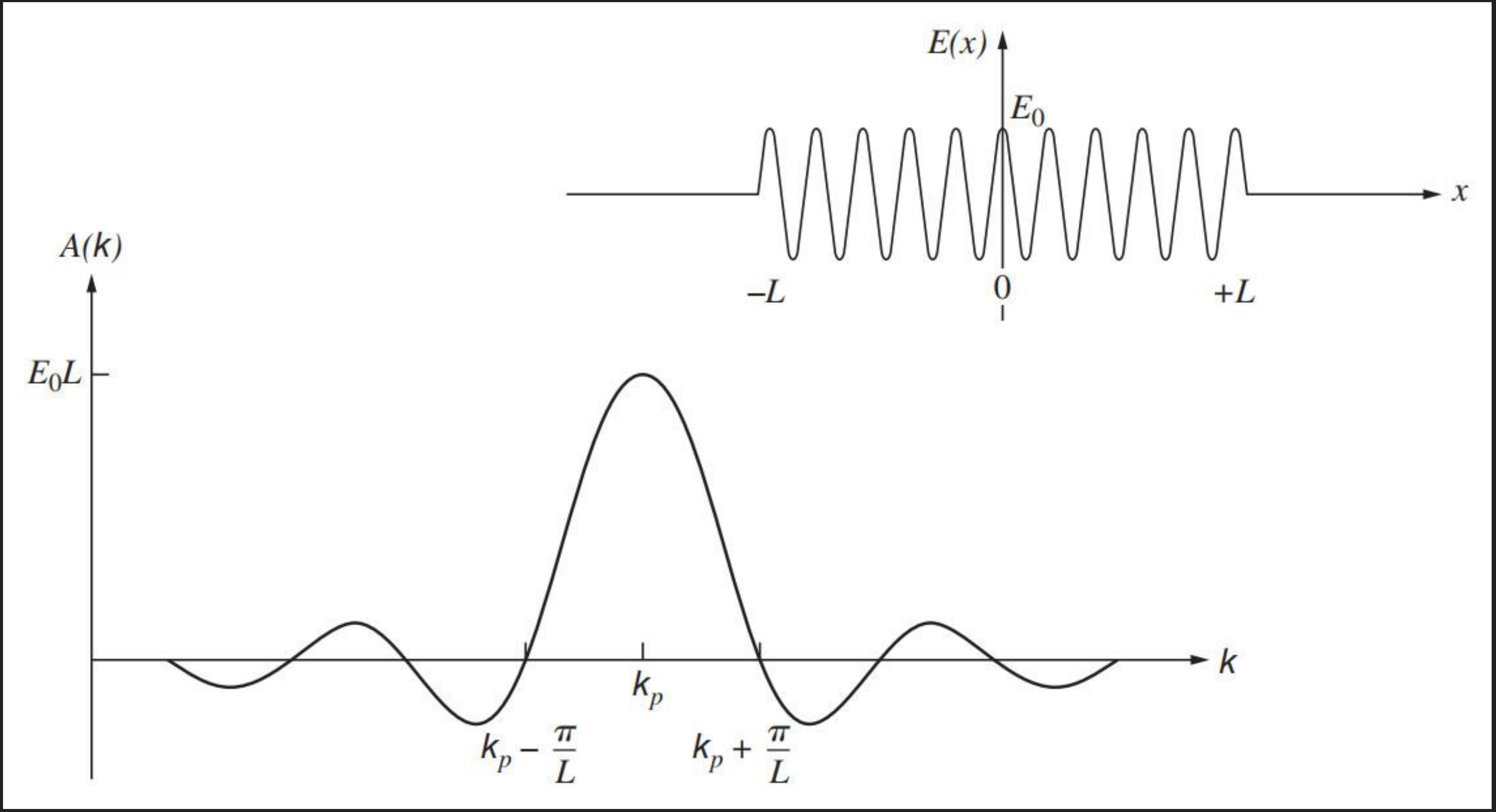
Non-period waves II



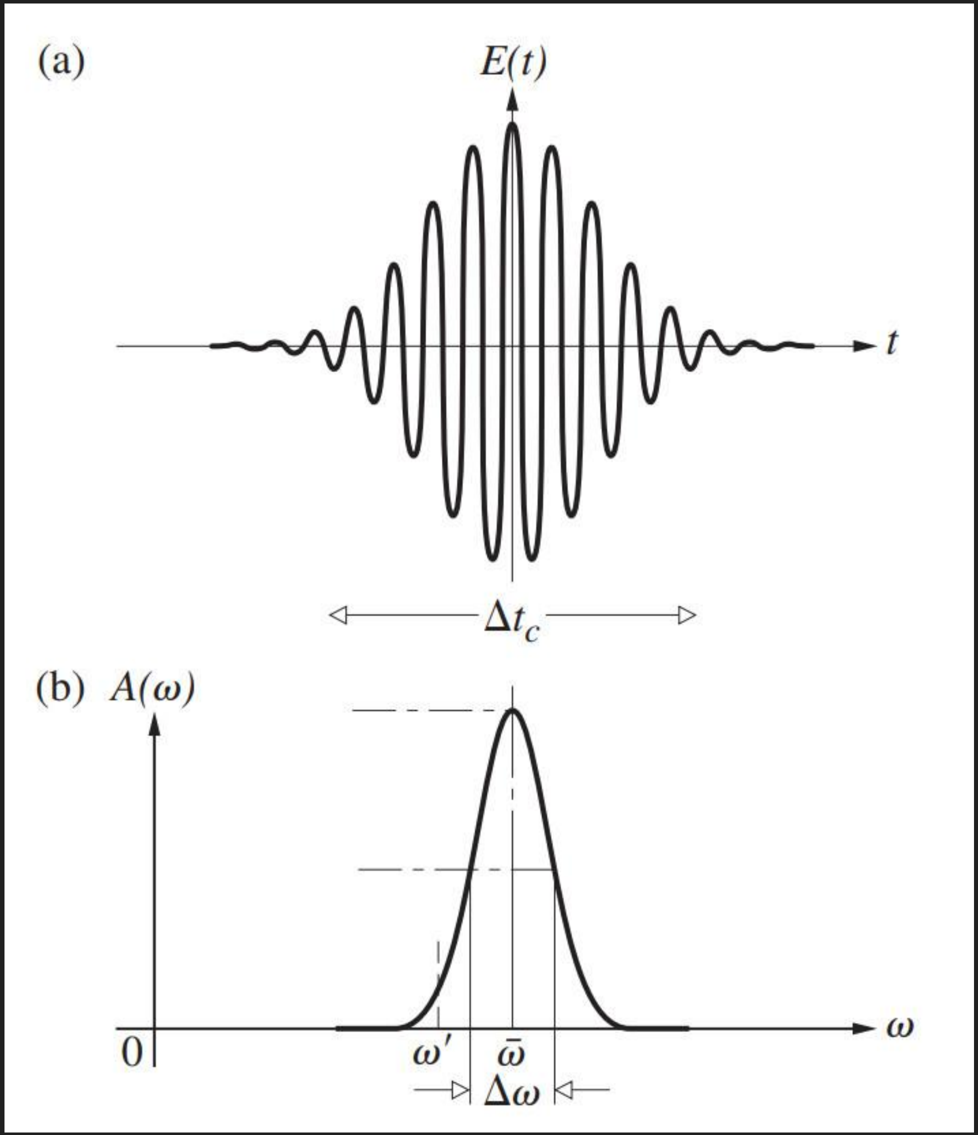
Fourier transform I



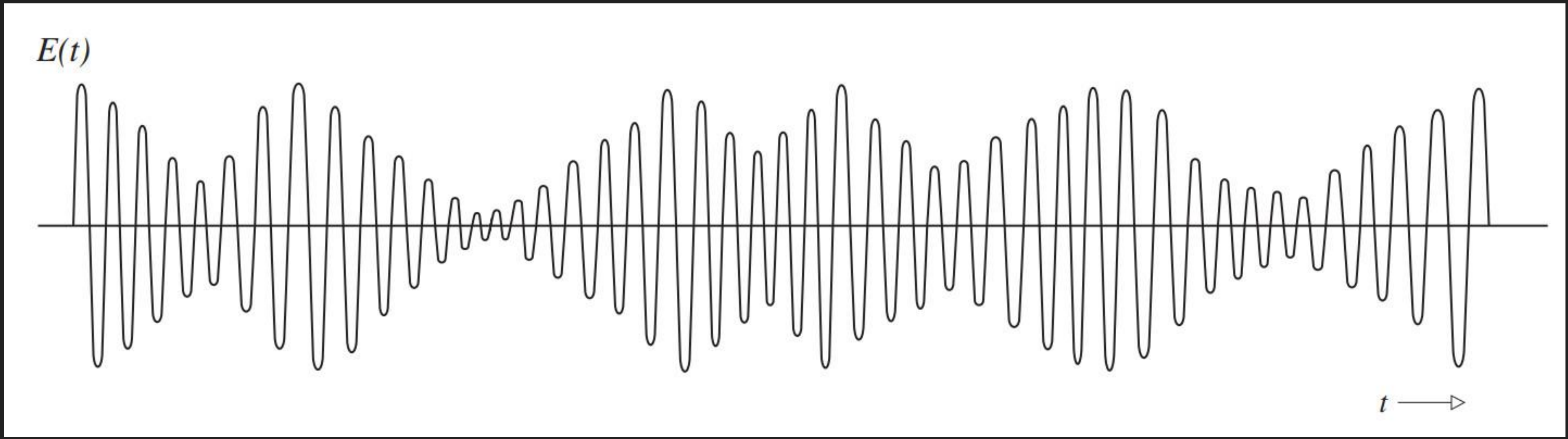
Fourier transform II



Gaussian wave packet



Quasi-monochromatic wave train



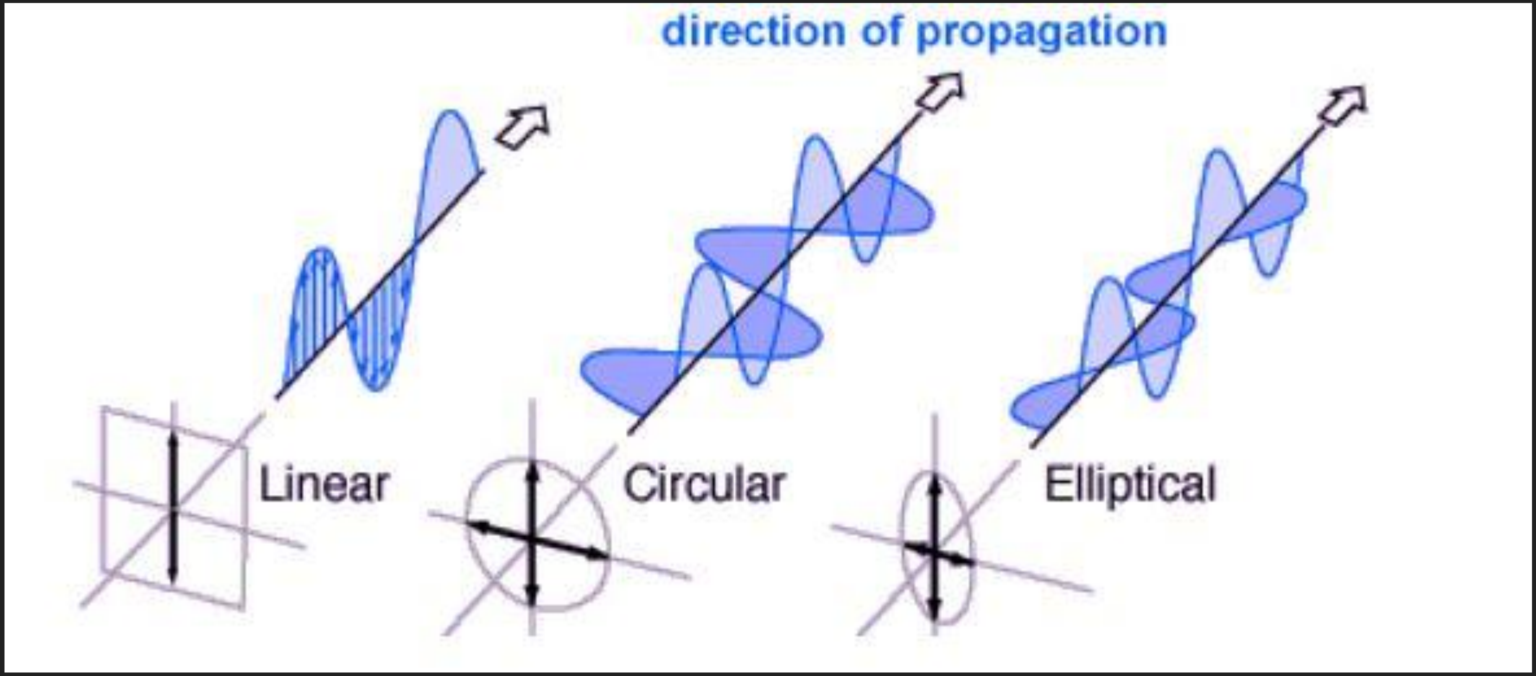
Summary Lecture 11

- Adding many waveforms of different frequency results in anharmonic but periodic signals, which can be decomposed into sums of harmonics (Fourier theorem).
- Real waves are non-periodic and single pulses can be represented via Fourier integrals, i.e. the limit of $\lambda \rightarrow \infty$ or $k \rightarrow 0$. Fourier transforms can be calculated in spatial as well as temporal coordinates.
- Quasi-monochromatic light is composed of individual Gaussian wave-packets, added with undefined relativ phase $\rightarrow$ coherence length is short.

PHYS 434 Optics

Lecture 12: Introduction to Polarisation

Reading: 8.1 - 8.3



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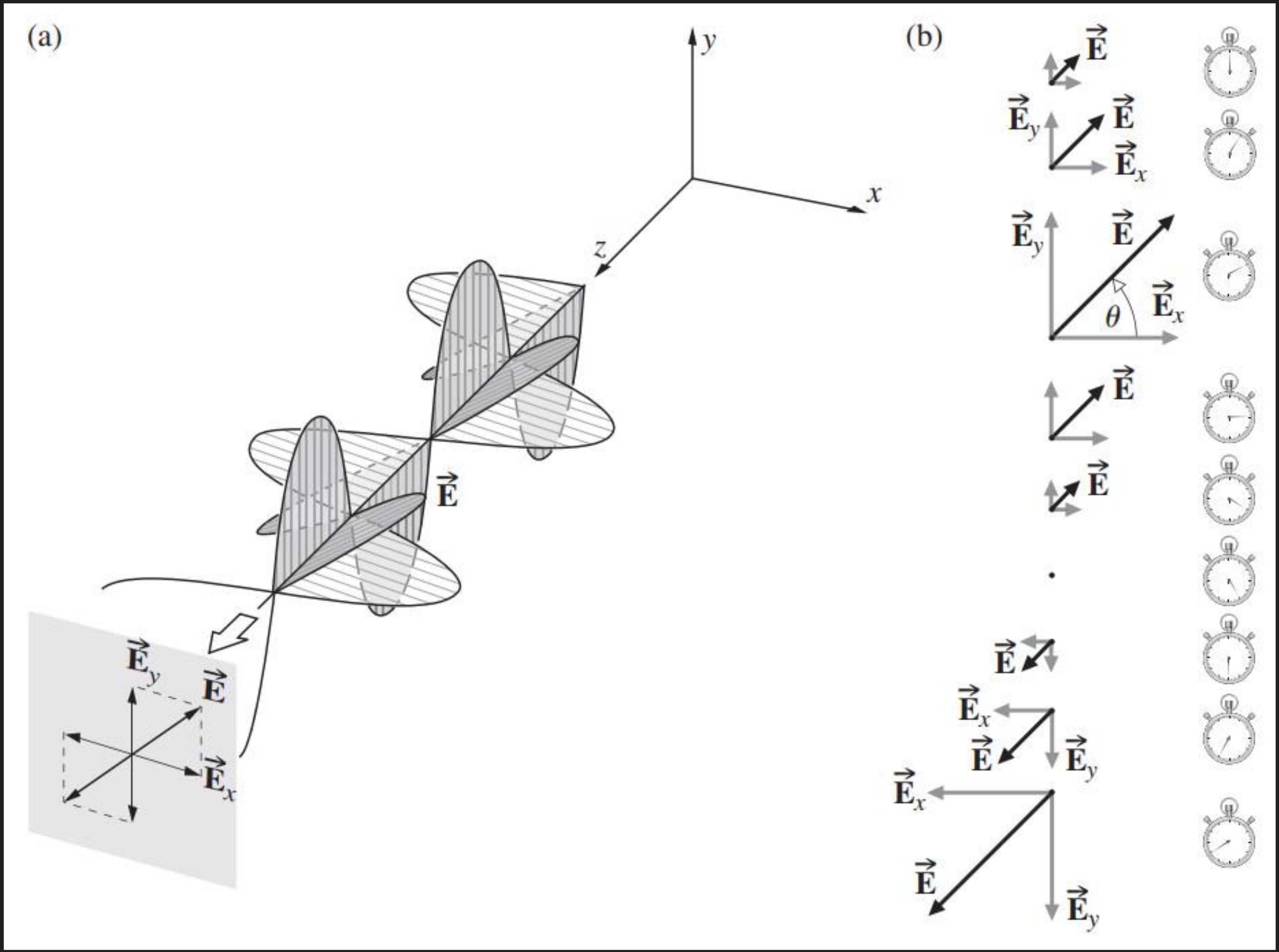
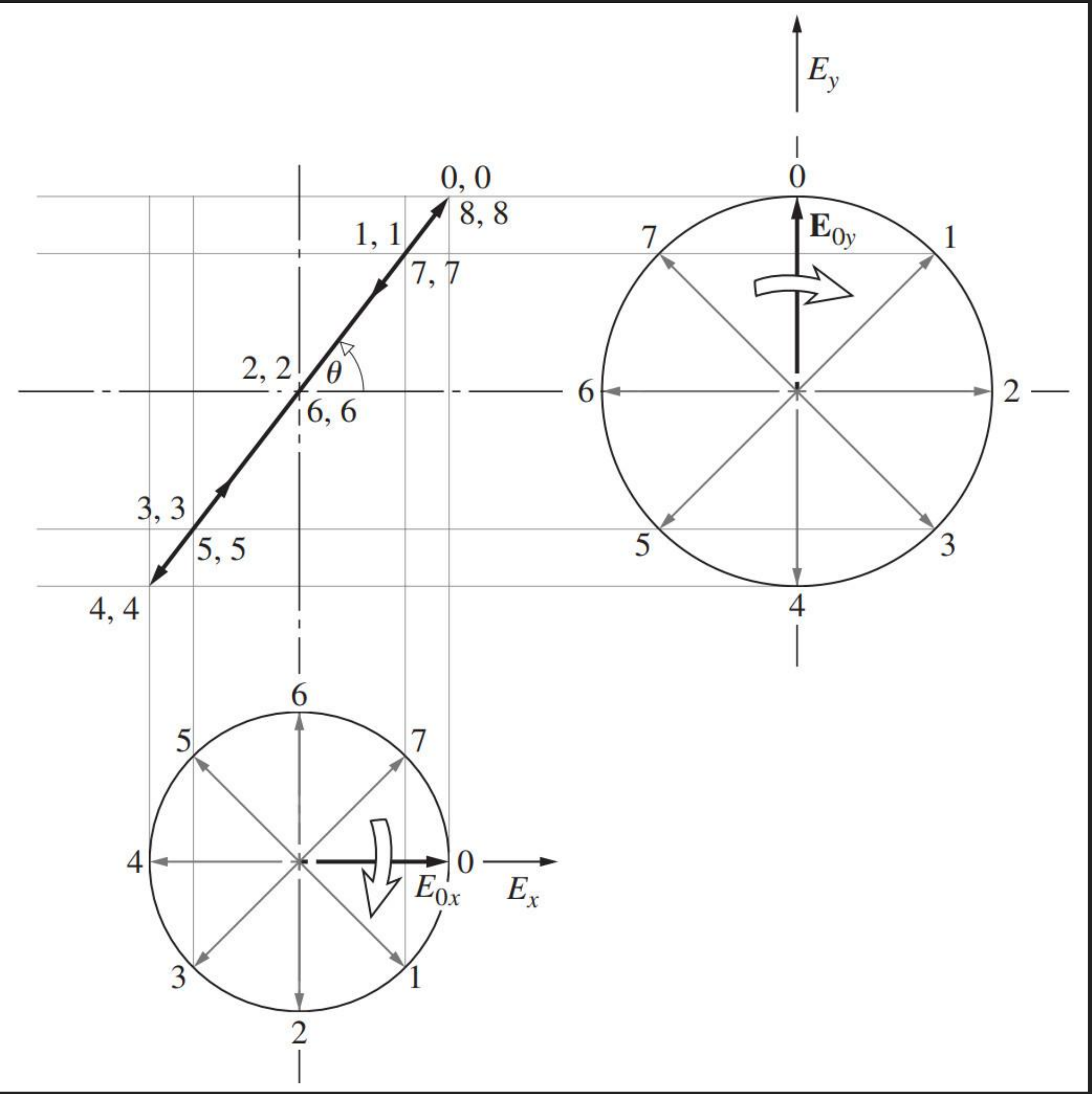
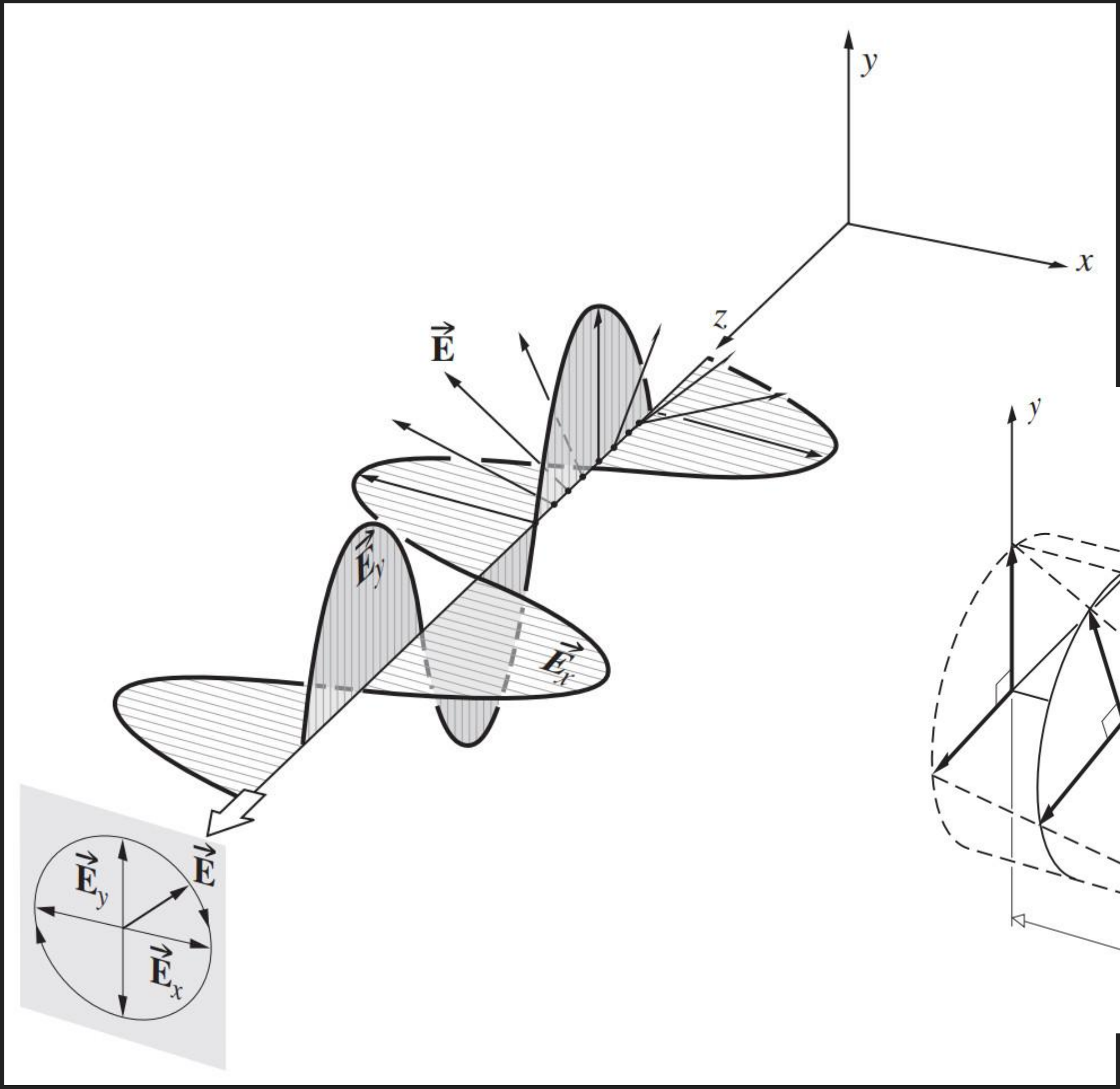
Linear polarisation

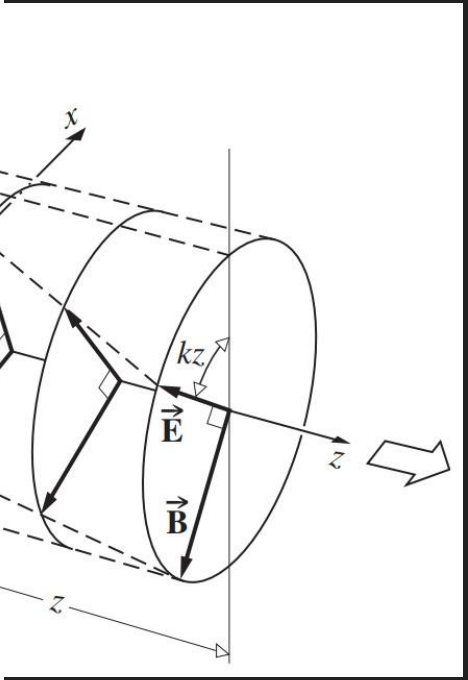


Phasor notation

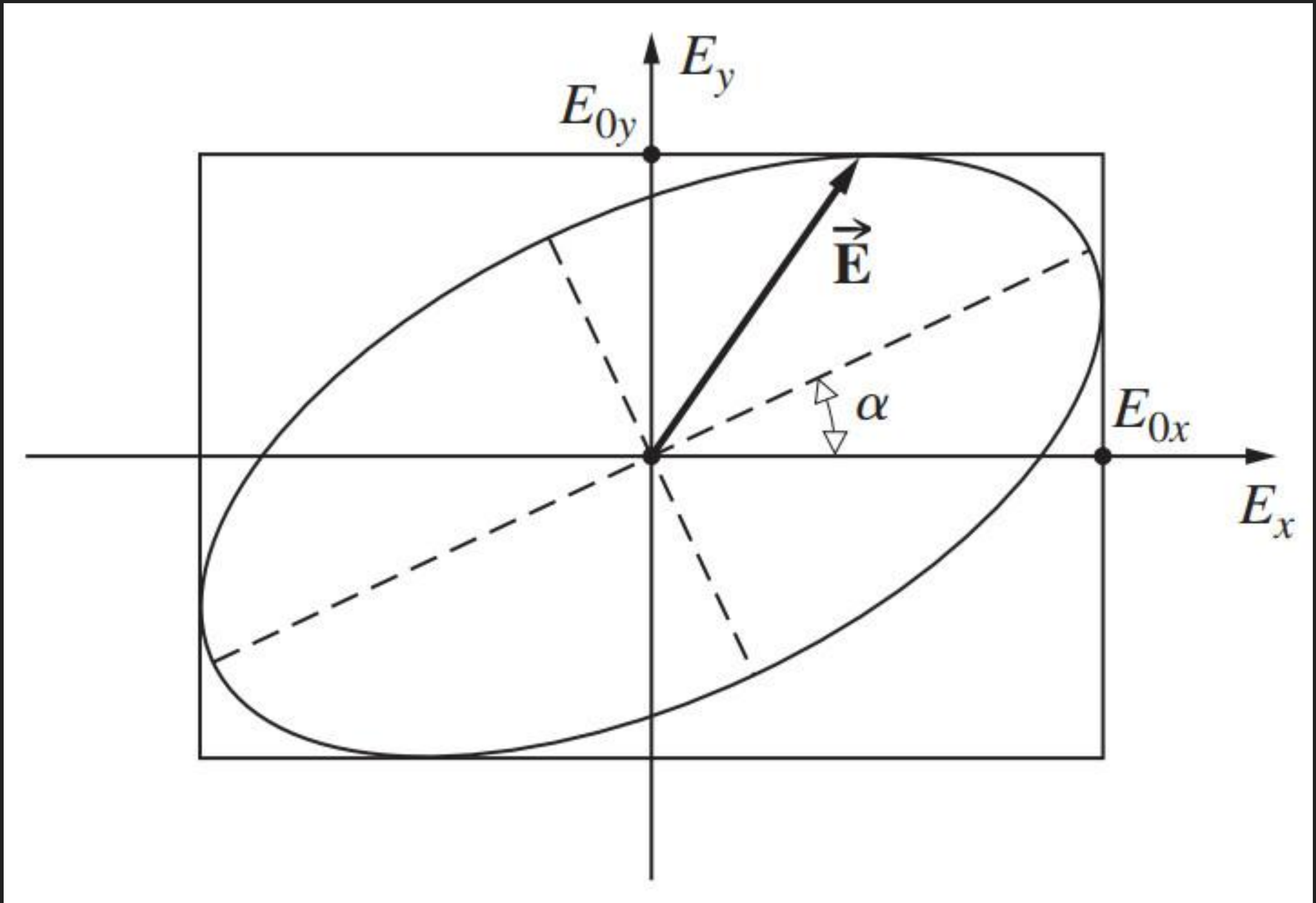


Right circular polarisation

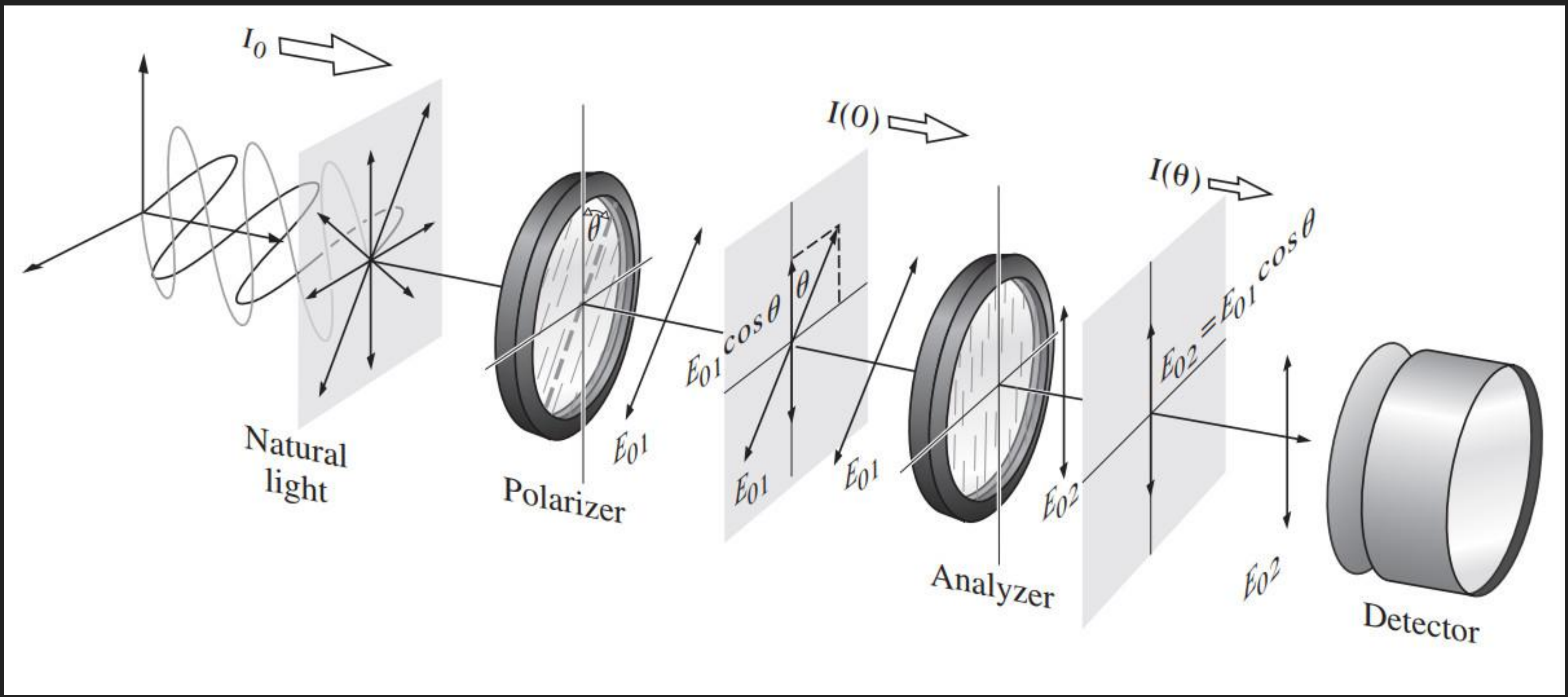




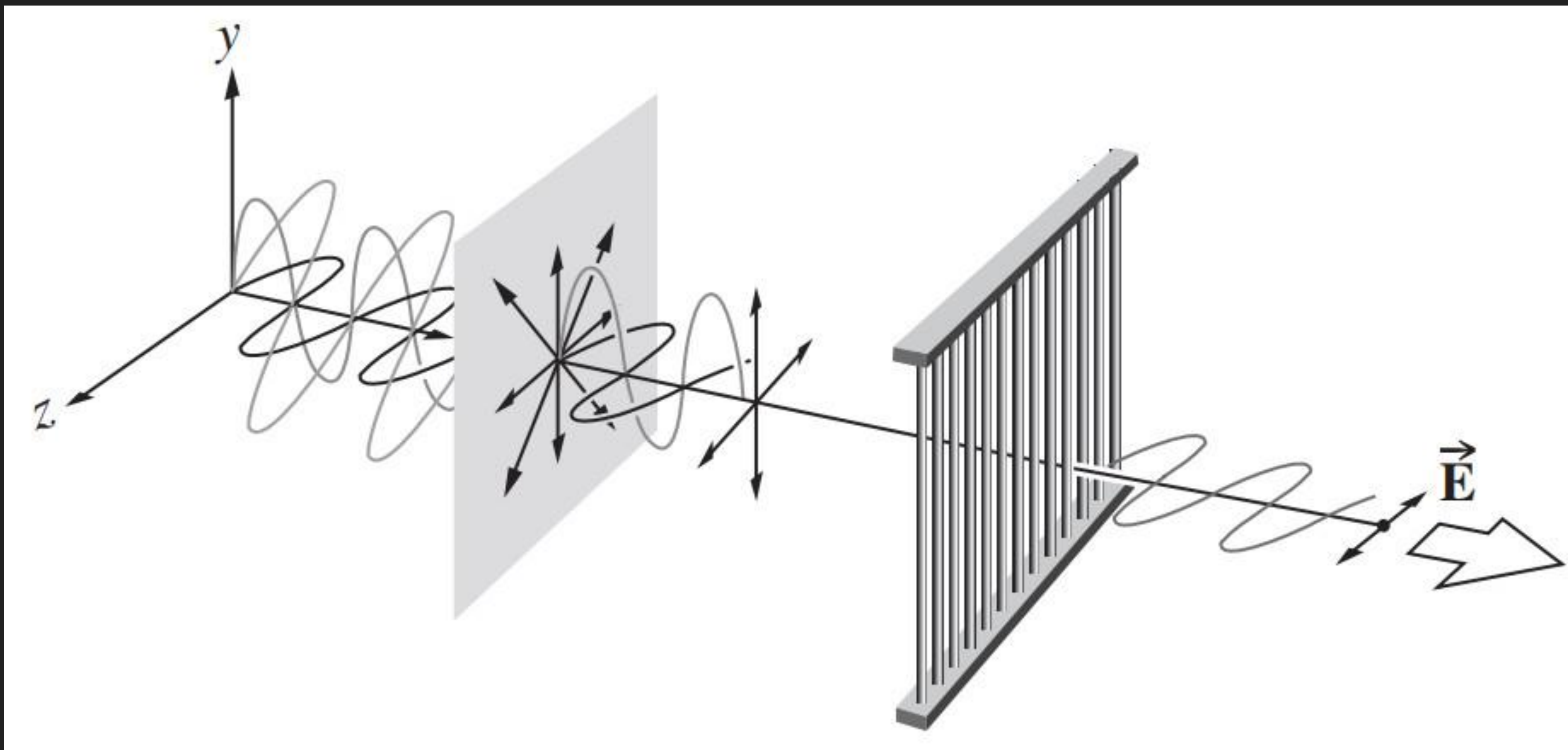
Elliptical polarisation



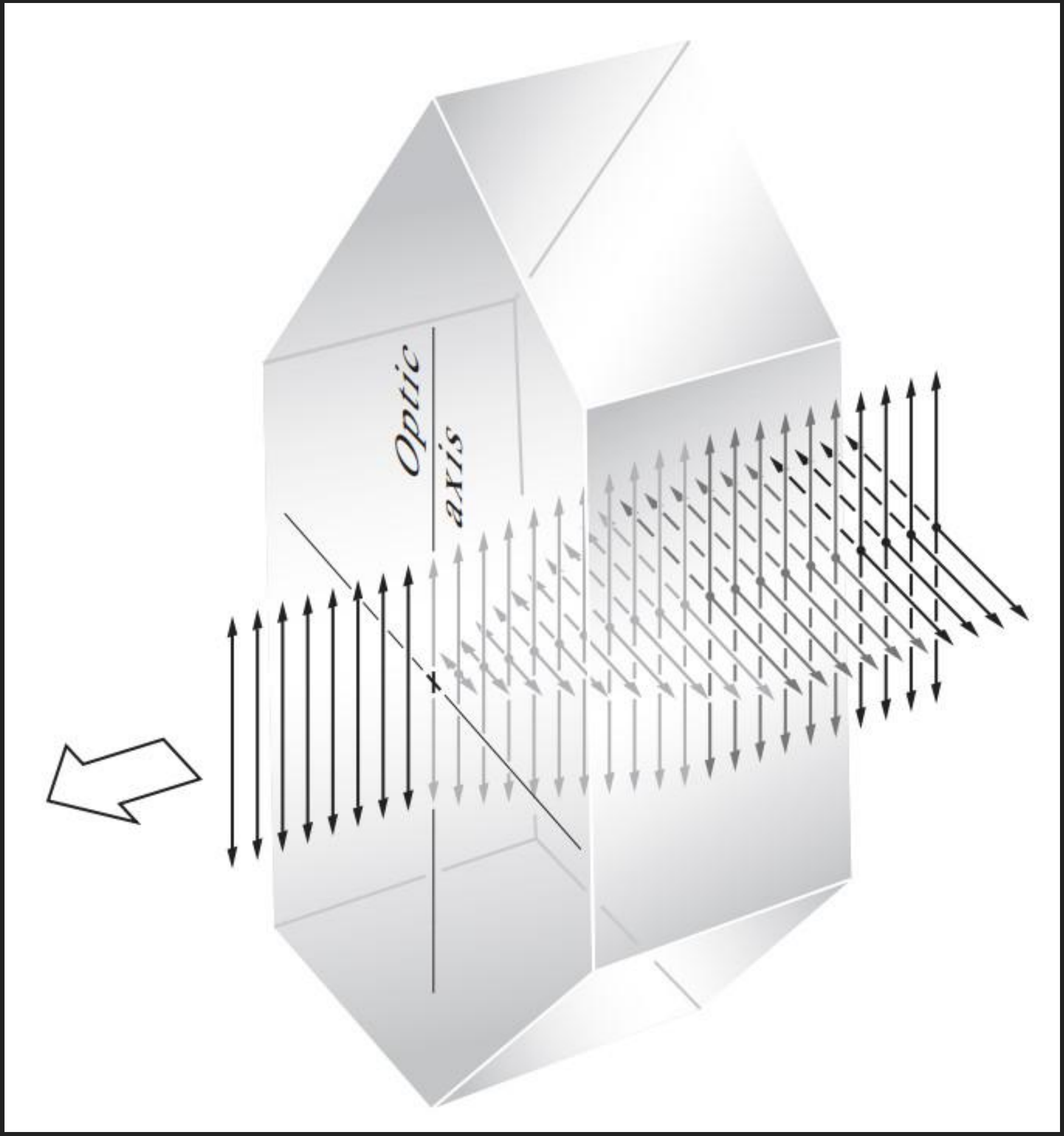
Malus law


I_0
$I(0)$
$I(\theta)$
θ
$E_{01}\cos\theta$
$E_{02} = E_{01}\cos\theta$
E_{01}
E_{02}
Natural light
Polarizer
Analyzer
Detector

Dichroism



Optical axis



Summary Lecture 12

- When discussing the properties of light, we need to consider the vector nature of the electric field.
- Depending on phase/amplitudes of two travelling waves, the resultant is linearly/circularly/elliptically polarised (can be represented in Jones notation).
- Natural or unpolarised light has polarisation that fluctuates on short timescales. It can be represented by Stokes parameters.
- The simplest polarisers exploit dichroism (i.e. such as a wired grid) to select a specific polarisation.

PHYS 434 Optics

Lecture 14: Birefringence, Scattering, Reflection, Retarders

Reading: 8.4 - 8.7

Summary Lecture 12

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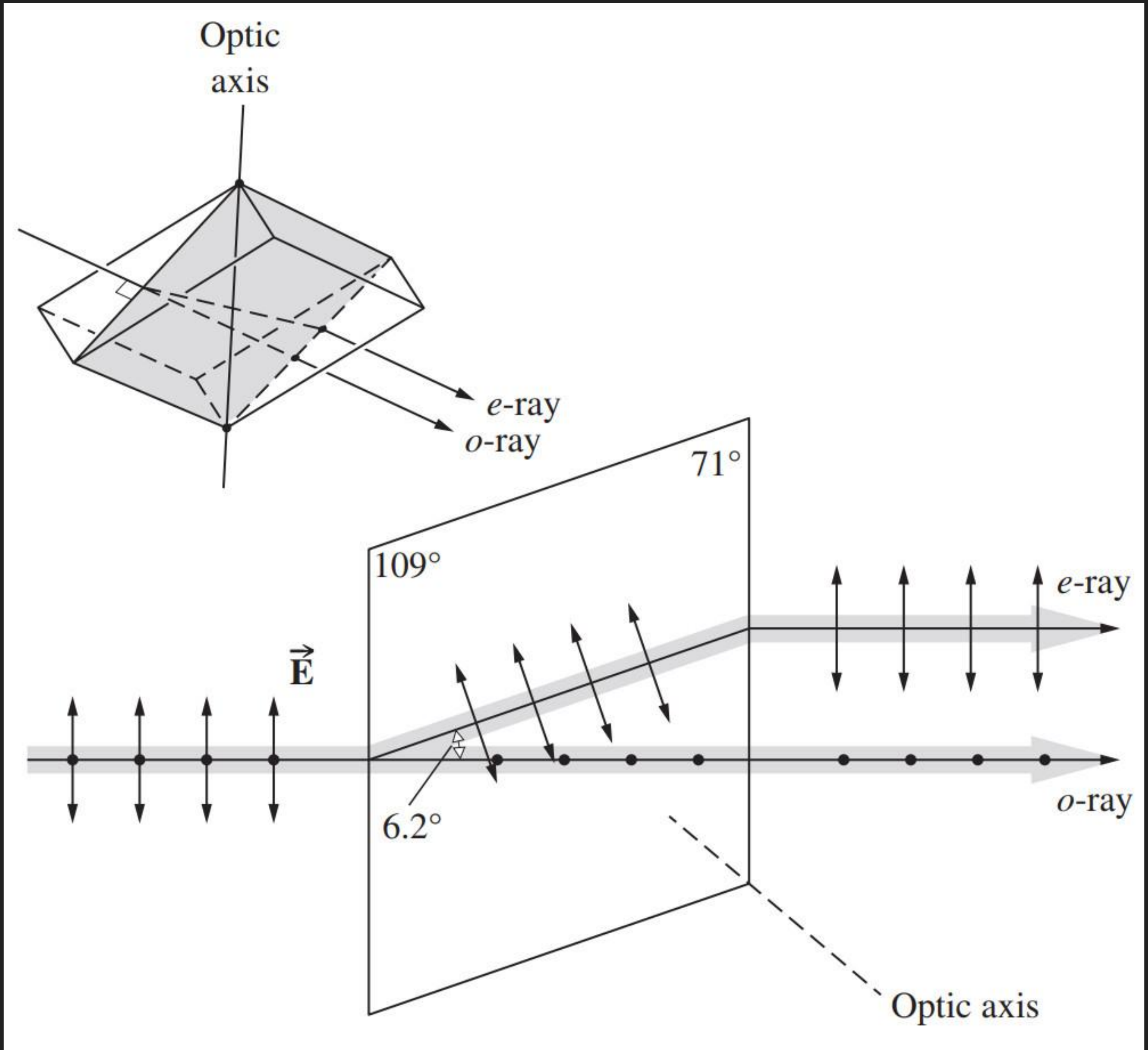
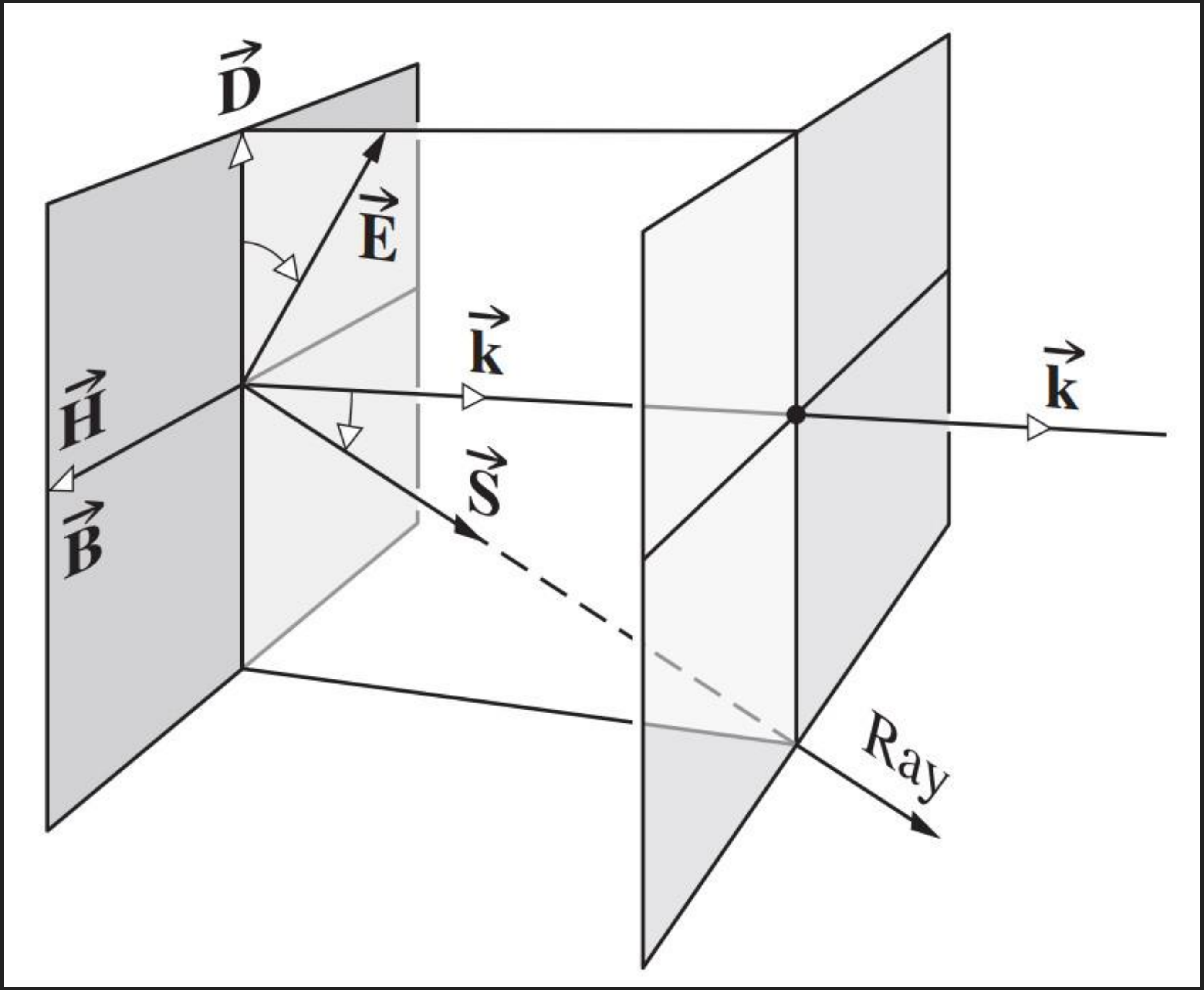
Double image in calcite

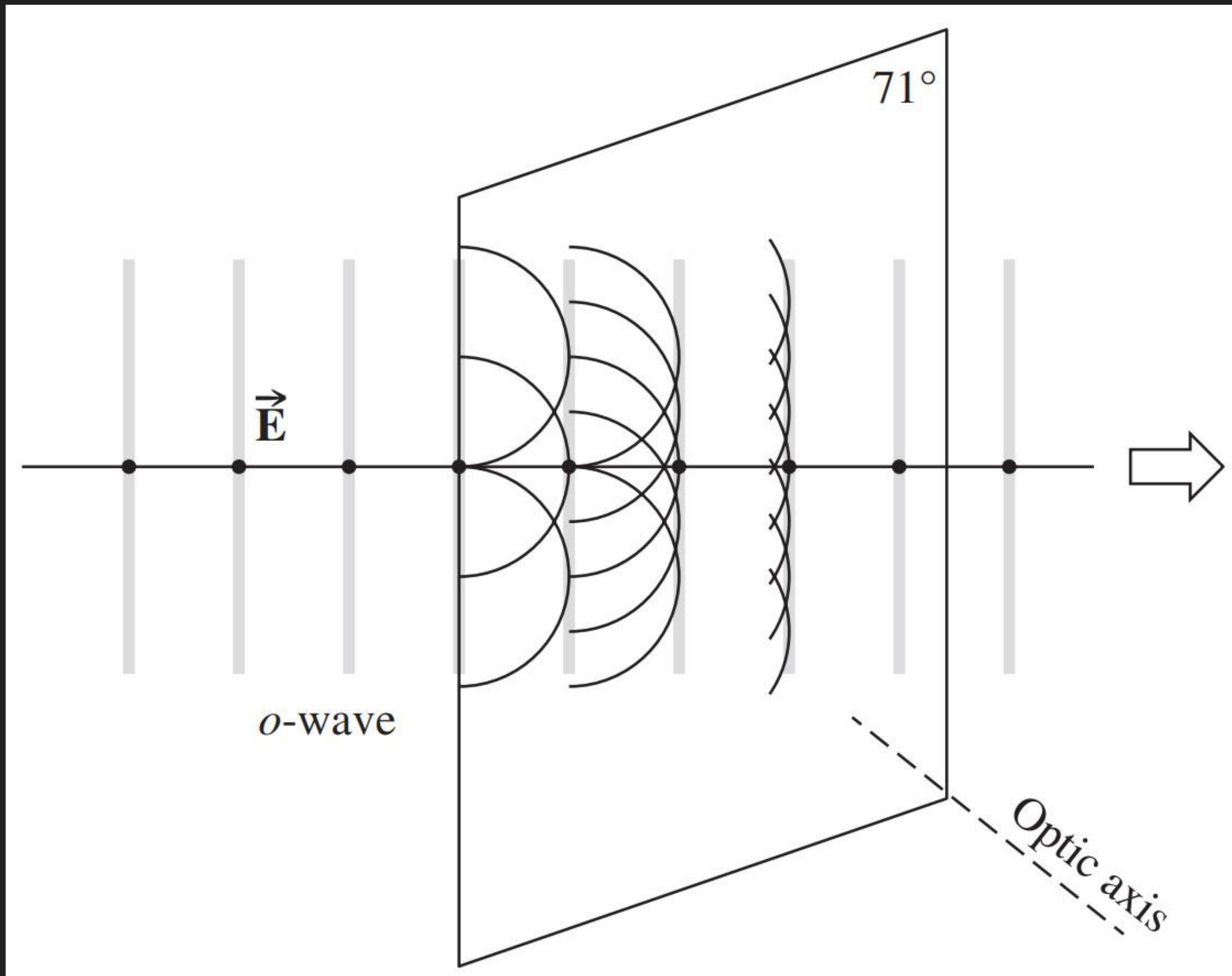
(Extra)ordinary rays



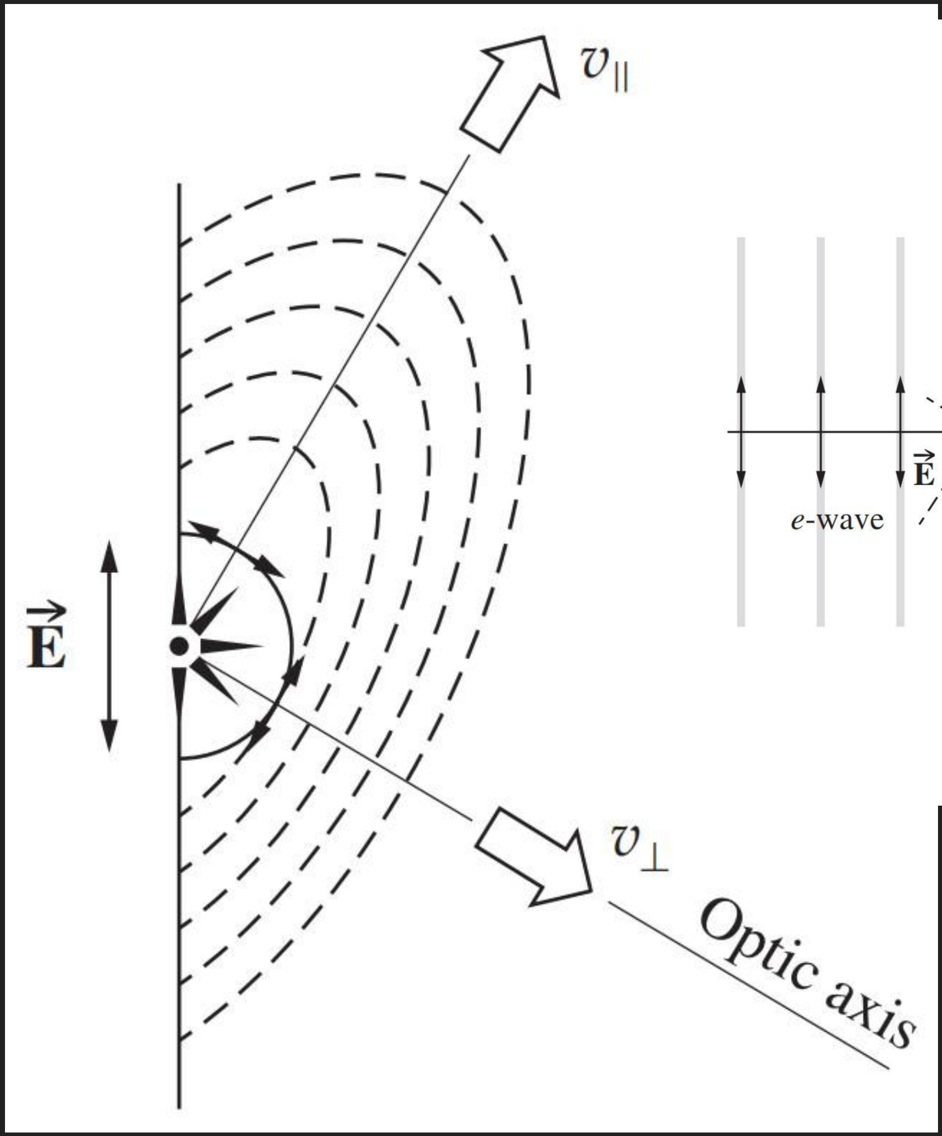
EM field geometry

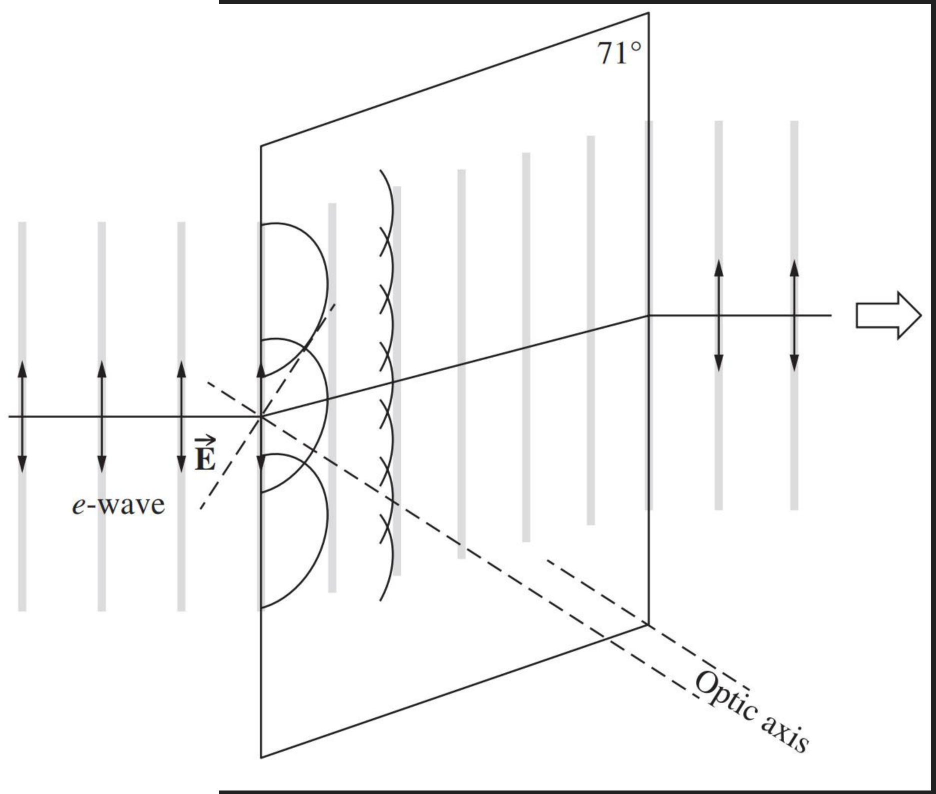


Ordinary wavelets

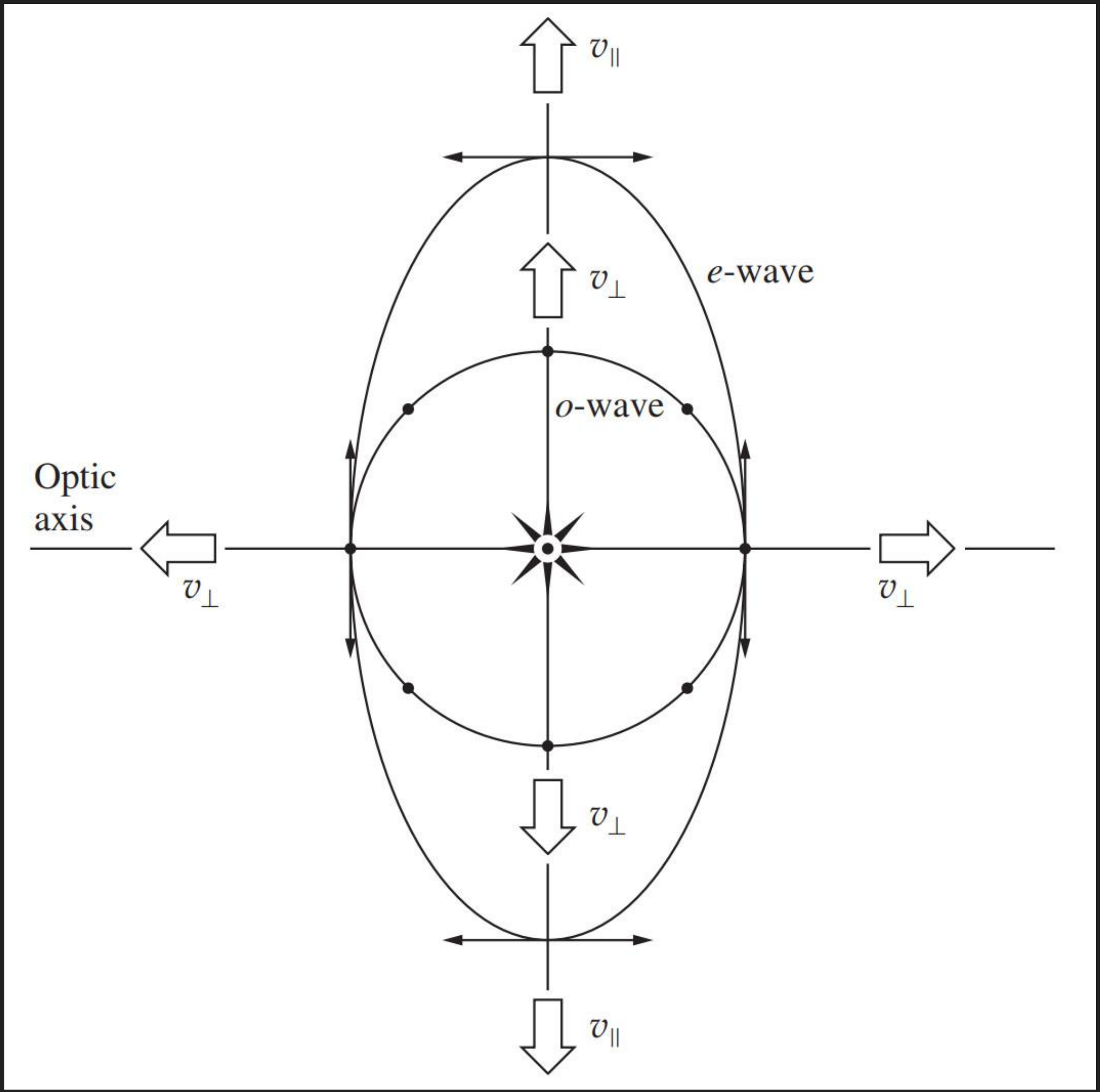


Extraordinary wavelets

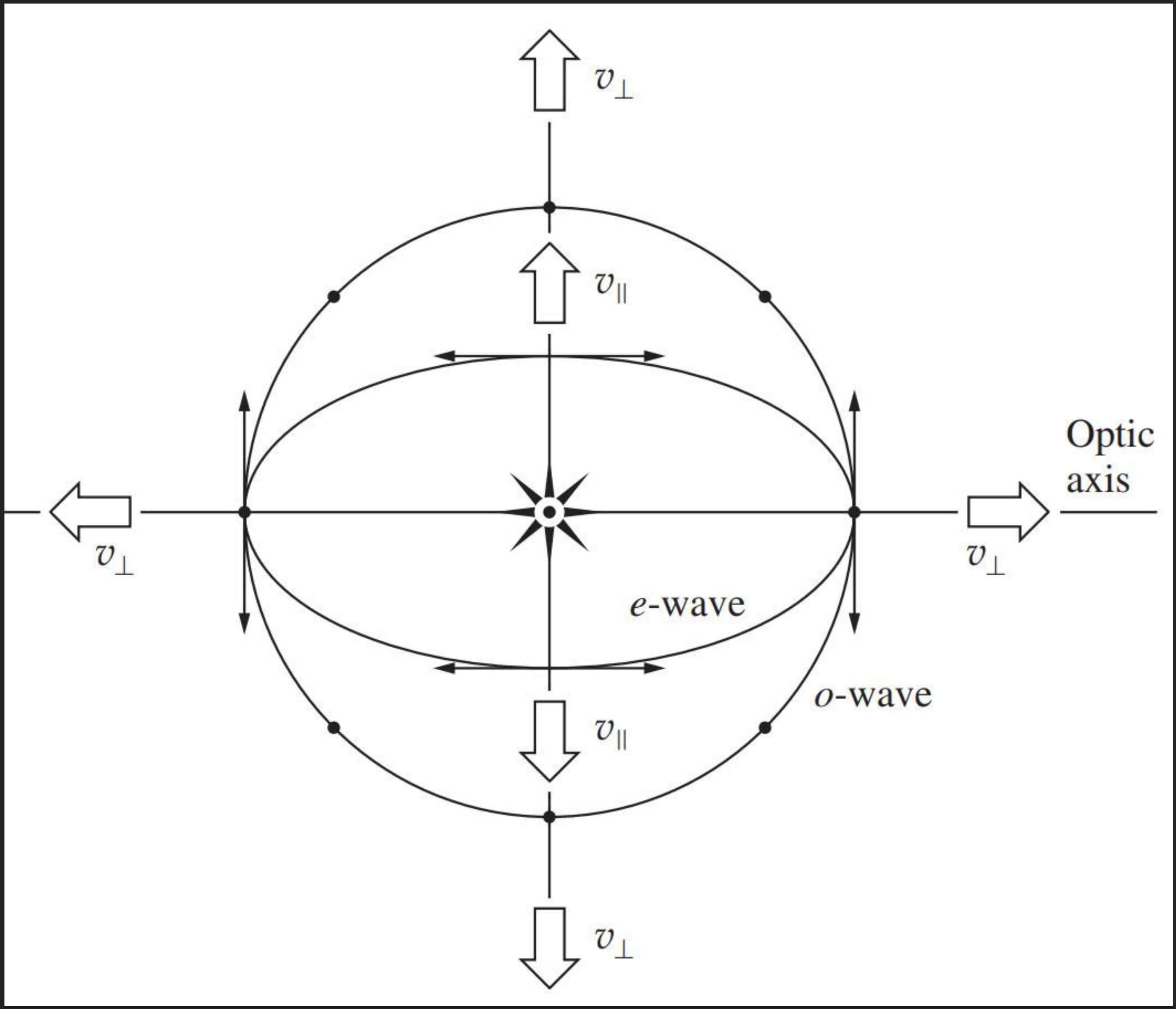




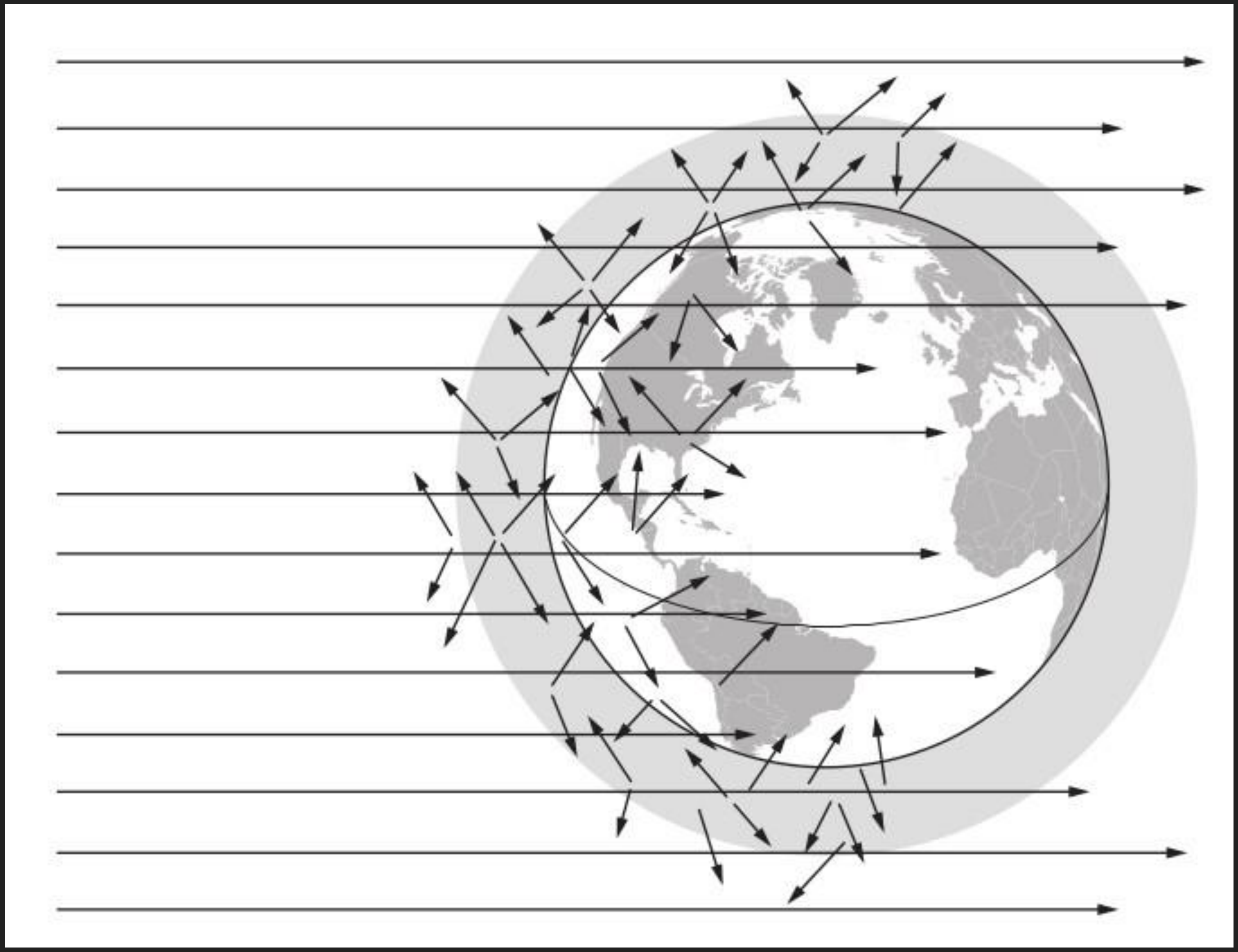
Negative uniaxial crystal



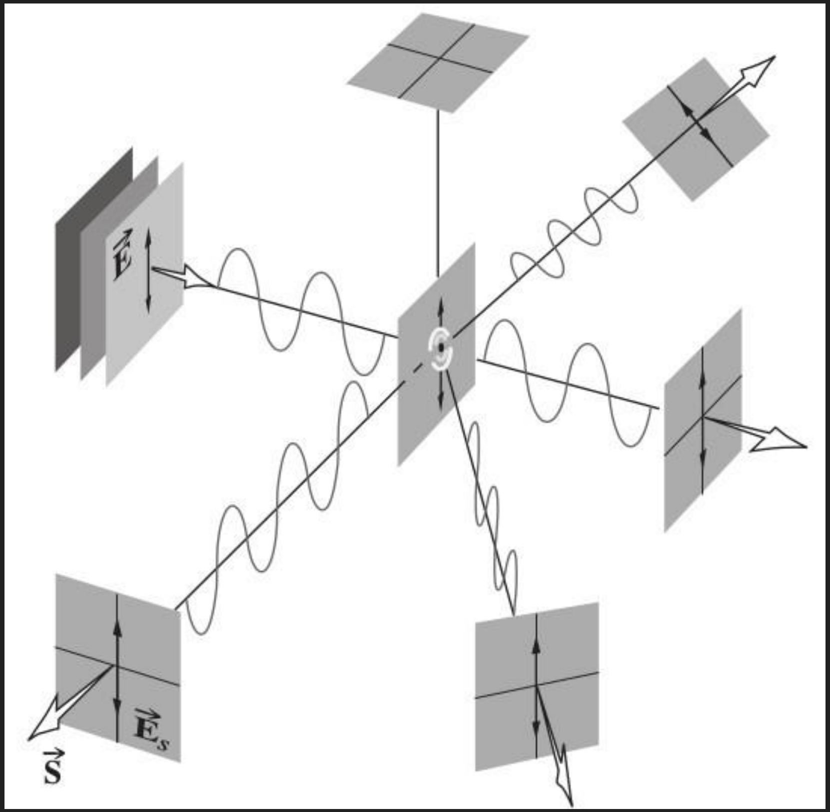
Positive uniaxial crystal

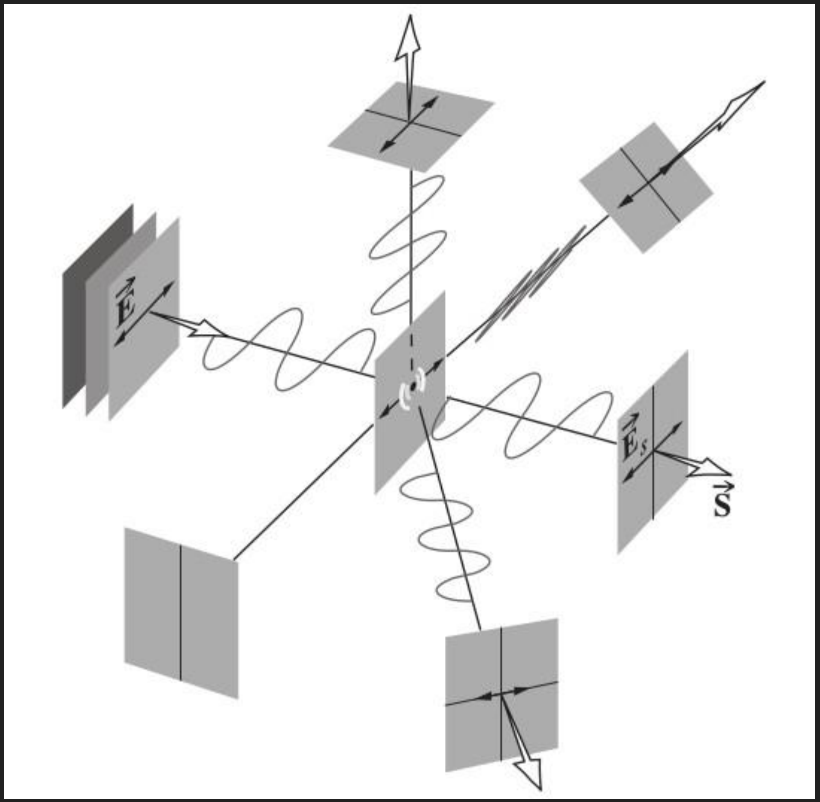


Atmospheric scattering

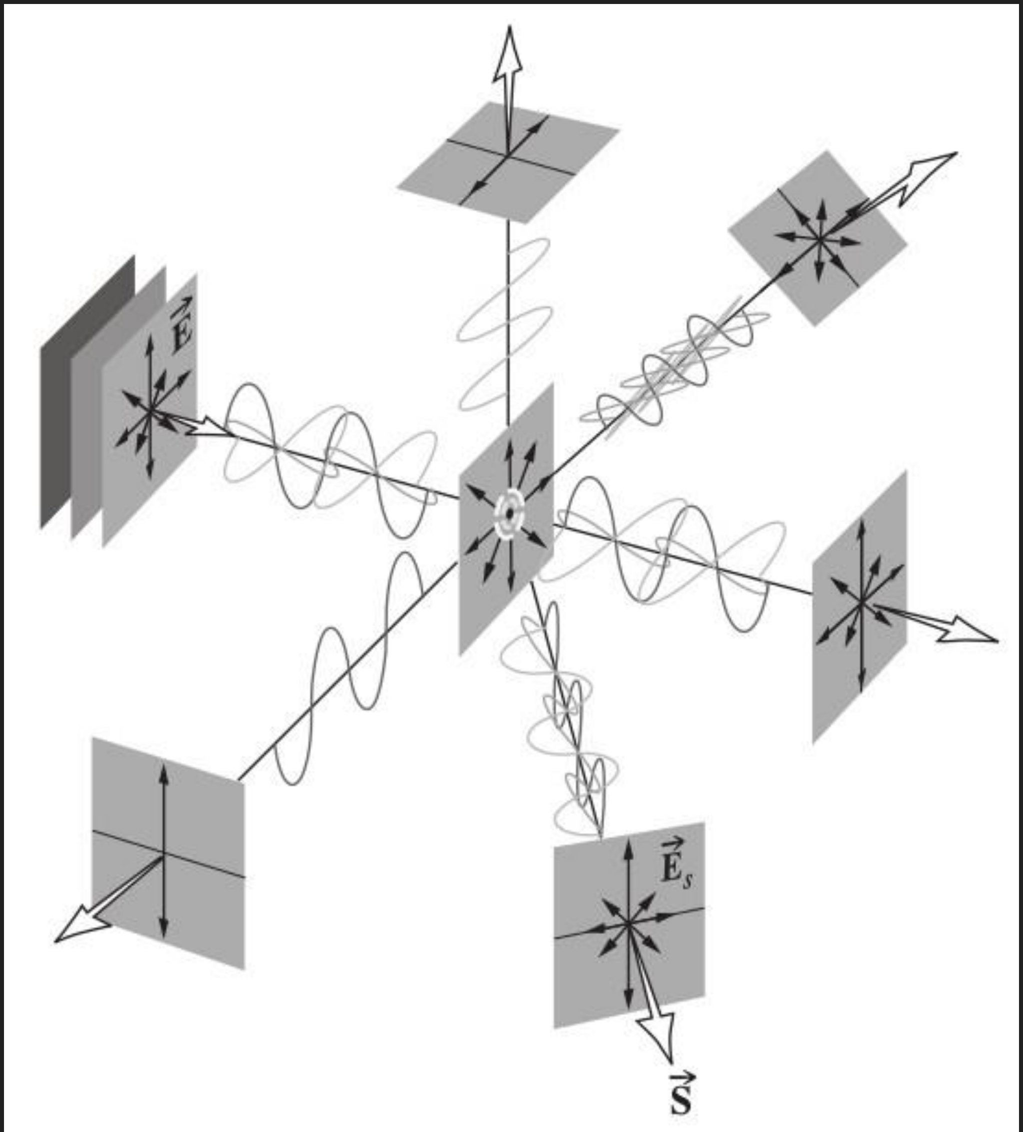


Polarisation by scattering I

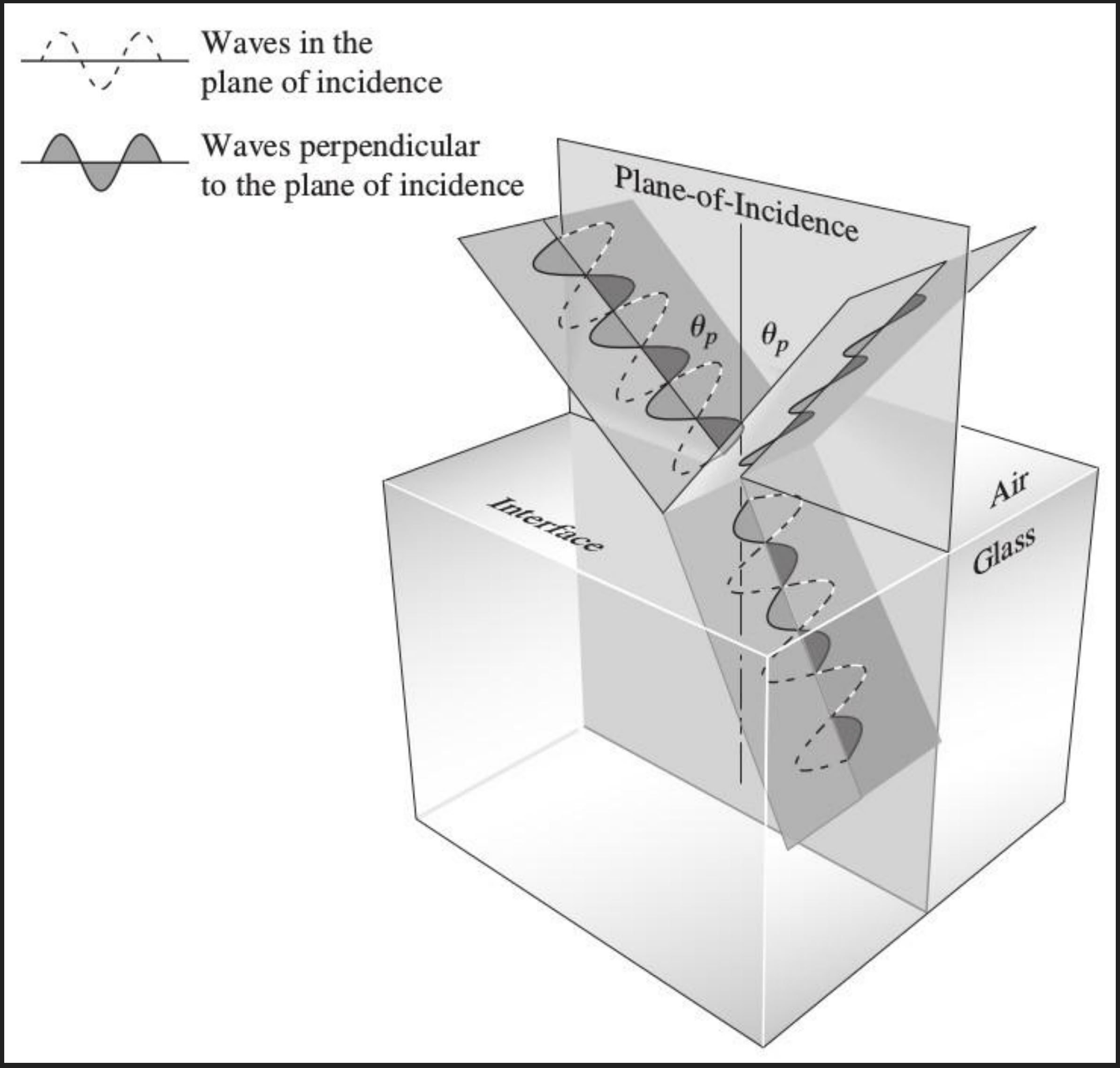




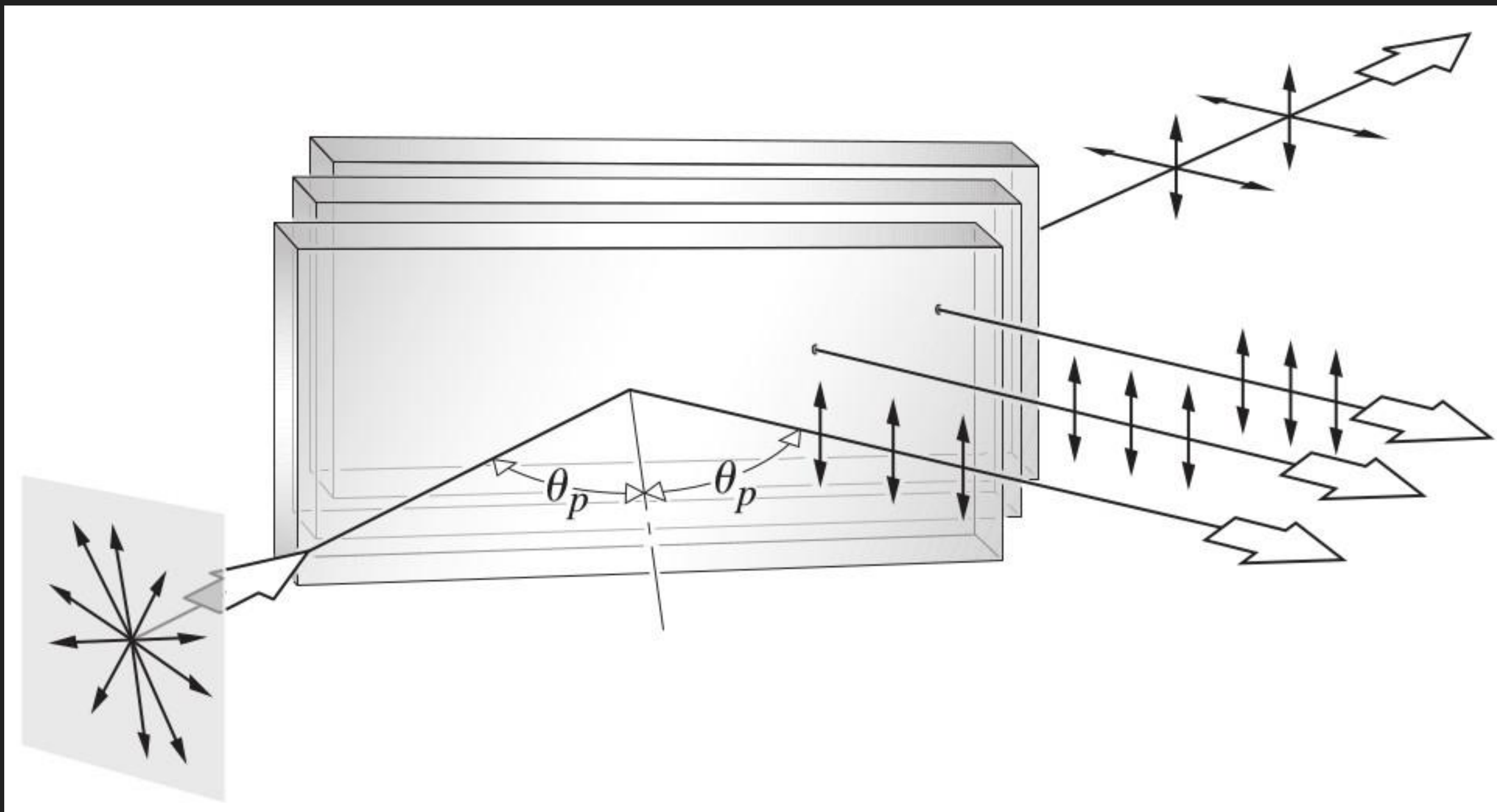
Polarisation by scattering II



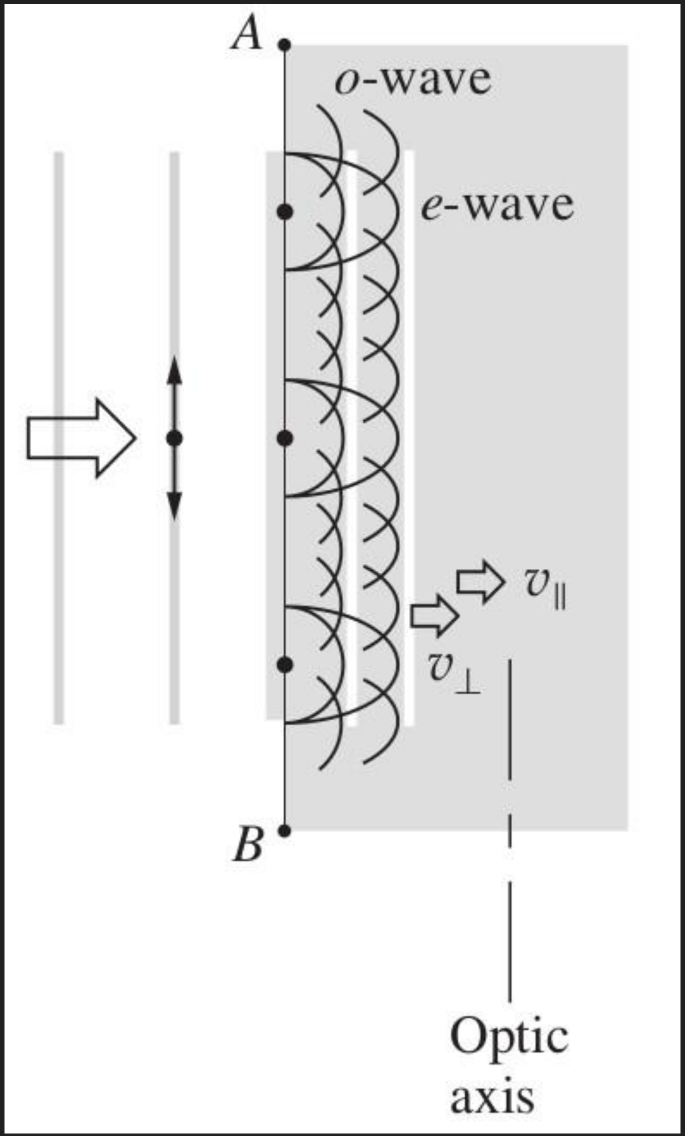
Polarisation by reflection



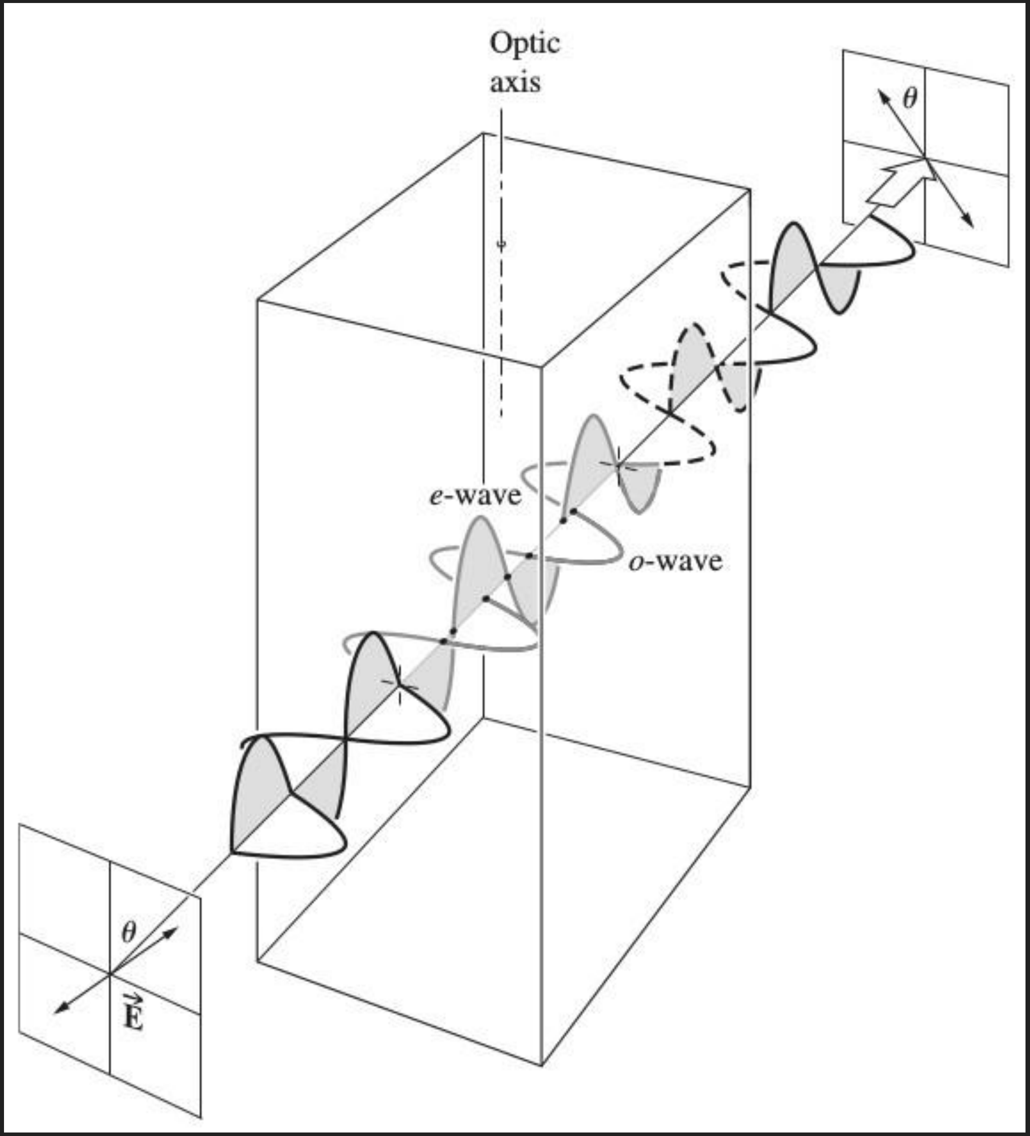
Pile-of-plates polariser



Retarders



Wave-plates



Summary Lecture 14

- Due to internal anisotropies, many materials are bi-refringent, i.e. characterised by two different refractive indices for different polarisation components.
- Light can be polarised by scattering and (more often) reflection on dielectric surfaces (at Brewster angle).
- While polarisers set a fixed polarisation state, retarders are able to coherently transform between them. They achieve this by introducing a phase shift between ordinary and extraordinary components dependent on the width of the waveplate.

PHYS 434 Optics

Lecture 15: Polarisers, Optical Activity, Modulators, Liquid Crystals

Reading: 8.8 - 8.12

Summary Lecture 14

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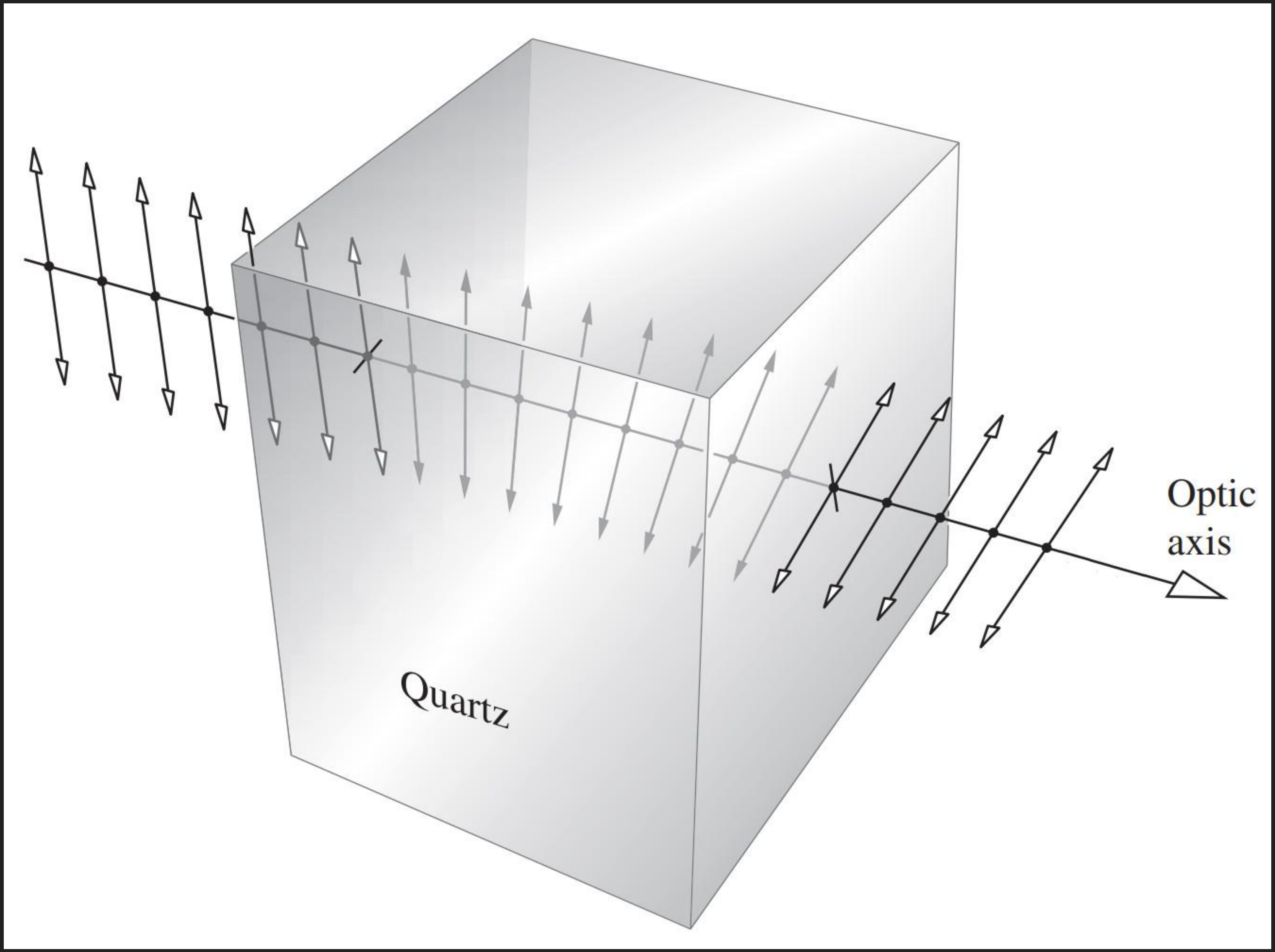
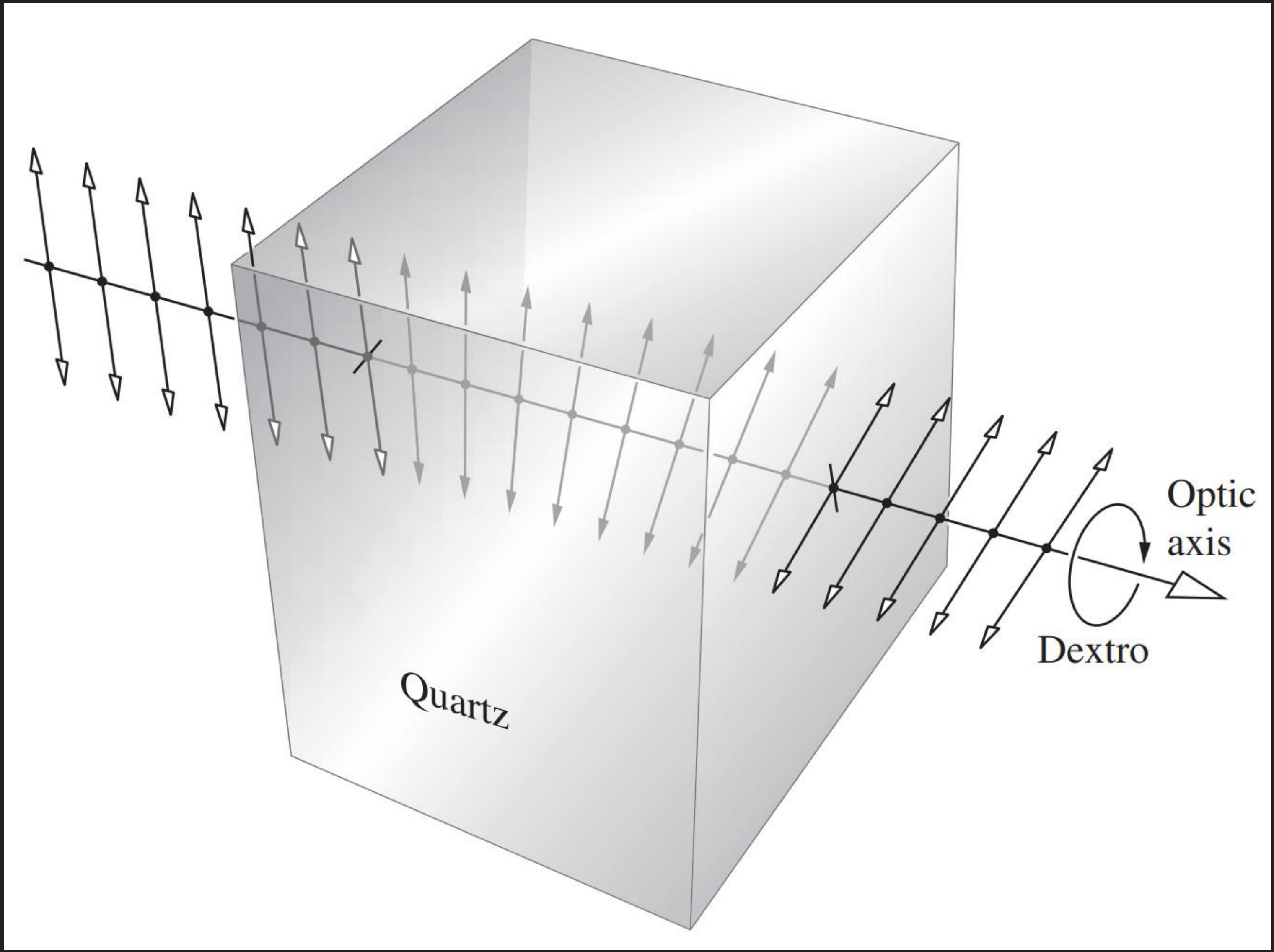
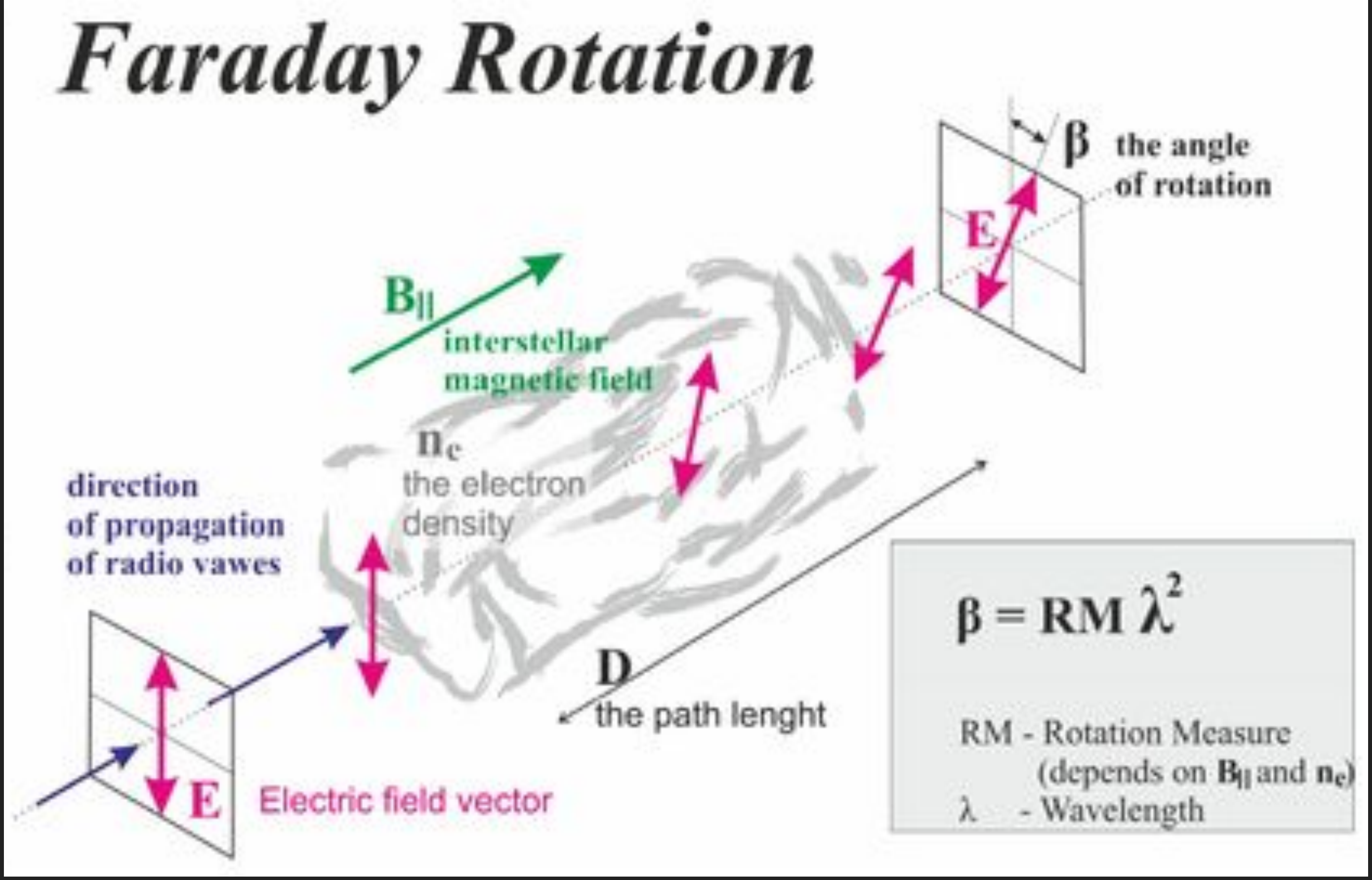
Optical activity



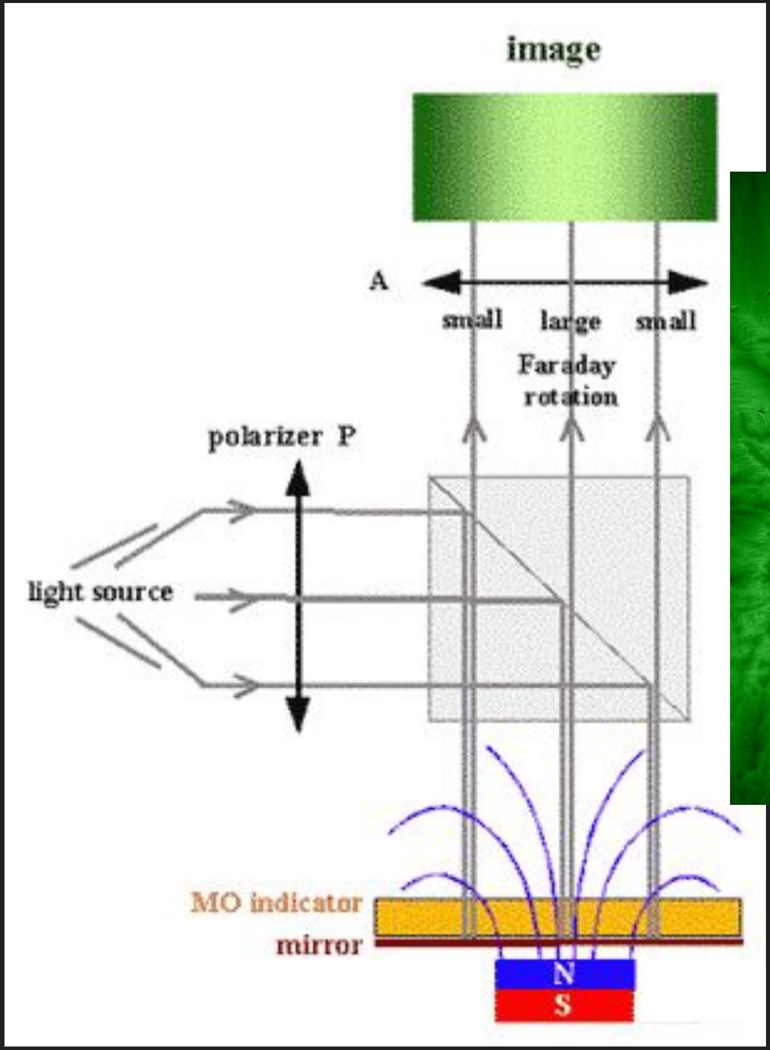
Optical activity

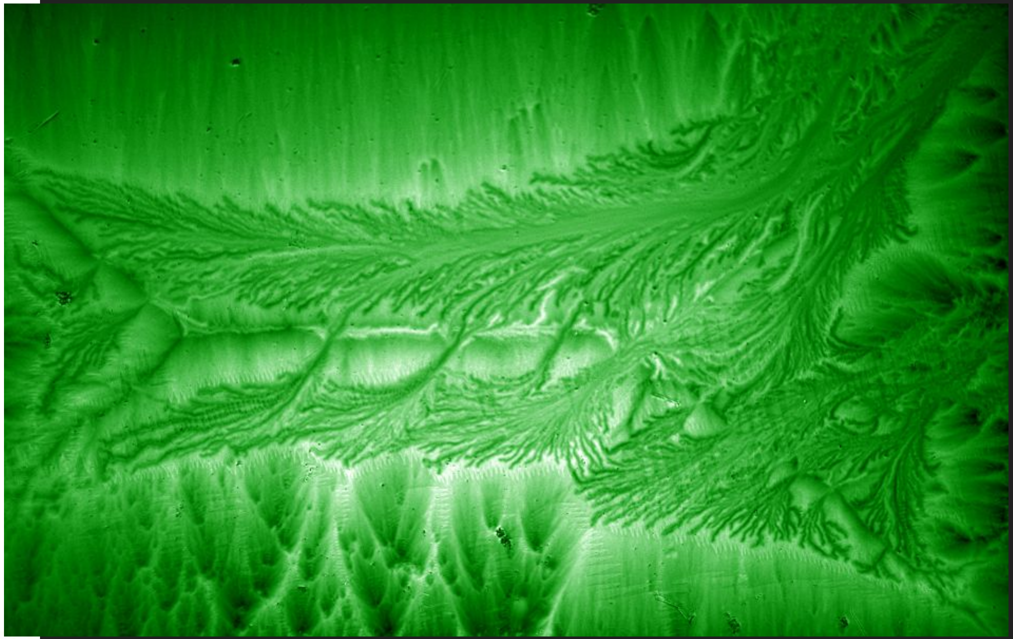


Faraday effect I

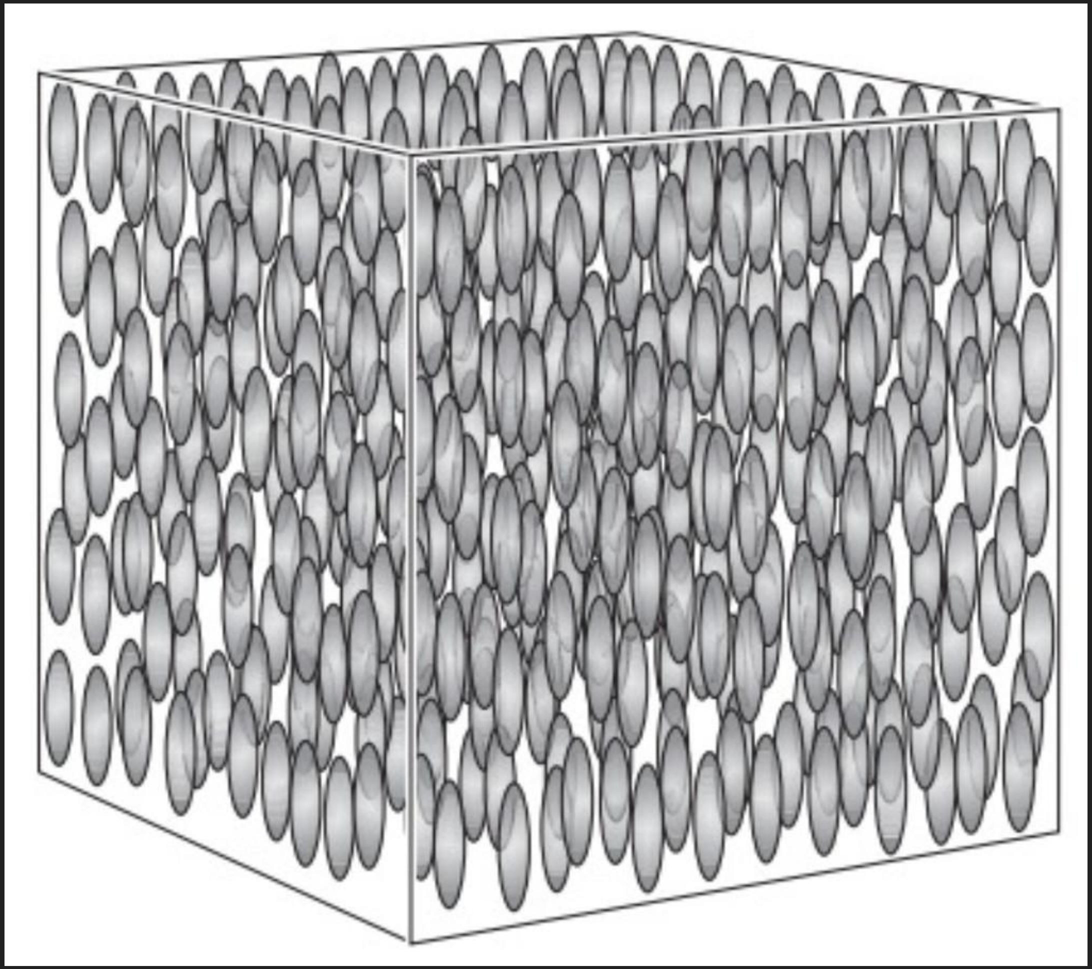


Faraday effect II

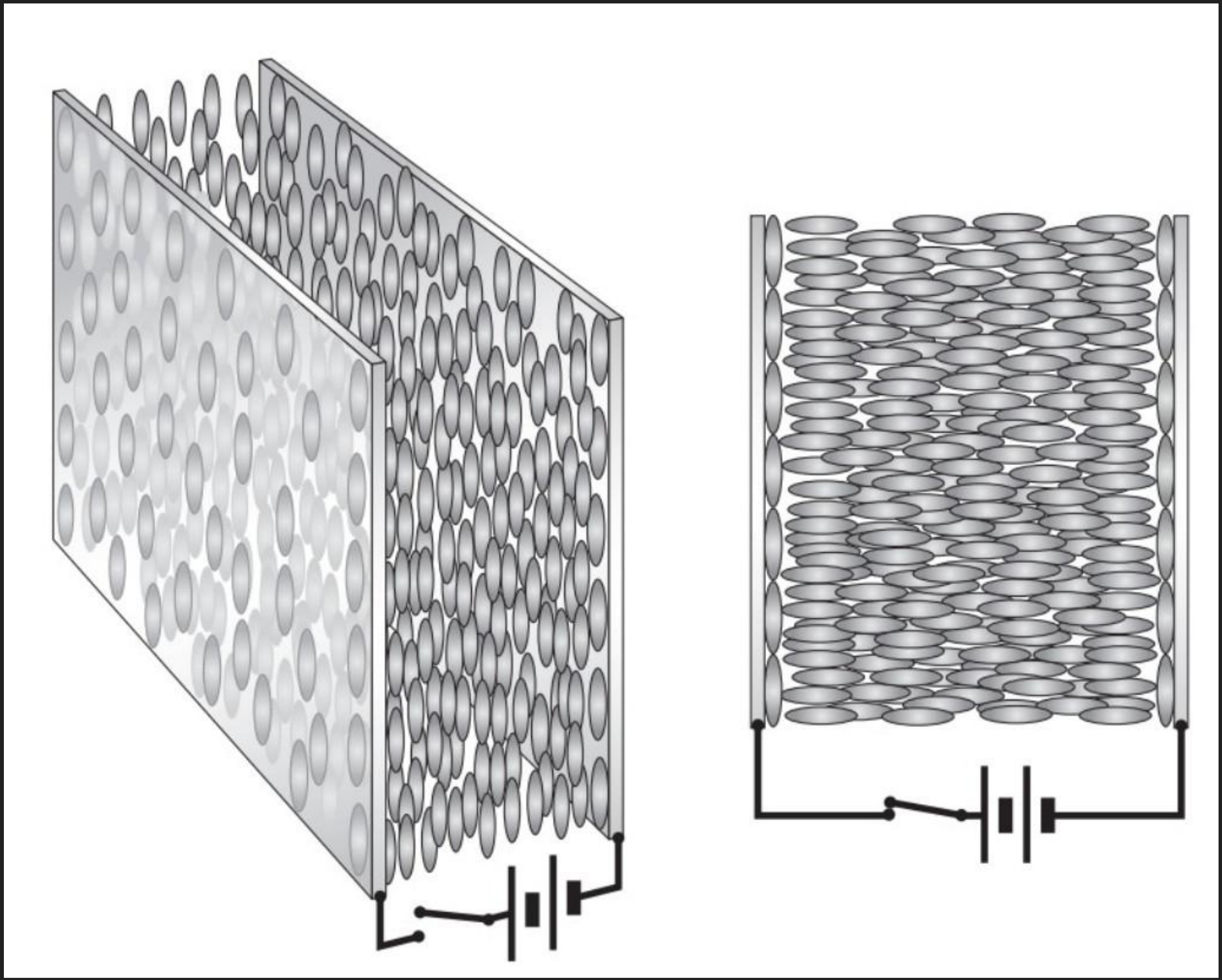




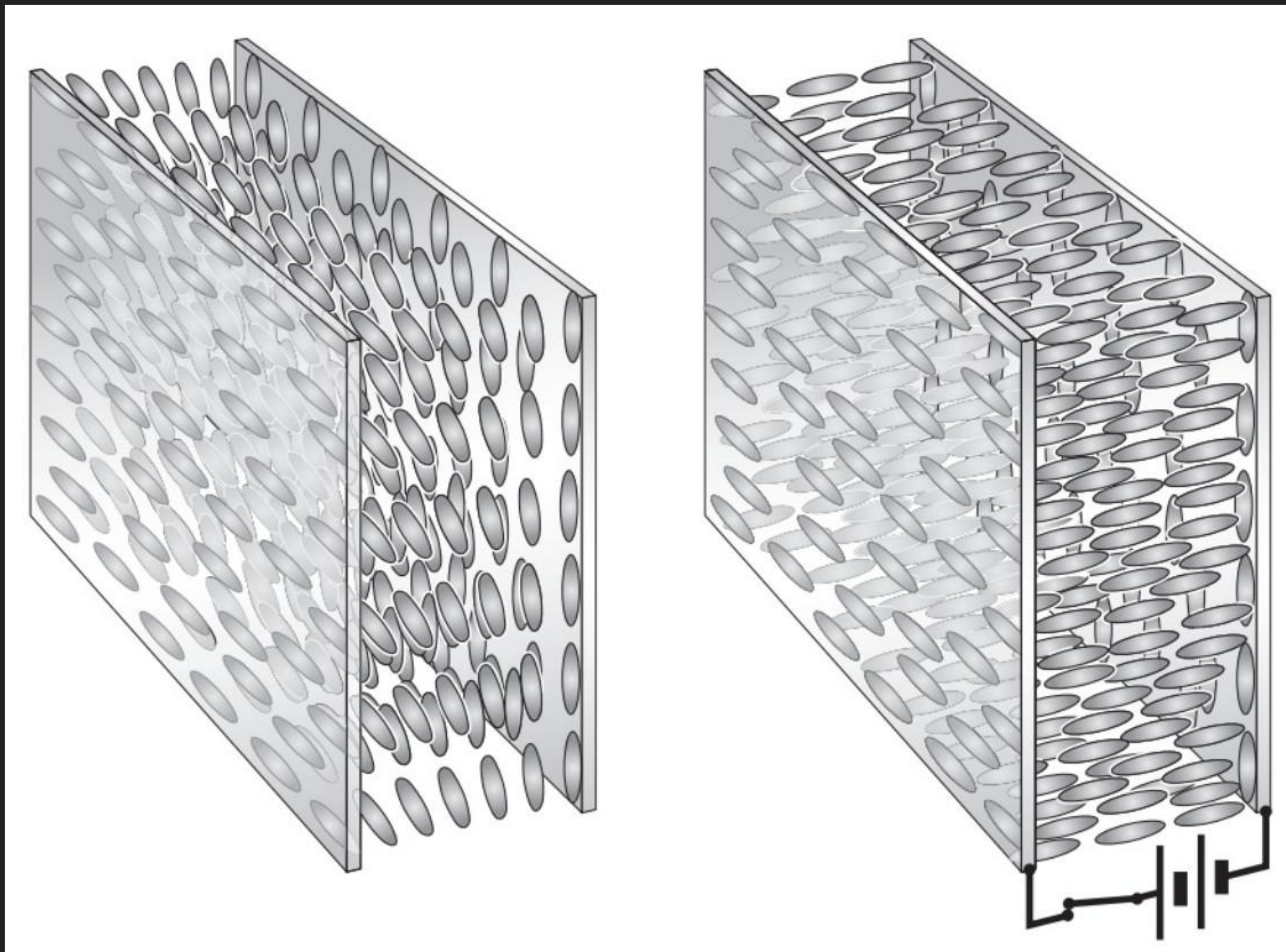
Liquid crystals



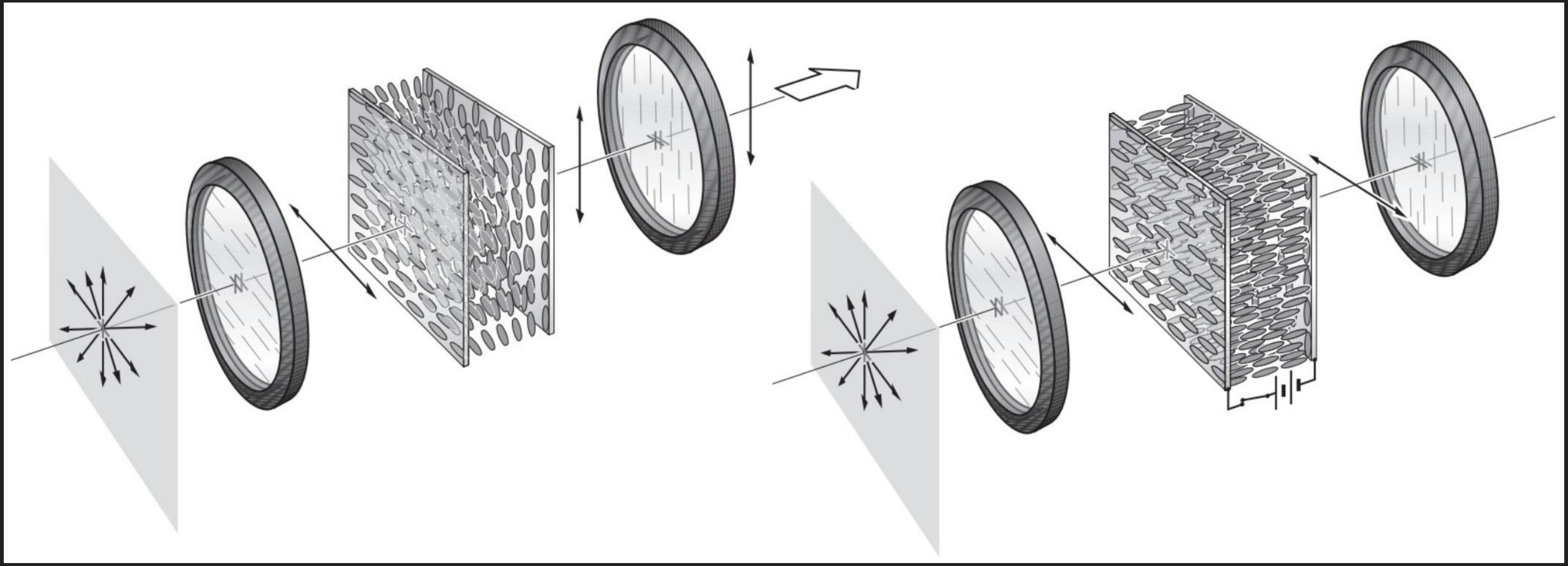
Nematic LC cell



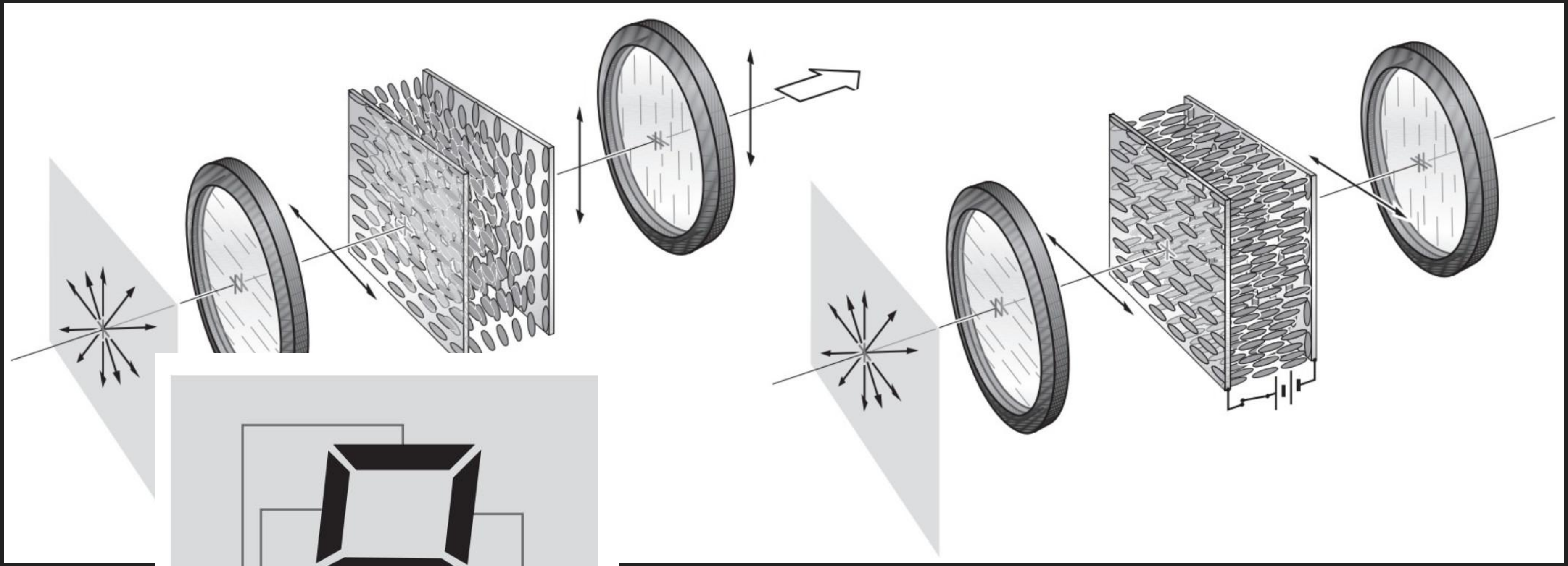
Twisted nematic LC cell

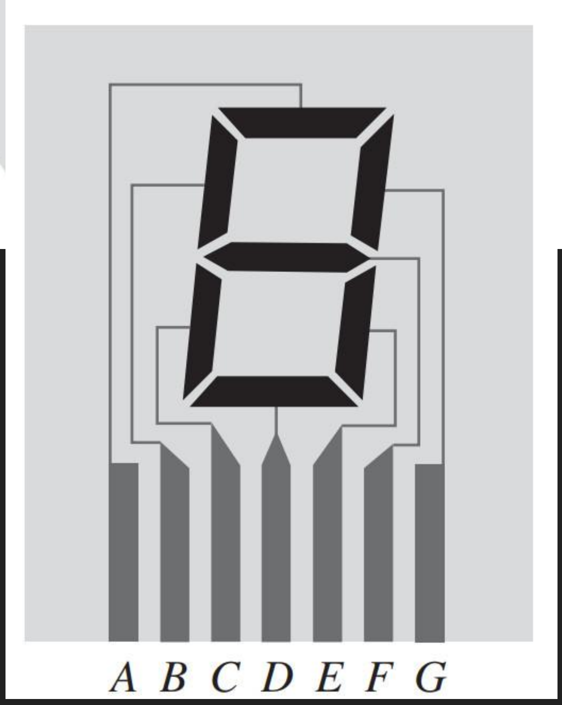


LCD

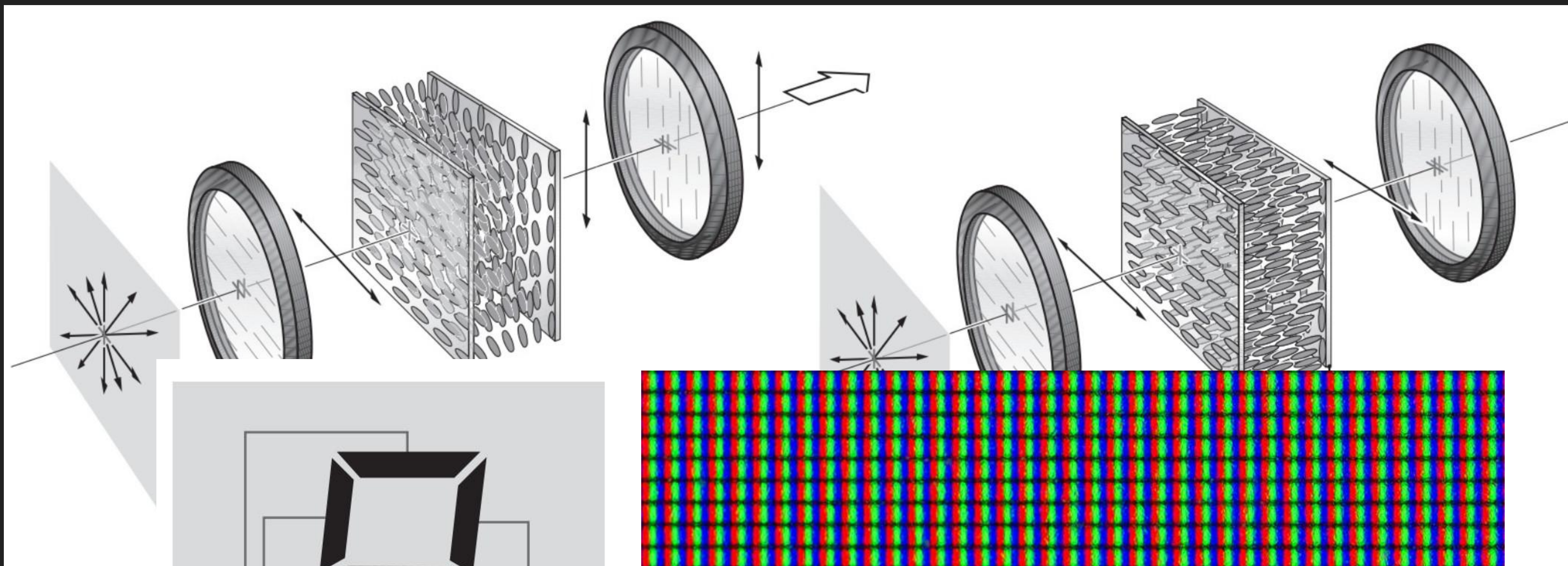


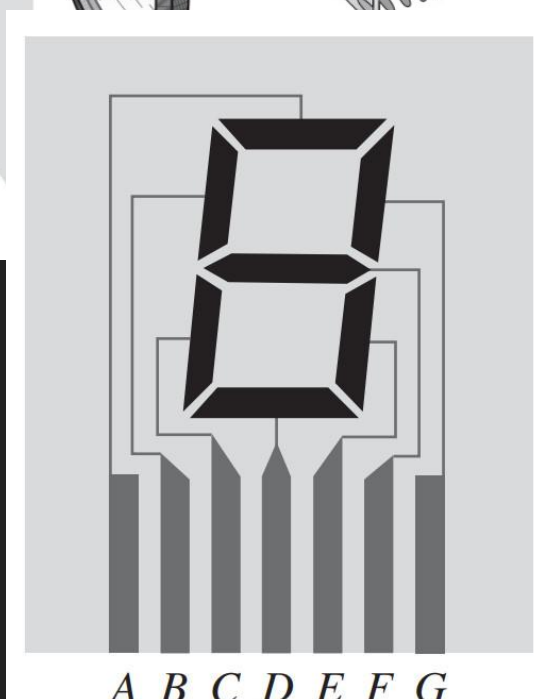
LCD

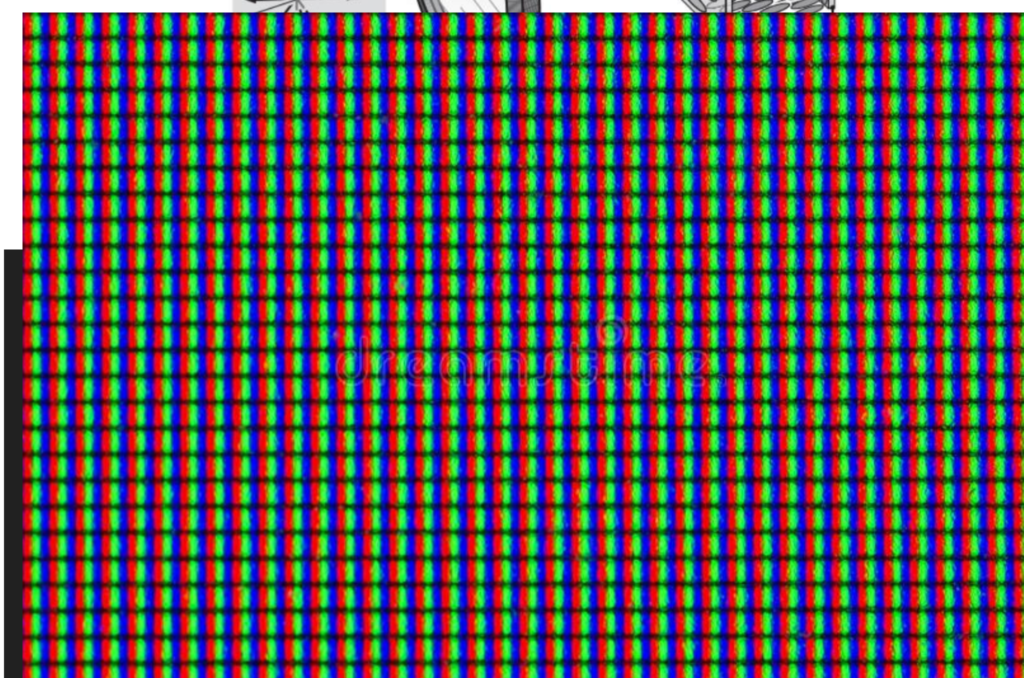




LCD







Summary Lecture 15

- The effect of optical elements on the polarisation of optical fields can be fully described by matrices.
- Optical activity occurs when left/right circular polarisation are experiencing different indices of refraction. This rotates the linear polarisation vector.
- Faraday effect: polarisation vector is rotated when an external field is present (important diagnostic).
- Liquid crystals en masse behave like a birefringent medium (positive uniaxial). We can exploit this to build energy efficient liquid crystal displays.

Midterm exam

	Points
Question 1 (max. 5 points)	
Question 2 (max. 5 points)	
Question 3 (max. 5 points)	
Question 4 (max. 5 points)	
Total (max. 20 points)	

Midterm exam

Question 1: Matrix methods (5 points)

Consider a system of two thin, spherical lenses in the
described by a system matrix

$$A_{\text{thin}} = \begin{pmatrix} 1 & \\ 0 & \end{pmatrix}$$

where f is the focal length of the lens.

Question 2: Collimating with a mirror (5 points)

Looking inside a flash light, you will notice a curved mirror that is used to redirect all the light from the filament into the forward direction, i.e. the mirror is used to convert a point source (the lamp) into a collimated beam (parallel outgoing rays).

	Points
Question 1 (max. 5 points)	
Question 2 (max. 5 points)	
Question 3 (max. 5 points)	
Question 4 (max. 5 points)	
Total (max. 20 points)	

Question 4: Cauchy's equation (5 points)

edium to an incident electro-magnetic field of frequency ω
s as driven harmonic oscillators. The refractive index of a
written as

$$) = 1 + \frac{\rho}{1 - \nu^2 - i\Gamma\nu}. \quad (4)$$

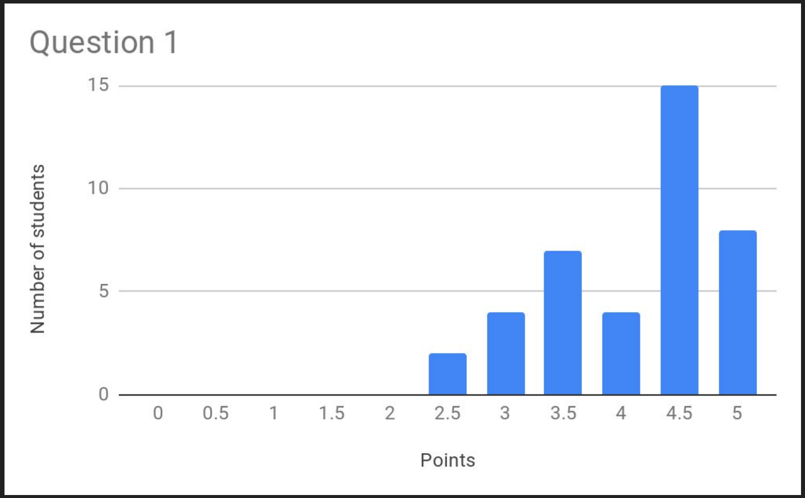
Question 3: Fourier series (5 points)

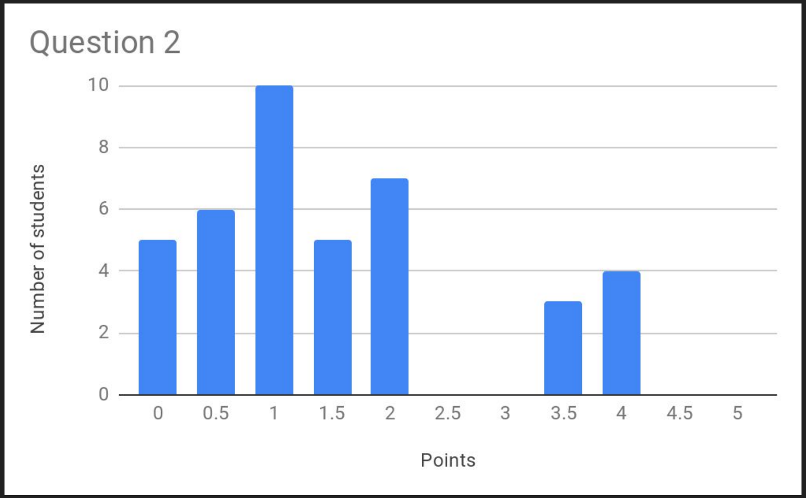
According to the Fourier theorem, any function $f(x)$ that has a spatial period λ can be synthesised by a sum of harmonic functions, whose wavelengths are integral submultiples of λ, i.e. we can write

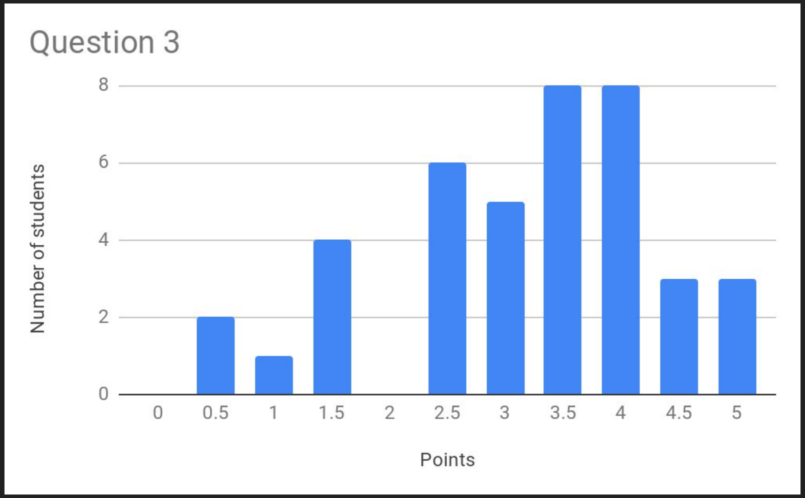
$$f(x) = \frac{A_0}{2} + \sum_{m=1}^{\infty} A_m \cos(kmx) + \sum_{m=1}^{\infty} B_m \sin(kmx), \quad (2)$$

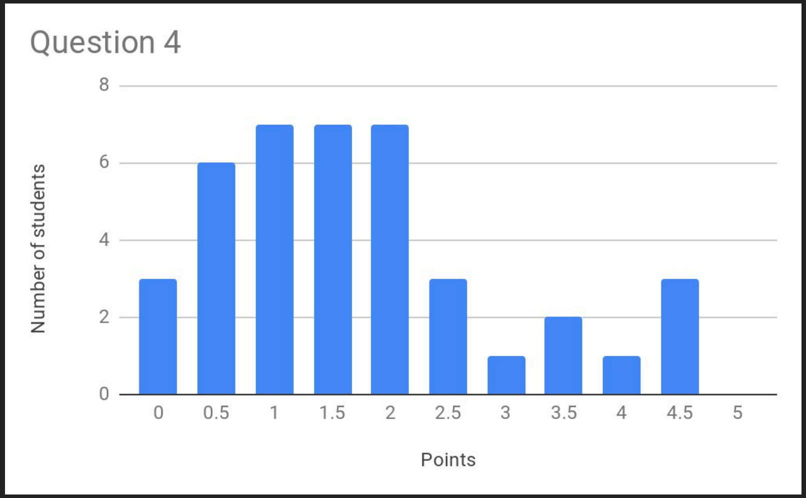
where k is the corresponding propagation number, and A_0, A_m and B_m are constant coefficients.

Midterm exam - Questions



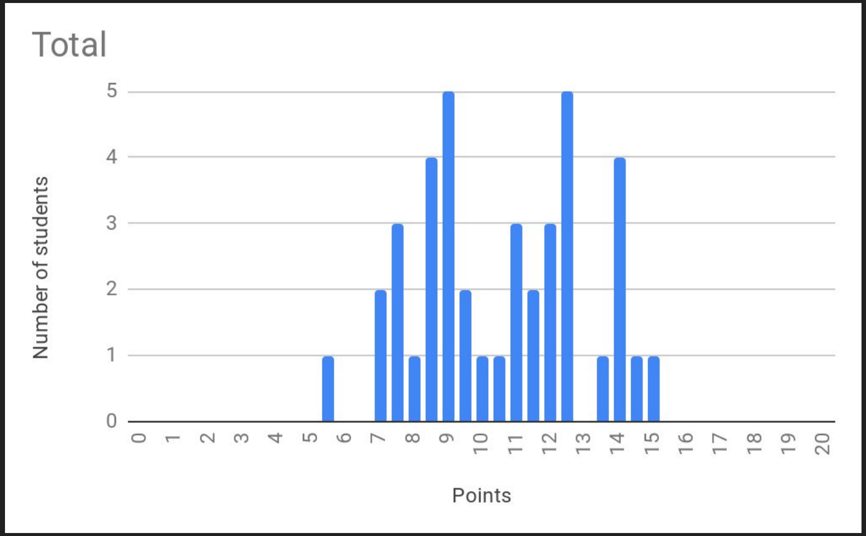


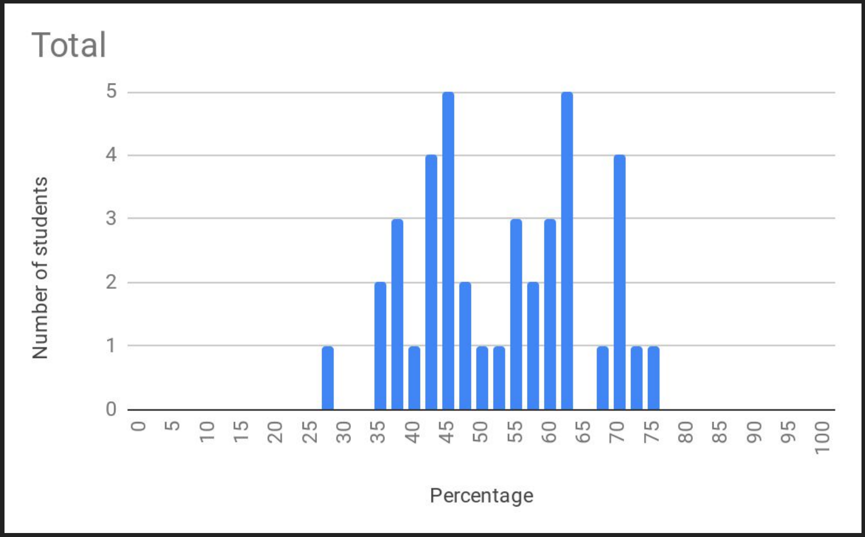




Midterm exam - Overall

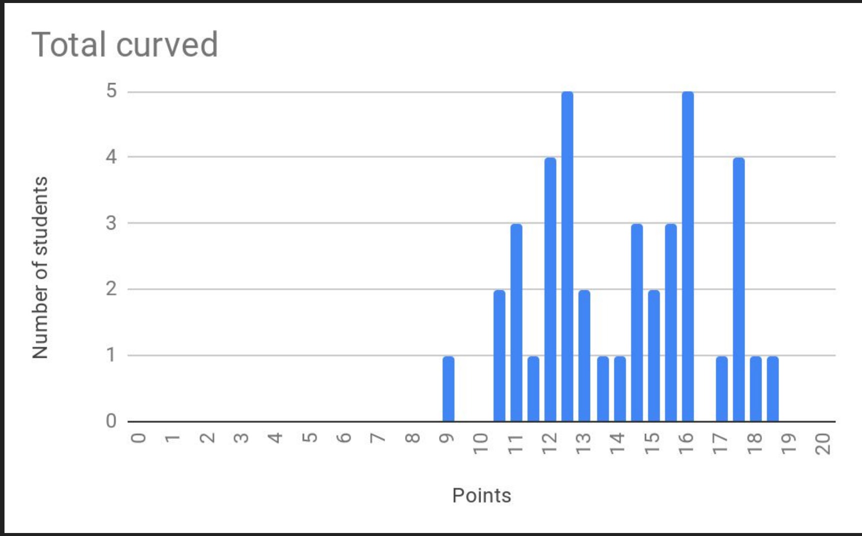
- Average for all questions 10.6 points (or 53%)

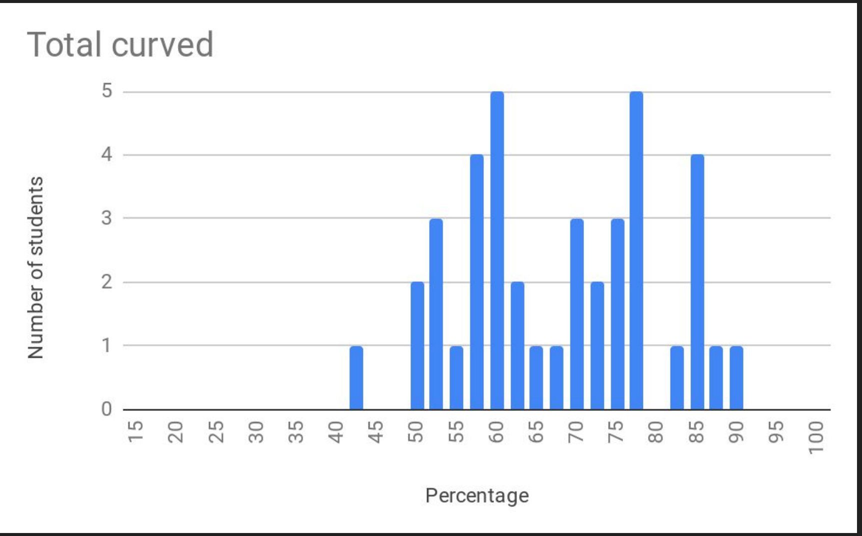




Midterm exam - Overall adjusted

- Average fixed to 69% (or 13.8 points),
  shift all results by 13.8 - 10.6 = 3.2 points





Research paper info

- Opportunity to replace half of the midterm grade with a research paper about a topic in Optics.
- The paper consists of two parts: a short and concise proposal (about 1/2 page) introducing the topic and highlights a few key references you will study, and the actual paper (about 3-4 pages).

Research paper info

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- Due dates: Proposal - Wednesday, Mar 13 8pm
  Research paper - Thursday, Apr 18 8pm
- Check information on myCourses (under Overview) for formal requirements, general info and topics.

PHYS 434 Optics

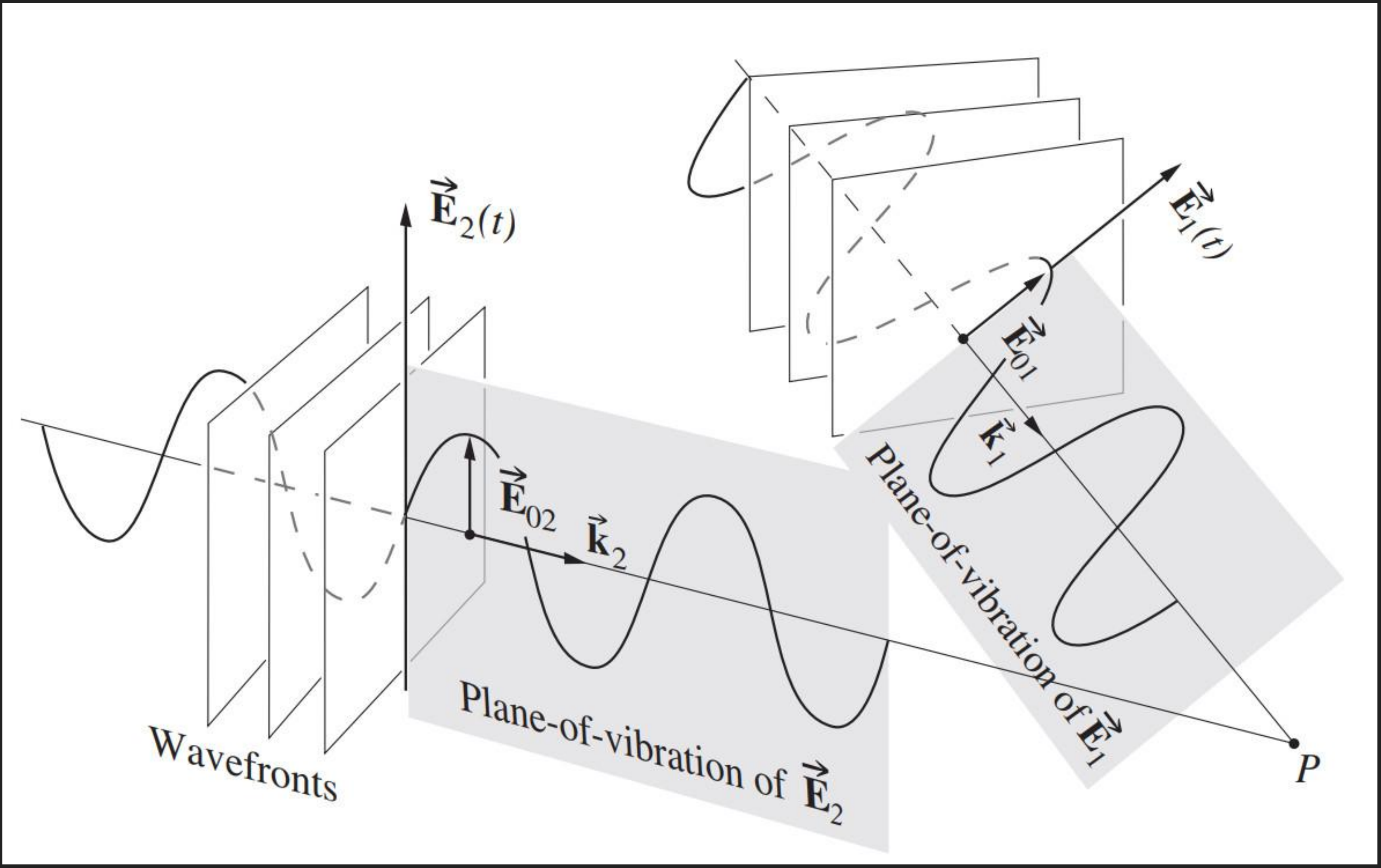
Lecture 15: Introduction to Interference

Reading: 9.1 - 9.3

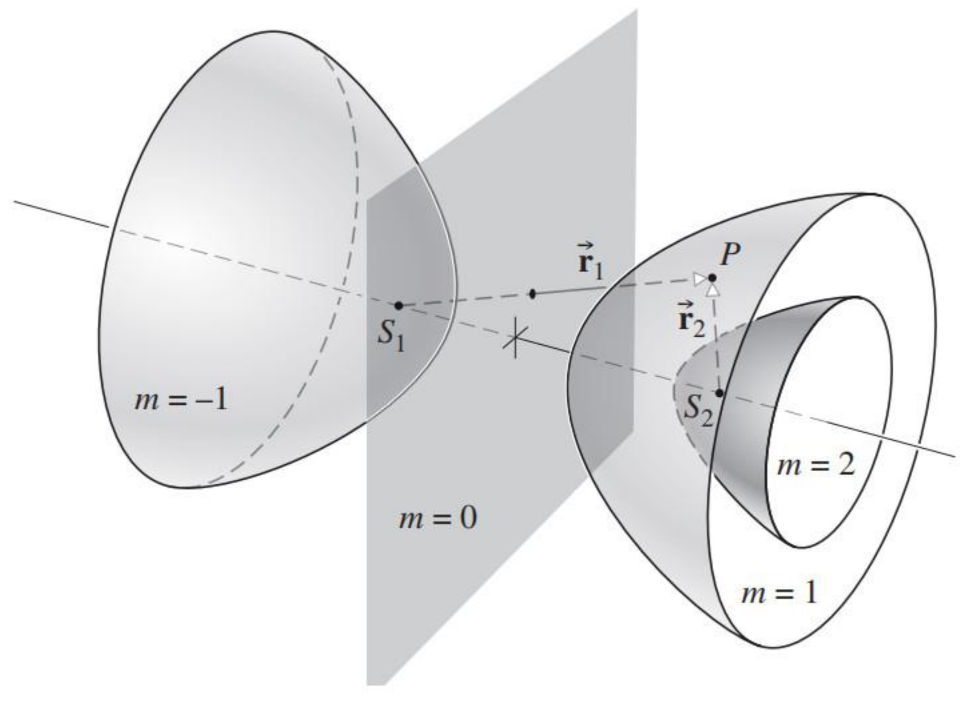
Summary Lecture 15

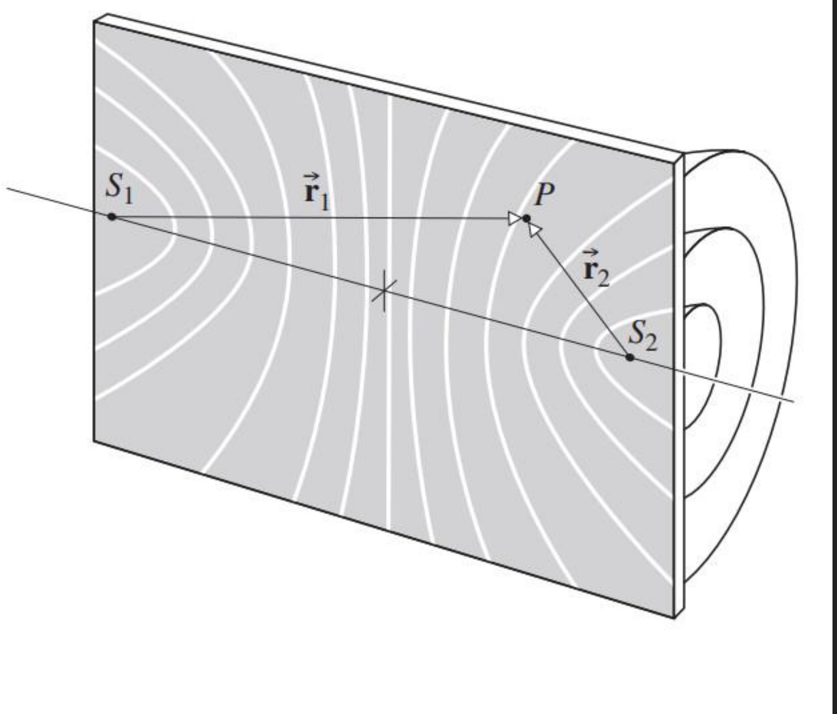
- The effect of optical elements on the polarisation of optical fields can be fully described by matrices.
- Optical activity occurs when left/right circular polarisation are experiencing different indices of refraction. This rotates the linear polarisation vector.
- Faraday effect: polarisation vector is rotated when an external field is present (important diagnostic).
- Liquid crystals en masse behave like a birefringent medium (positive uniaxial). We can exploit this to build energy efficient liquid crystal displays.

Superposition of polarised waves

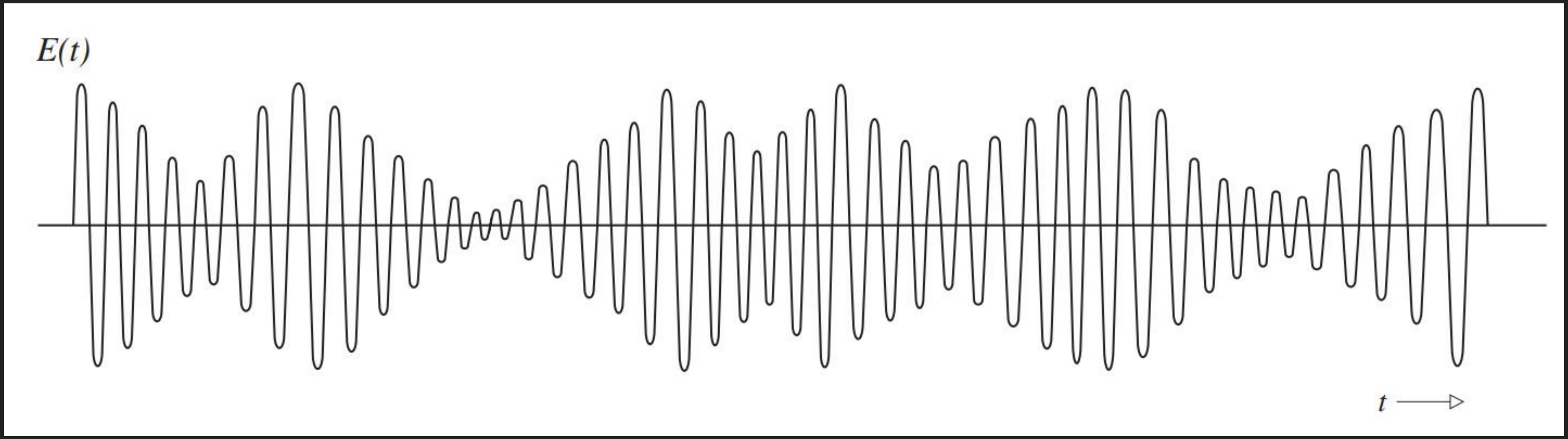


Interference fringes

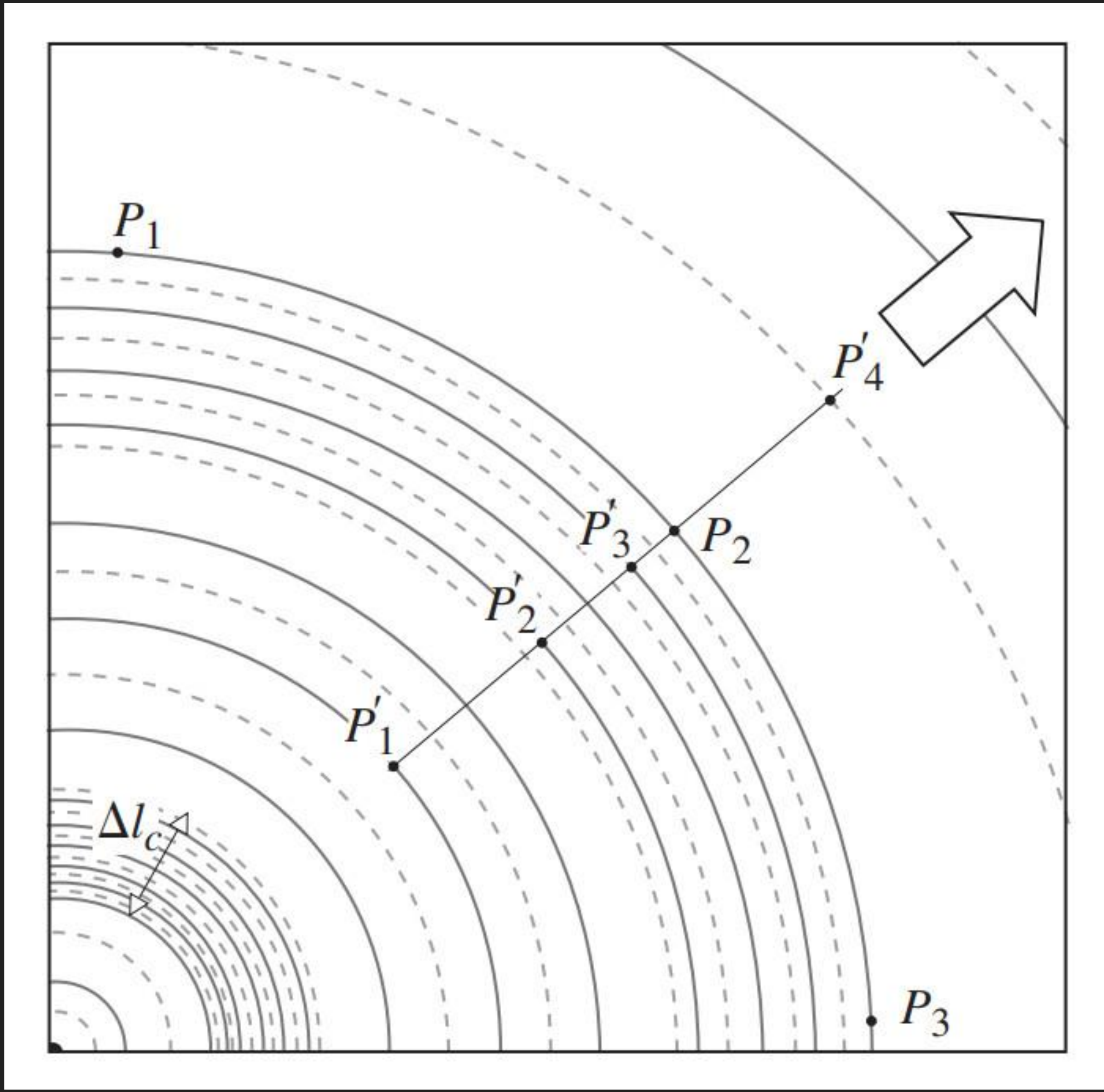




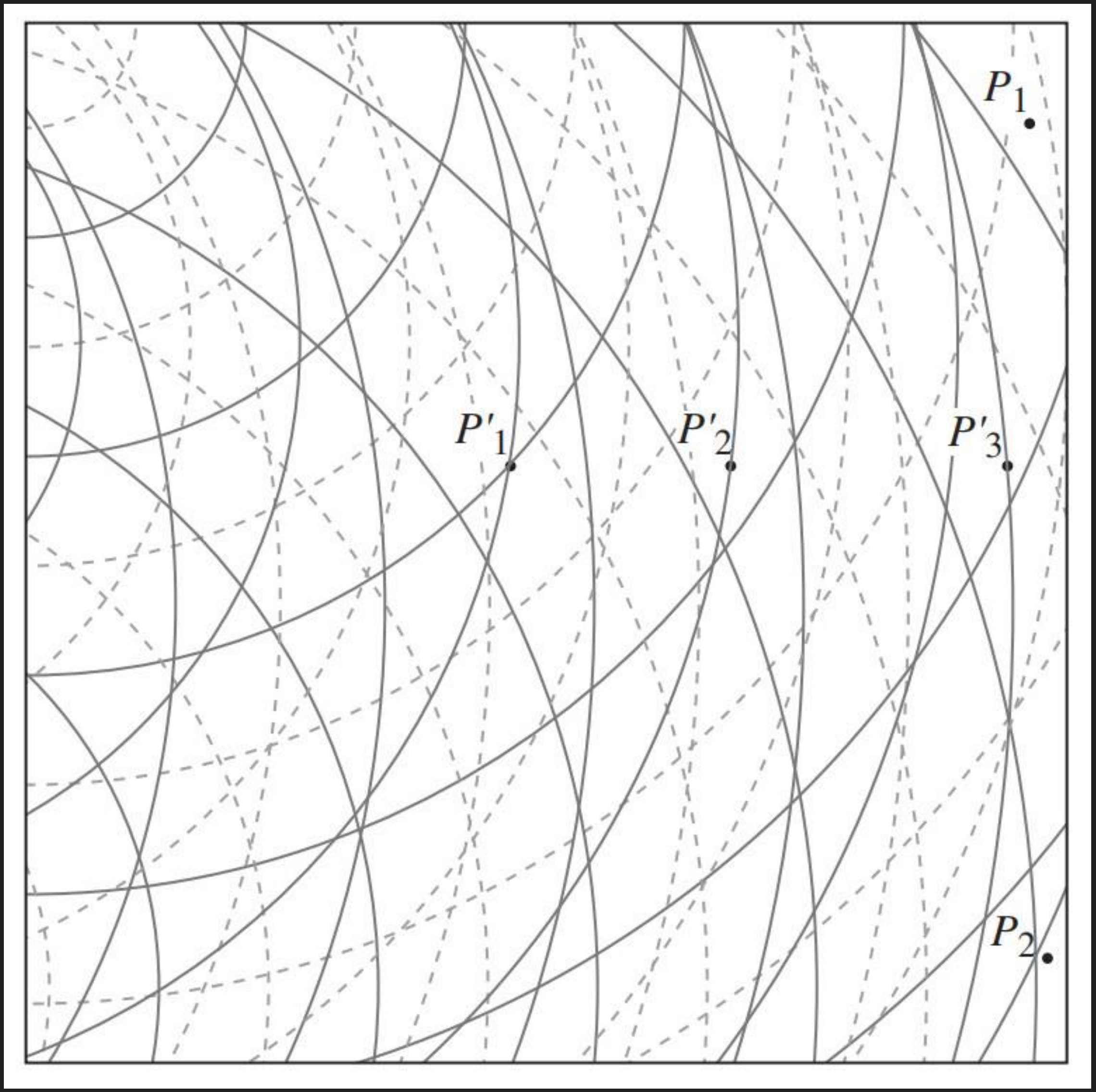
Temporally coherent wavetrain



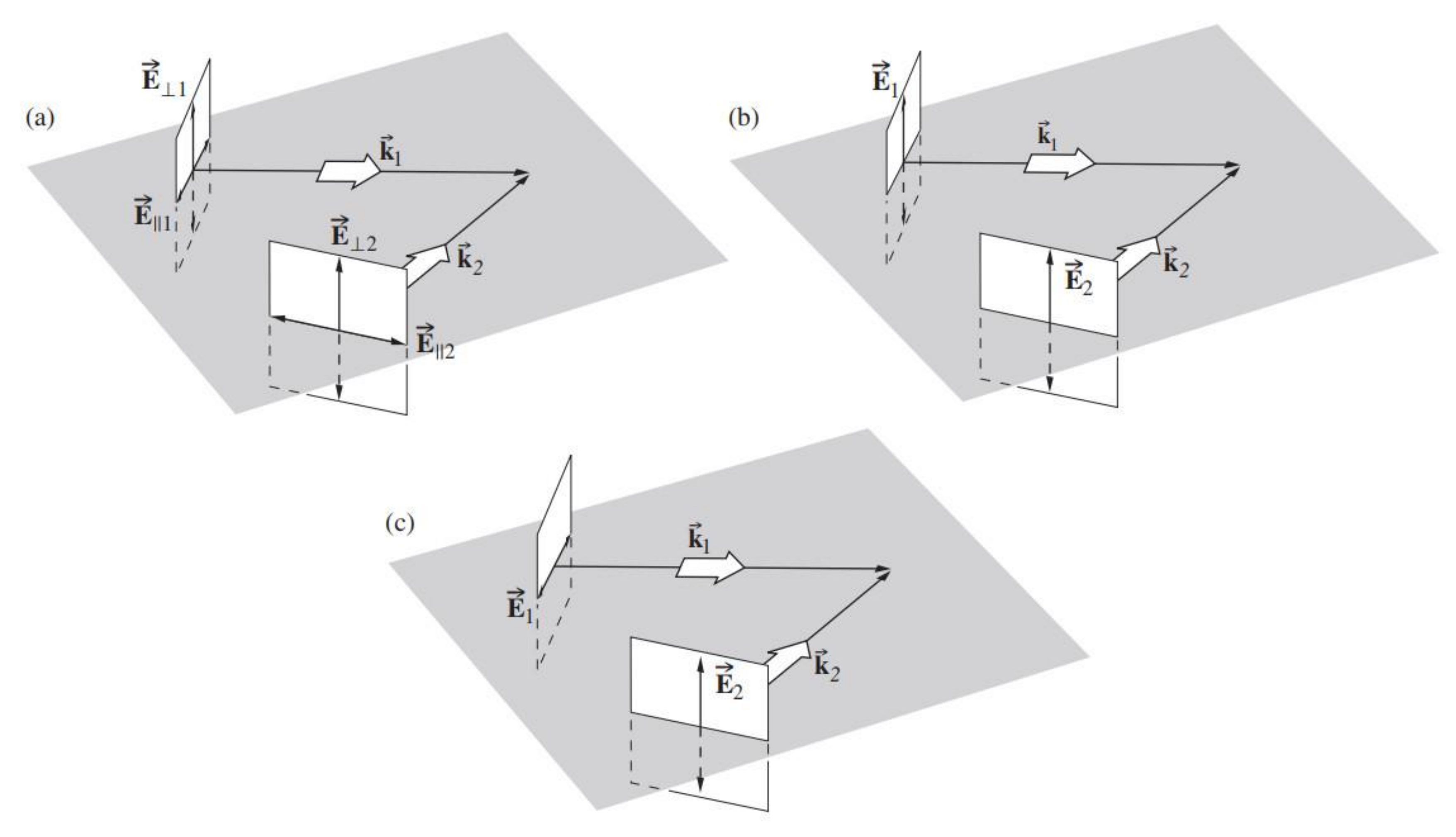
Spatial/temporal coherence I



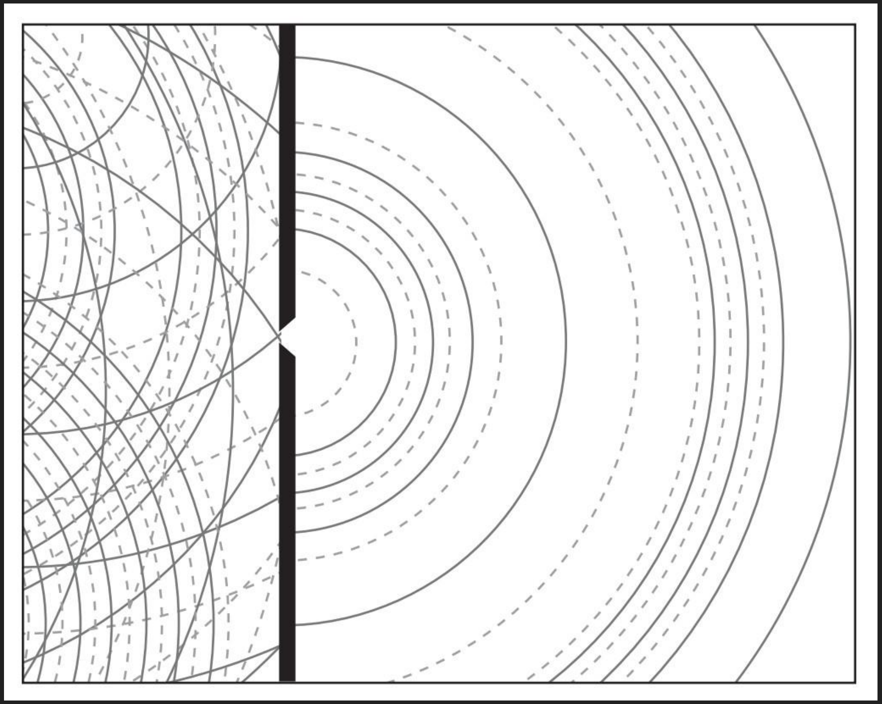
Spatial/temporal coherence II

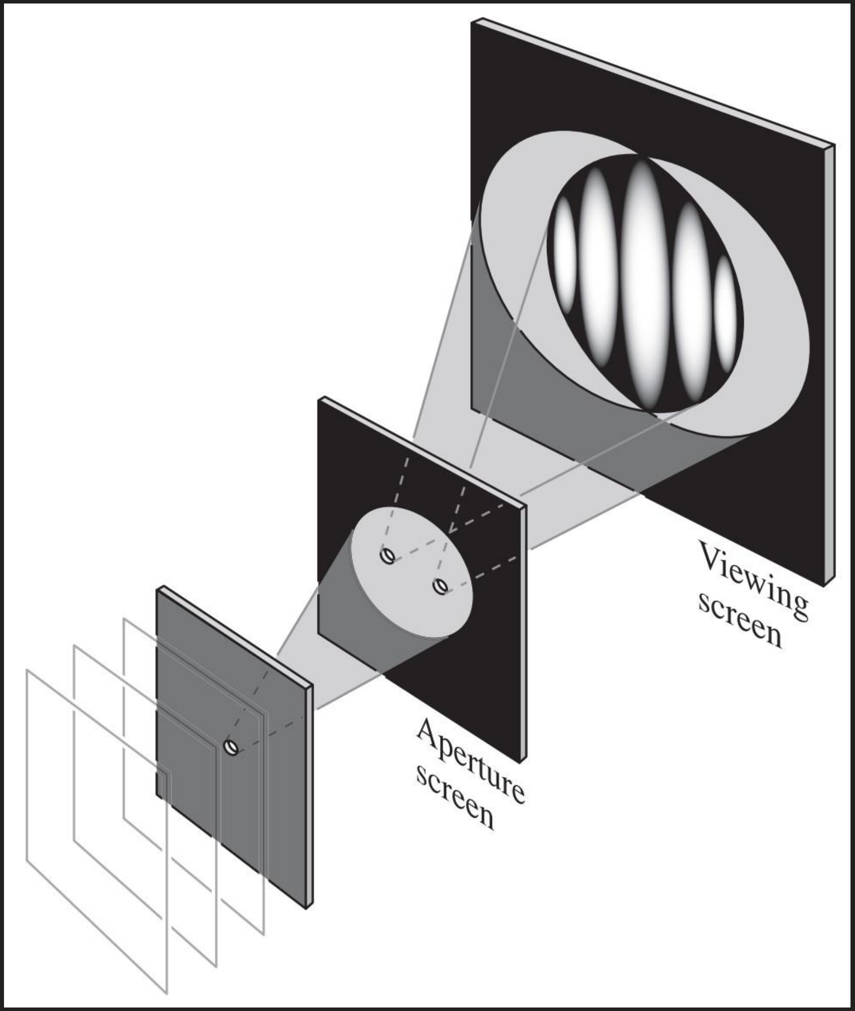


Fresnel-Arago Laws

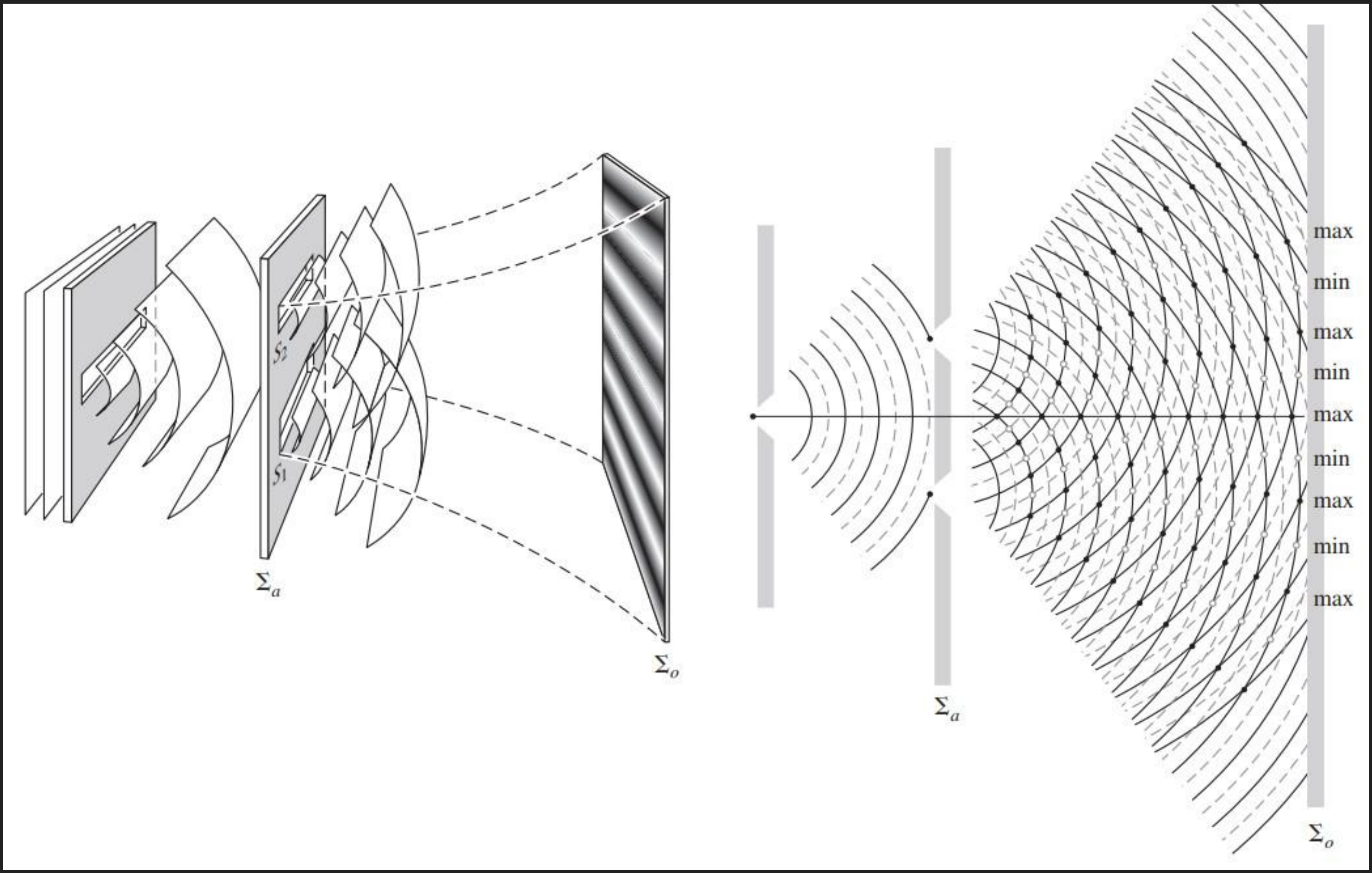


Double-slit experiment I

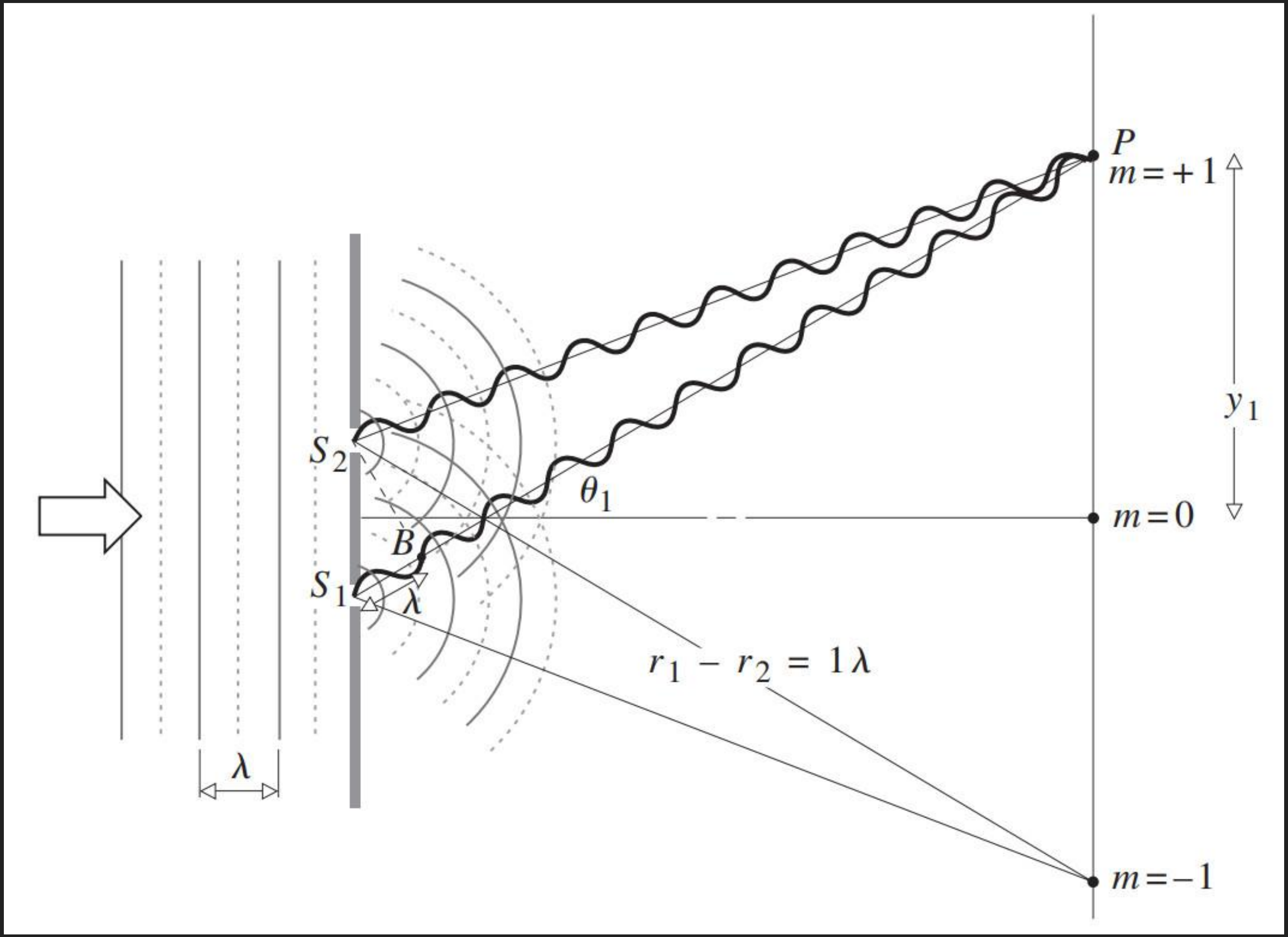




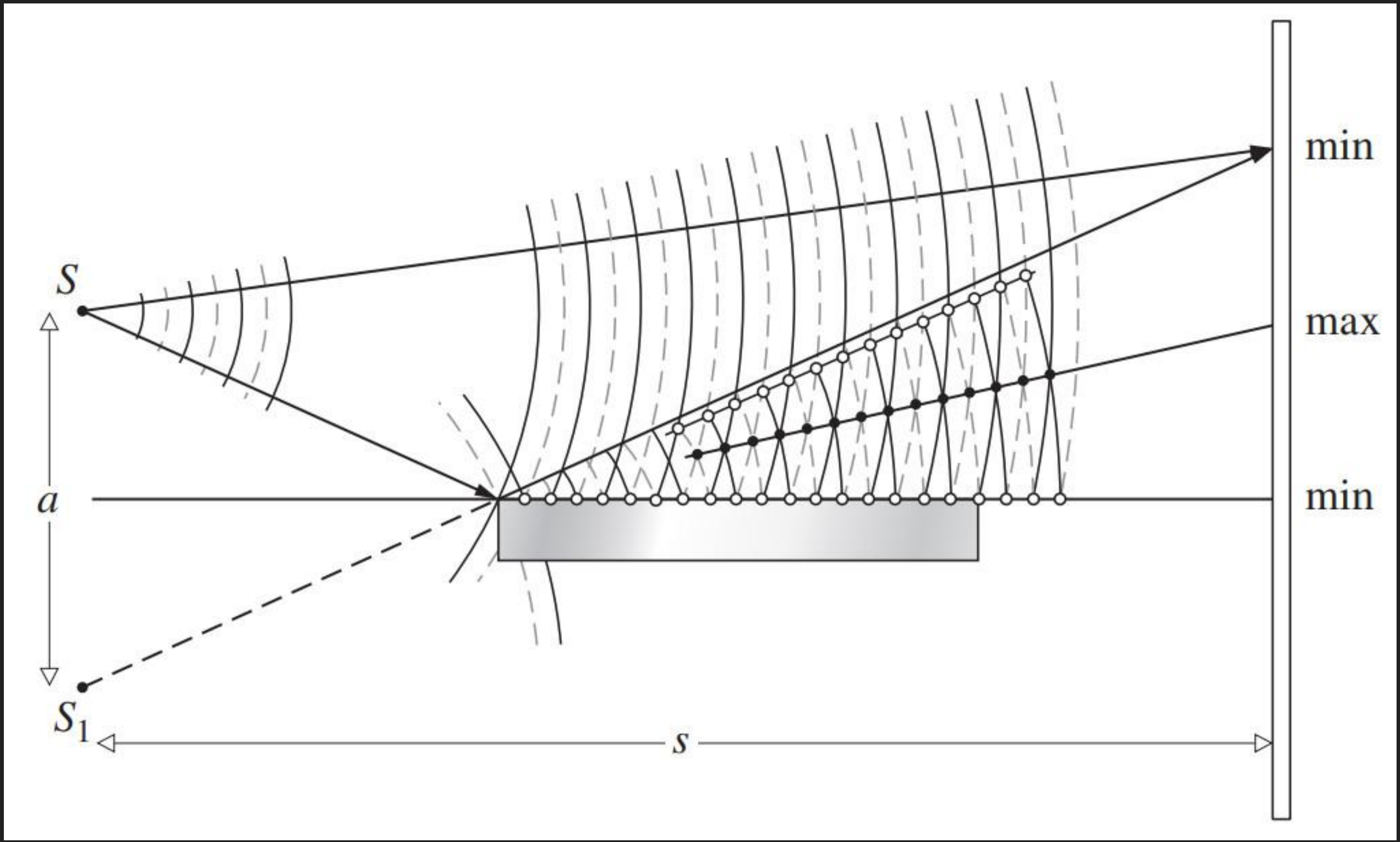
Double-slit experiment II



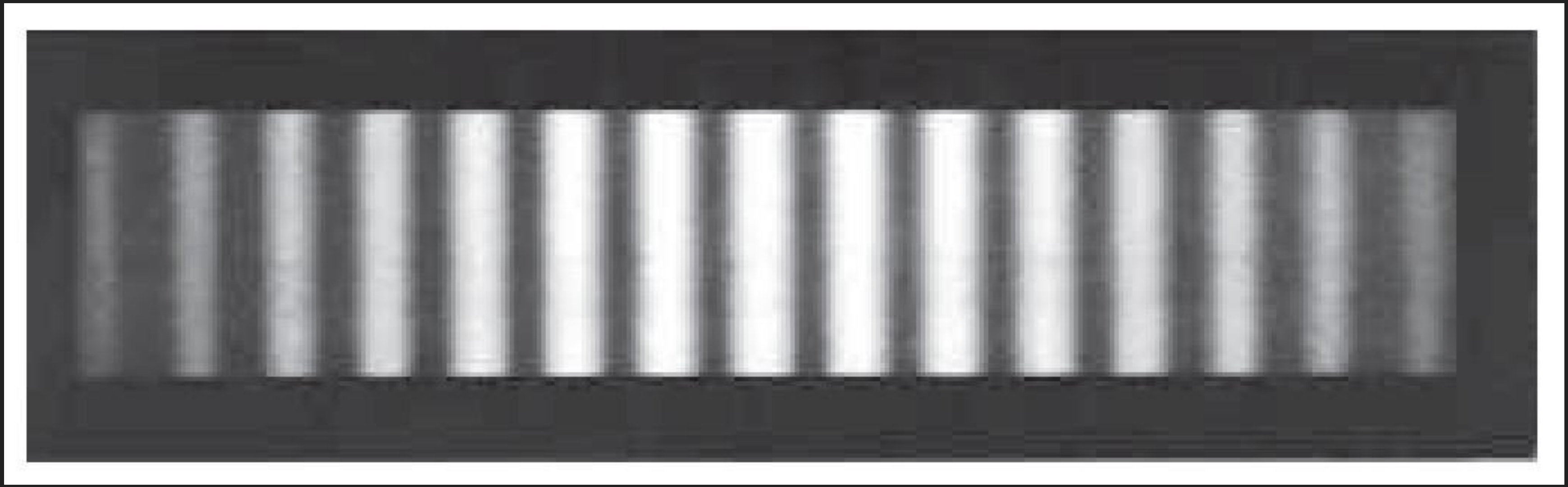
Double-slit experiment III



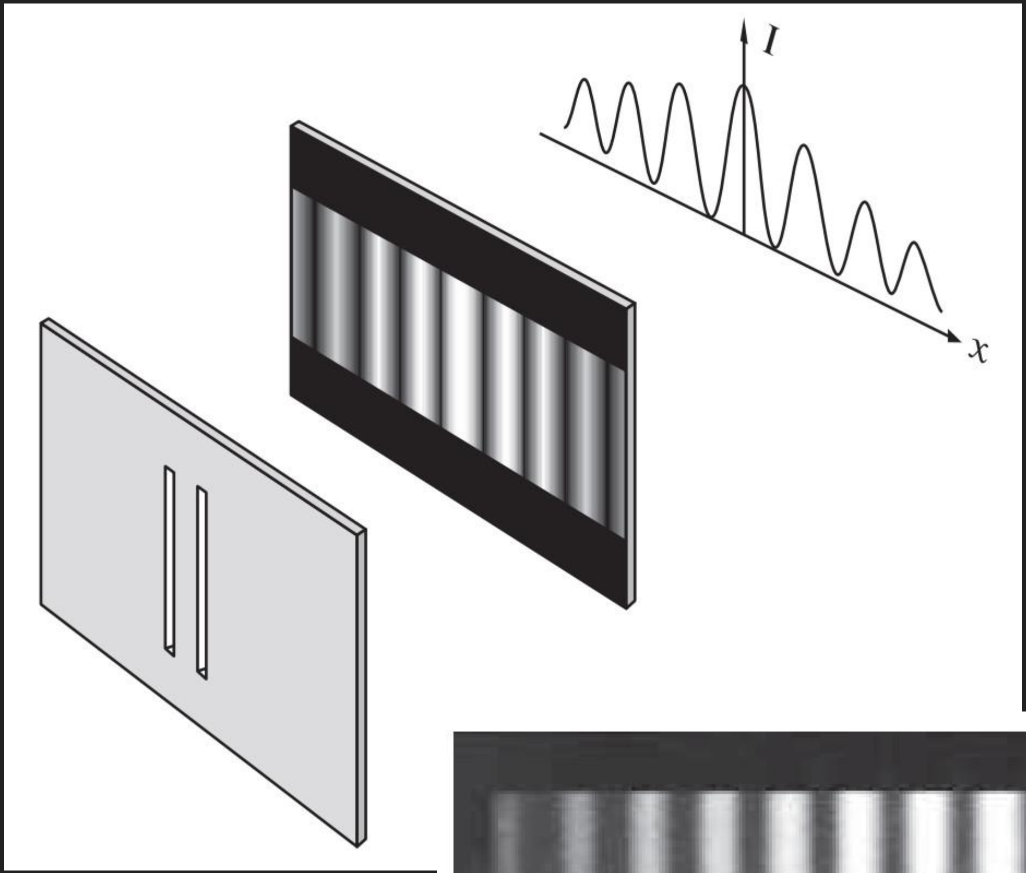
Lloyd’s mirror

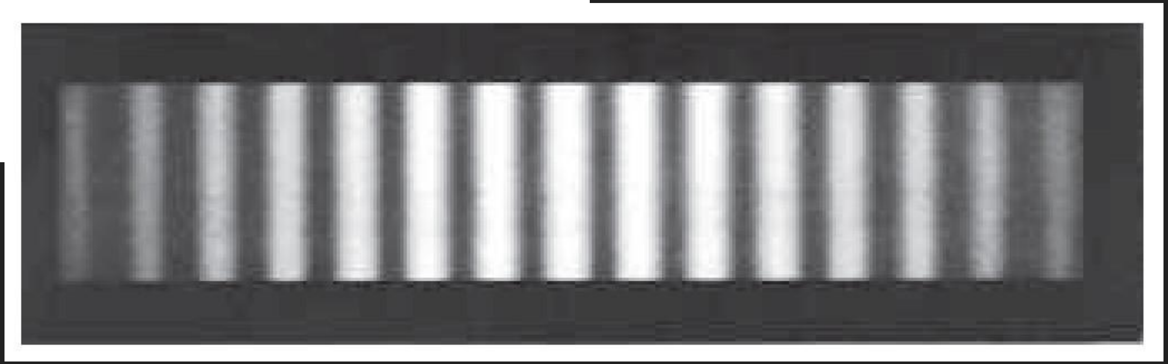


Double-slit experiment IV



Double-slit experiment V





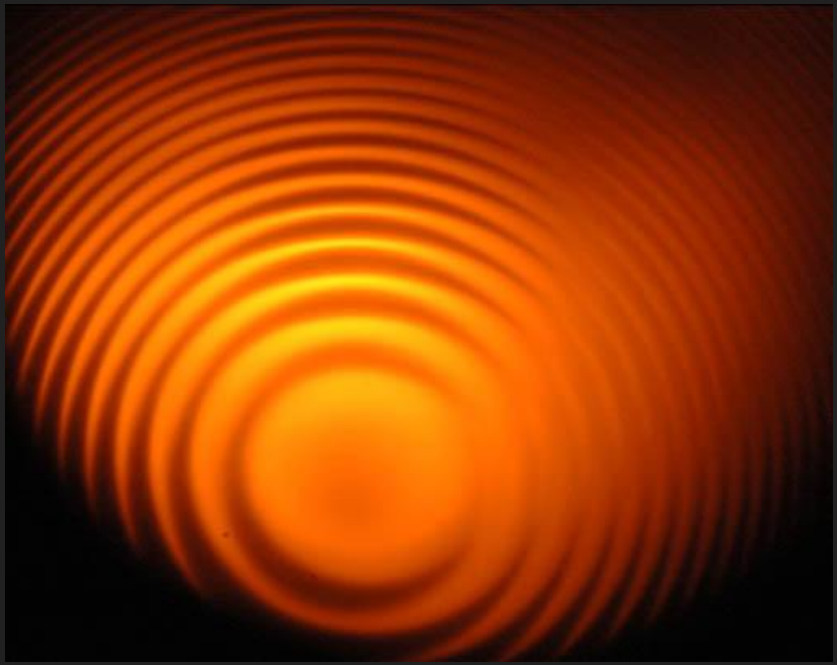
Summary Lecture 16

- Optical interference refers to interaction of light with resultant irradiance that differs from the sum of the constituent irradiances (vector nature is crucial).
- Interference redistributes the flux intensity, which results in the appearance of fringe patterns.
- For interference to take place, the sources have to be coherent (have a well-defined relative phase) and their polarisations have to satisfy Fresnel-Arago laws.
- Use wavefront-splitting devices (Young's double-slit experiment) to study interference properties.

PHYS 434 Optics

Lecture 17: Amplitude-splitting & Multi-beam Interferometry

Reading: 9.4 - 9.6



Admin

- Fifth problem set will be on myCourses tomorrow:
    - Grader: Rigel
    - Due date: Monday, March 25 (beginning of class)

- For those who haven't filled out feedback form for Demo #1 (including those that did not add their names, check report) - do so by Friday, March 15 at midnight to get those points!!!!!

Summary Lecture 16

- Optical interference refers to interaction of light with resultant irradiance that differs from the sum of the constituent irradiances (vector nature is crucial).
- Interference redistributes the flux intensity, which results in the appearance of fringe patterns.
- For interference to take place, the sources have to be coherent (have a well-defined relative phase) and their polarisations have to satisfy Fresnel-Arago laws.
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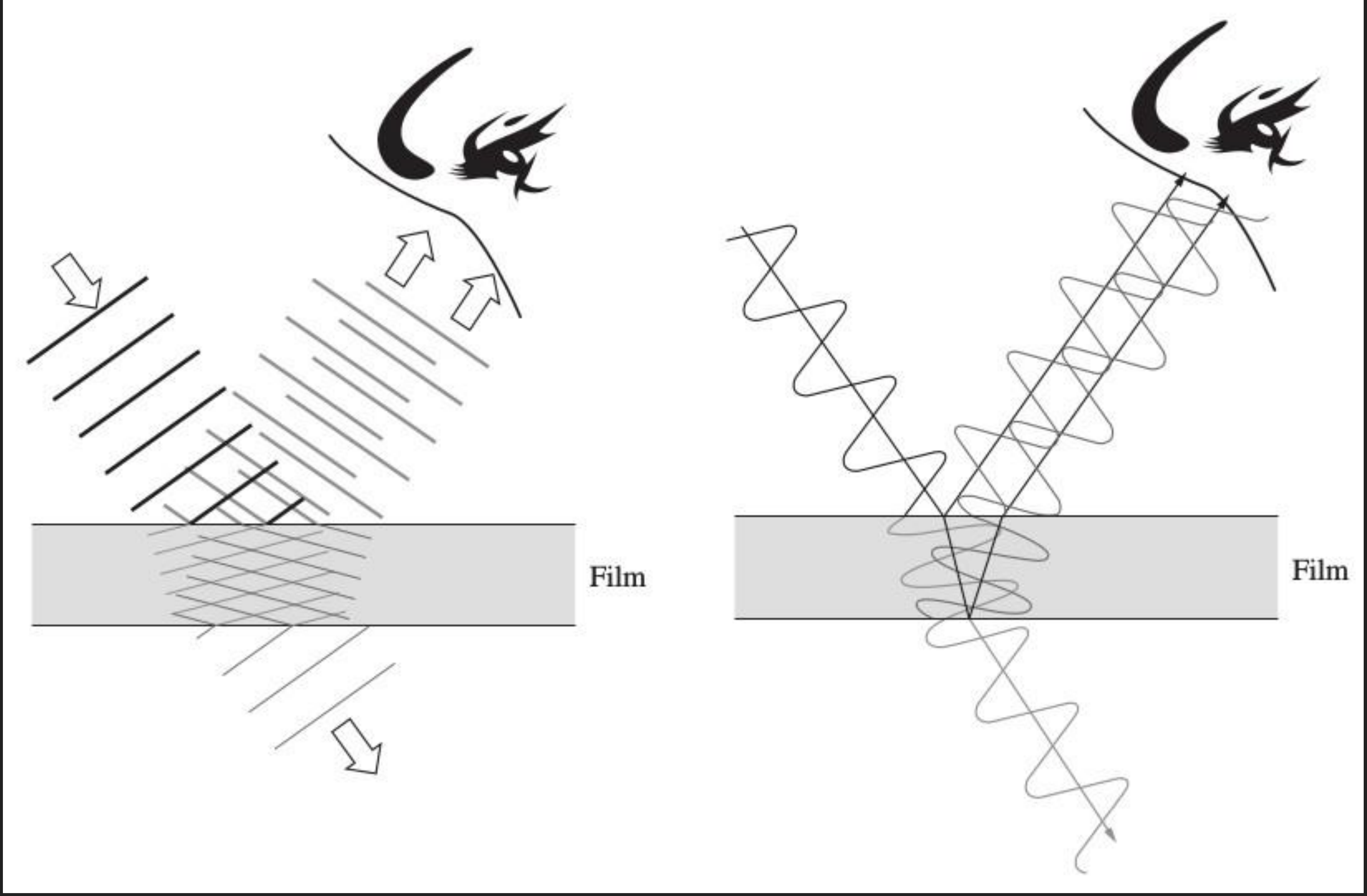
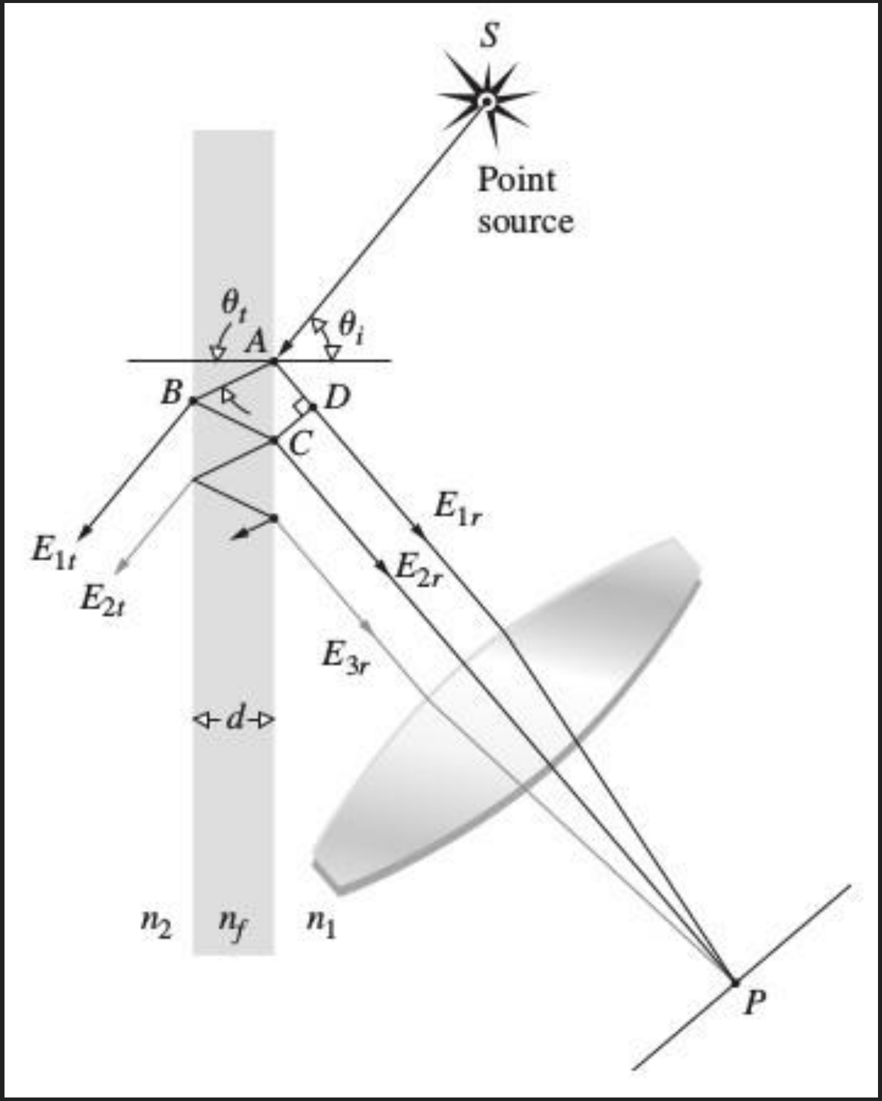
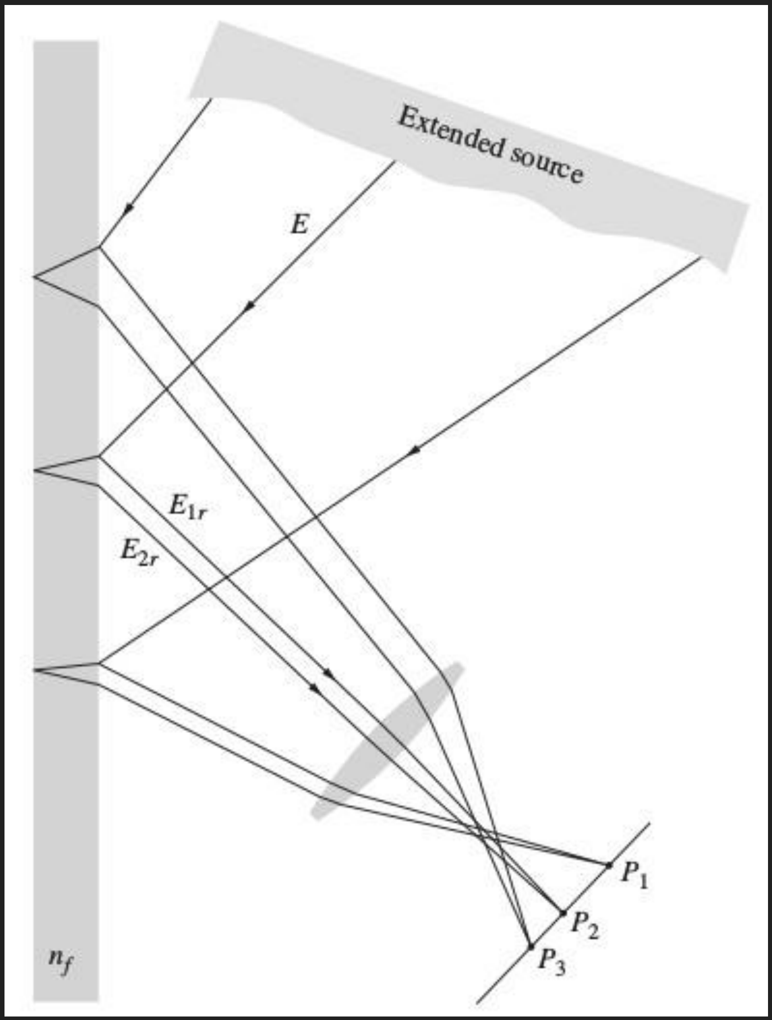
Thin-film interference I

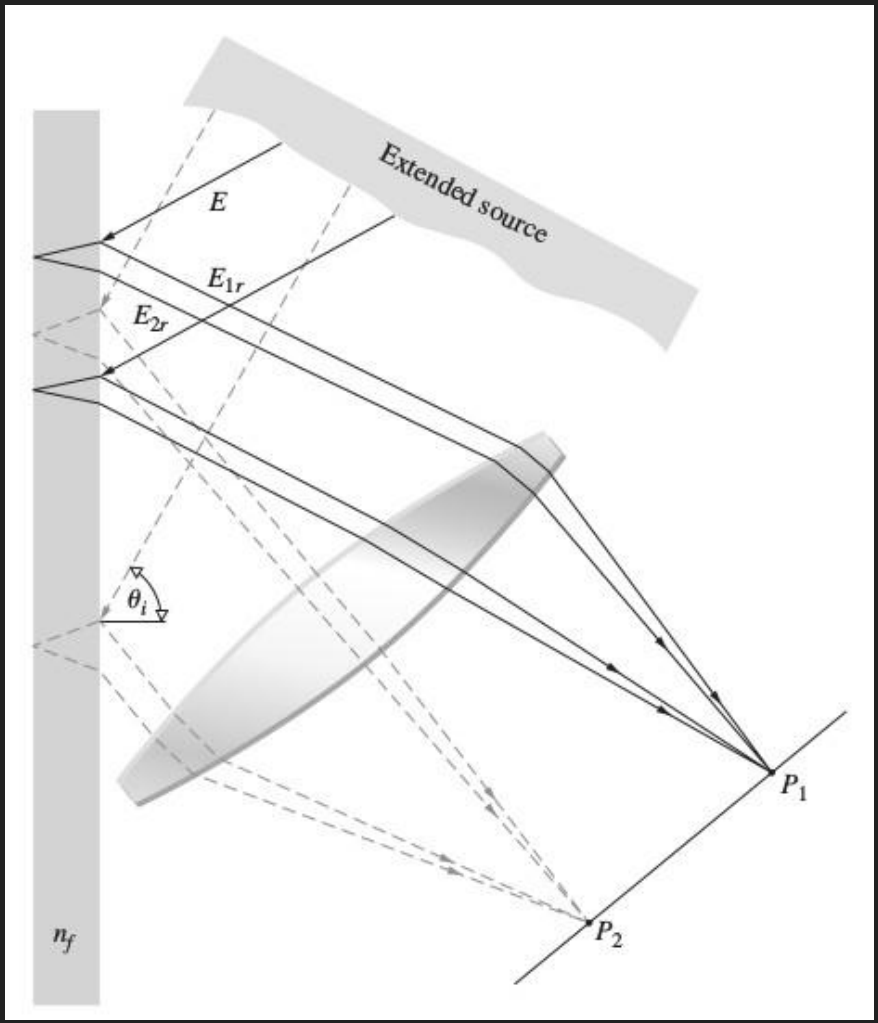


Thin-film interference II

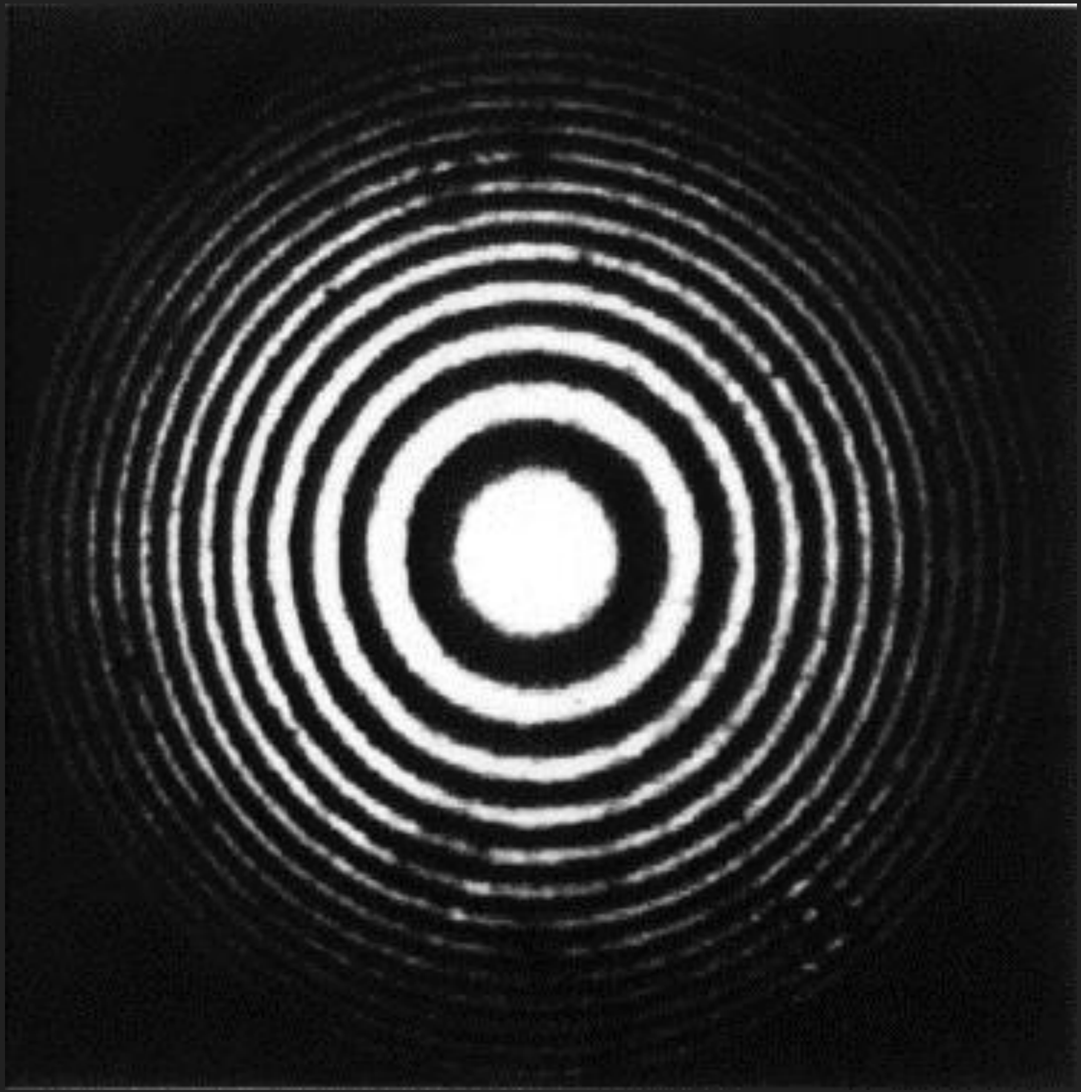


Fringes of equal inclination

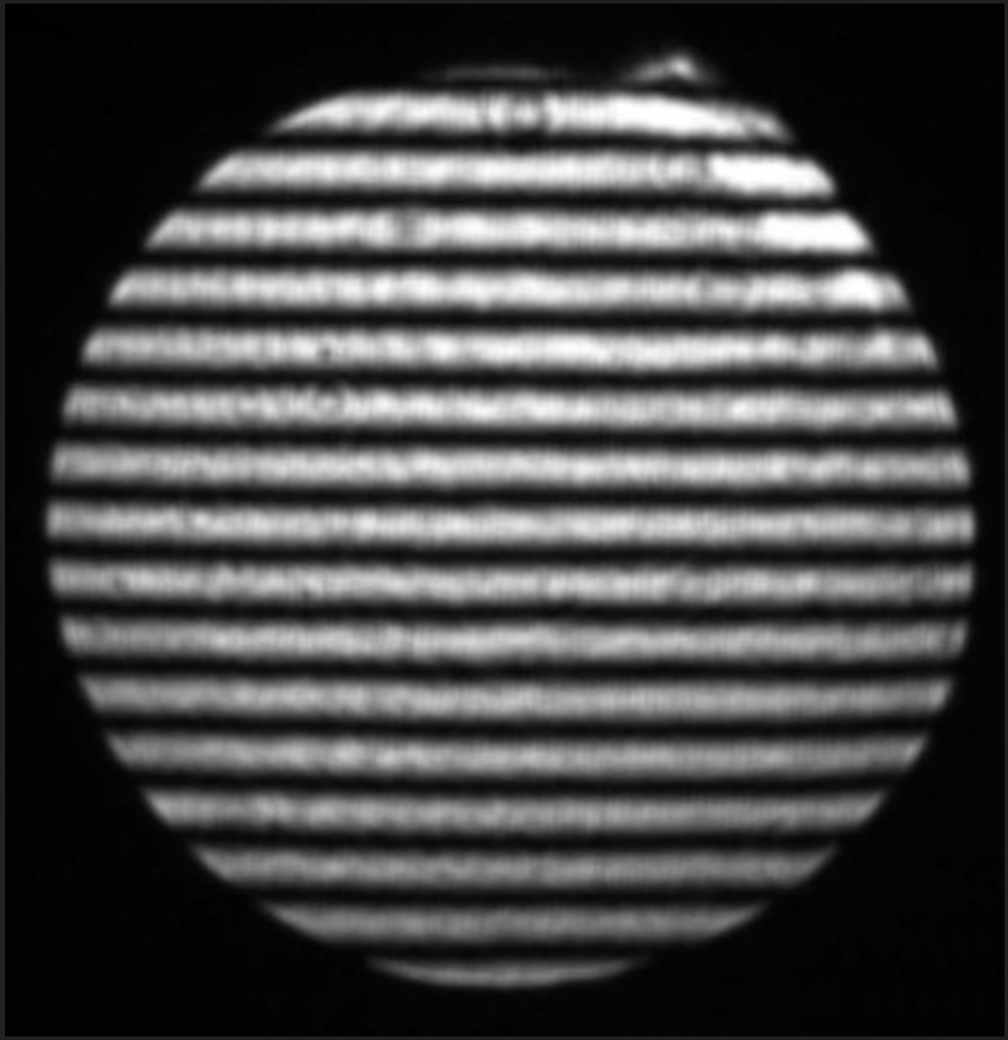




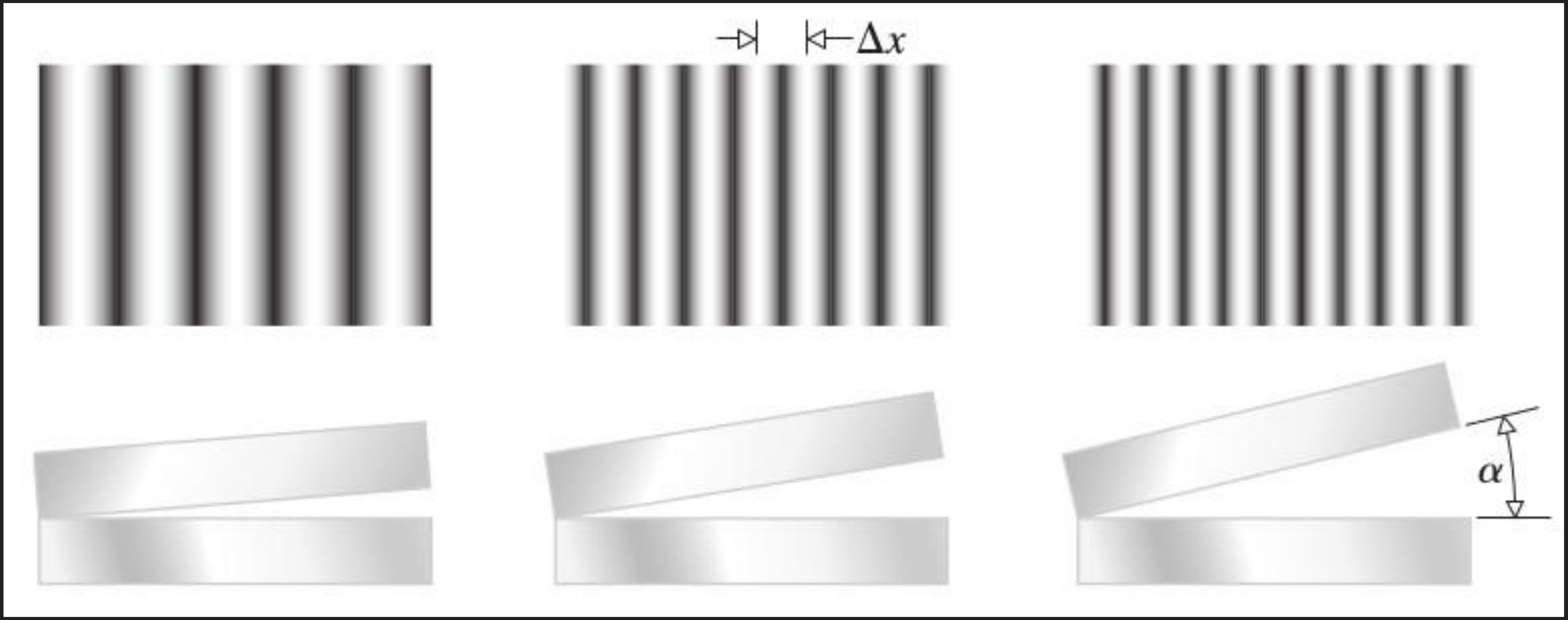
Haidinger fringes



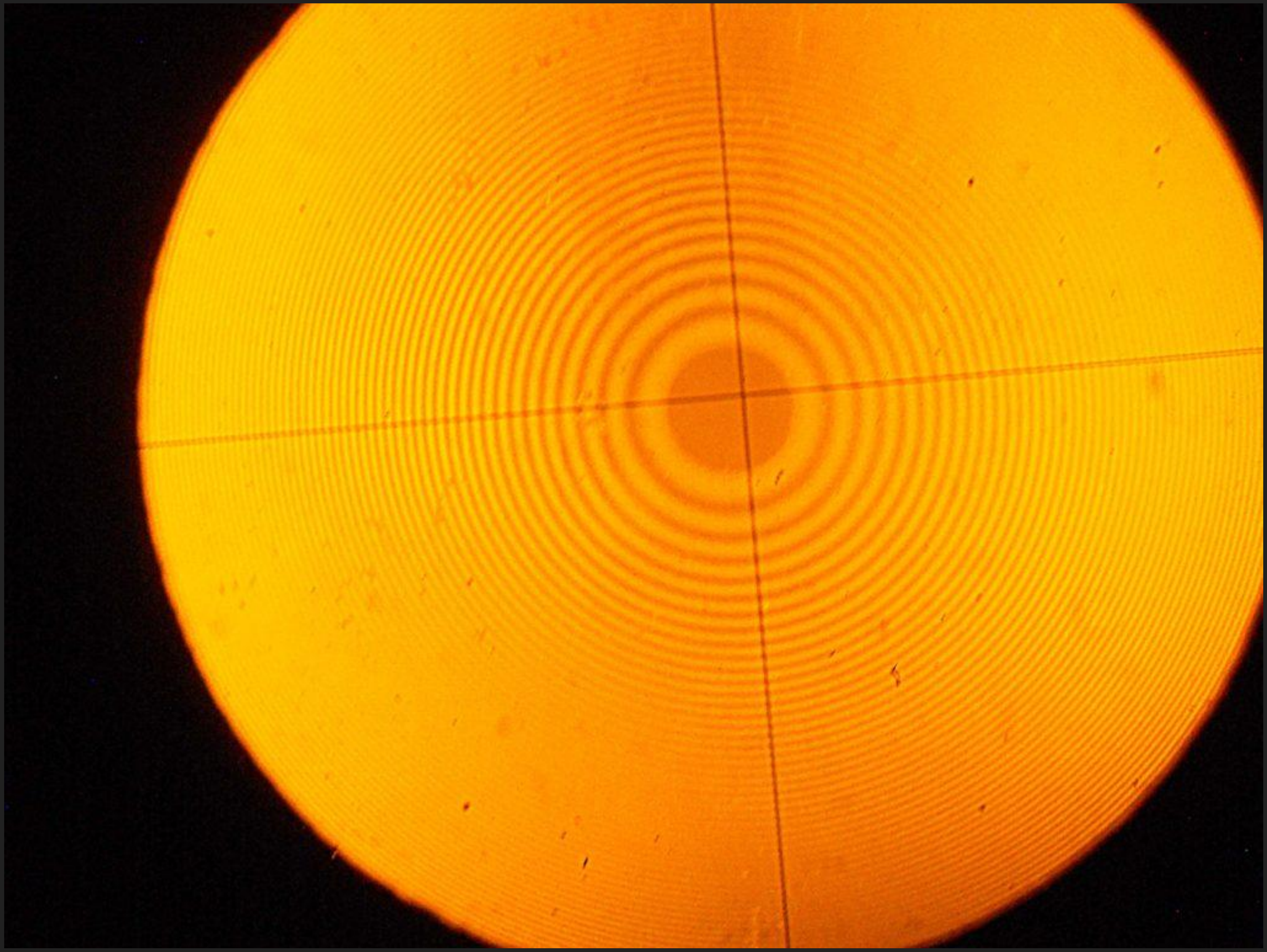
Fizeau fringes I



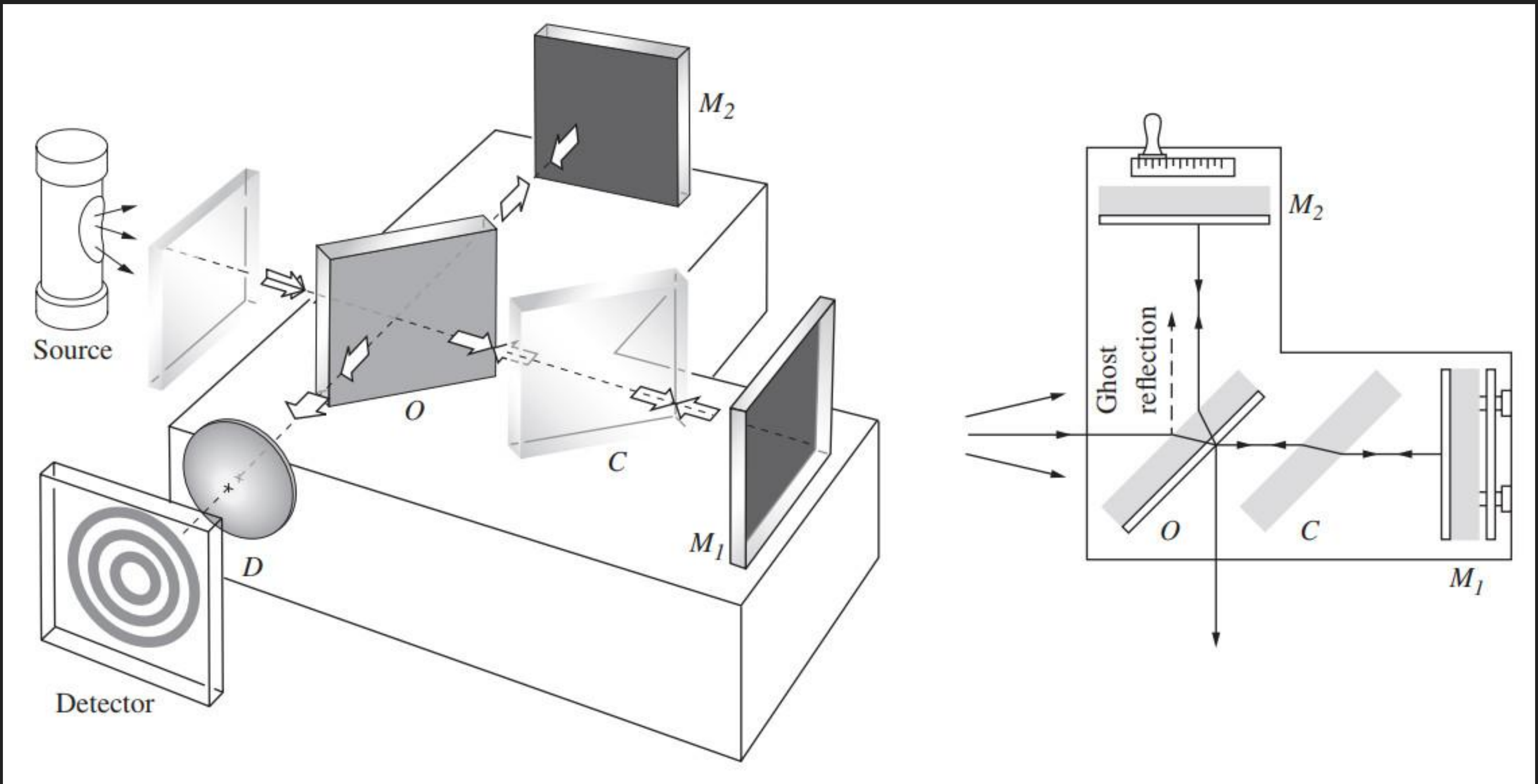
Fizeau fringes II



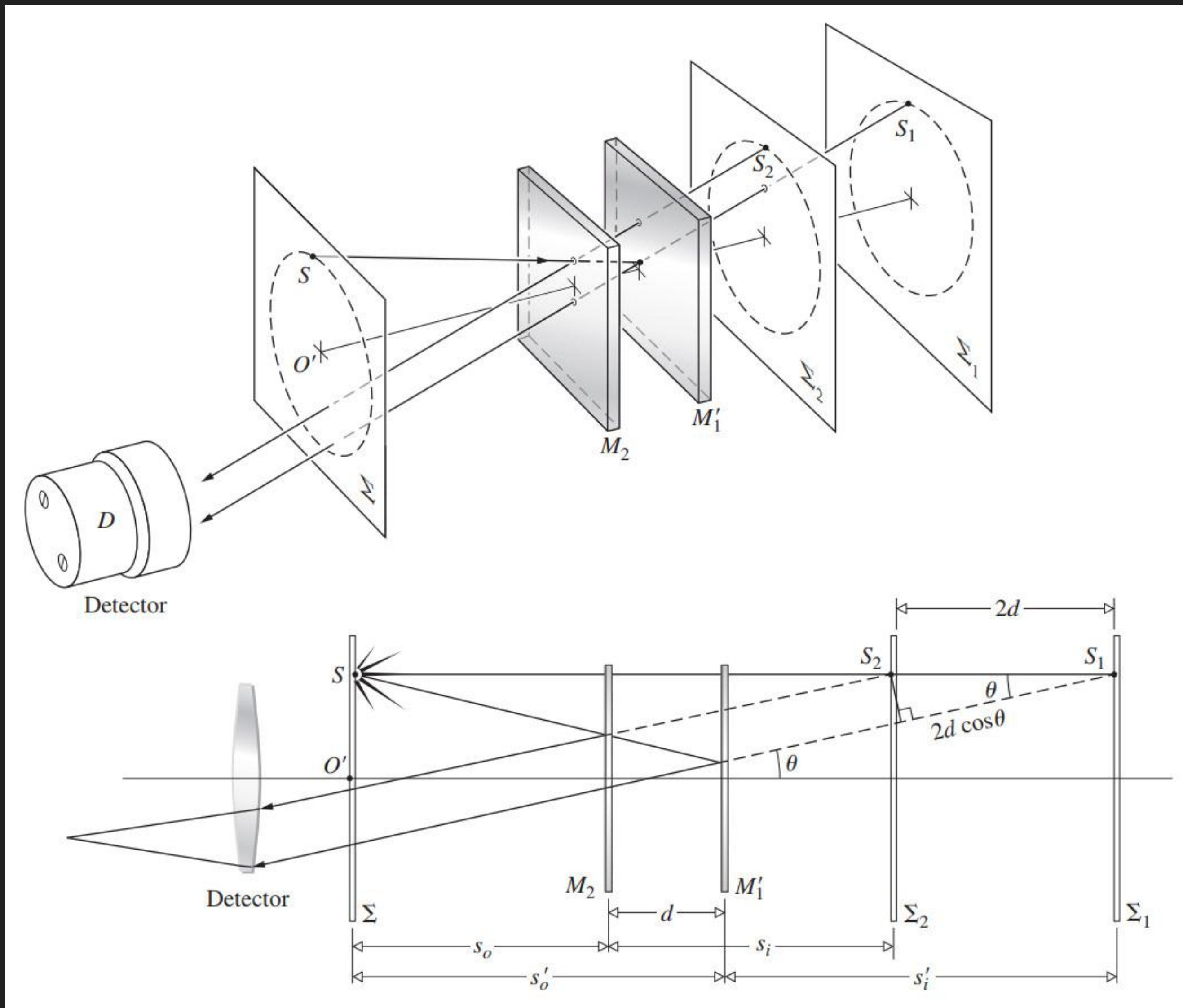
Newton rings



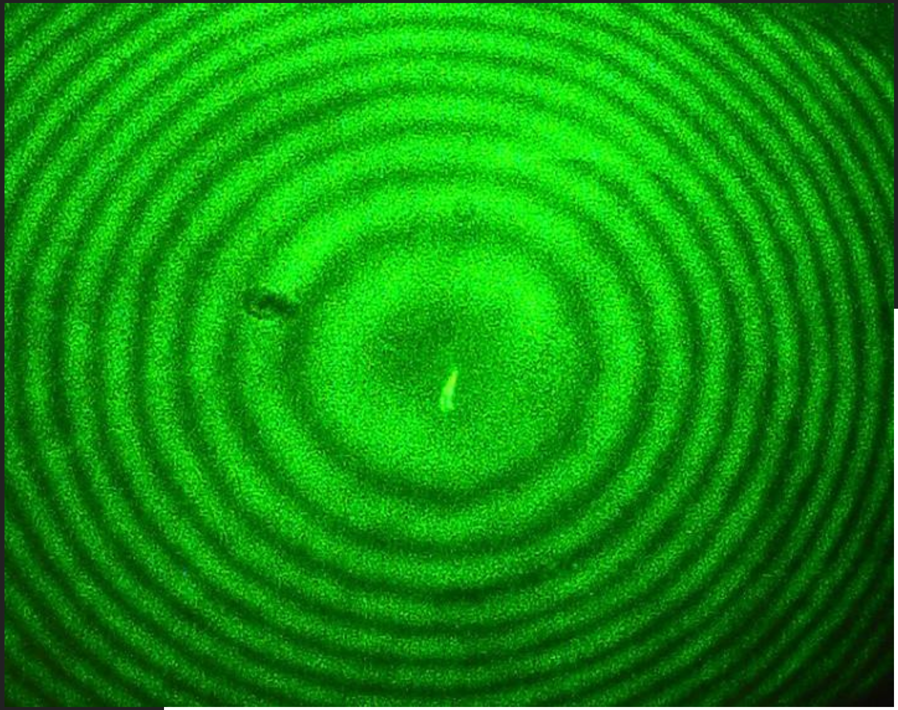
Michelson interferometer I

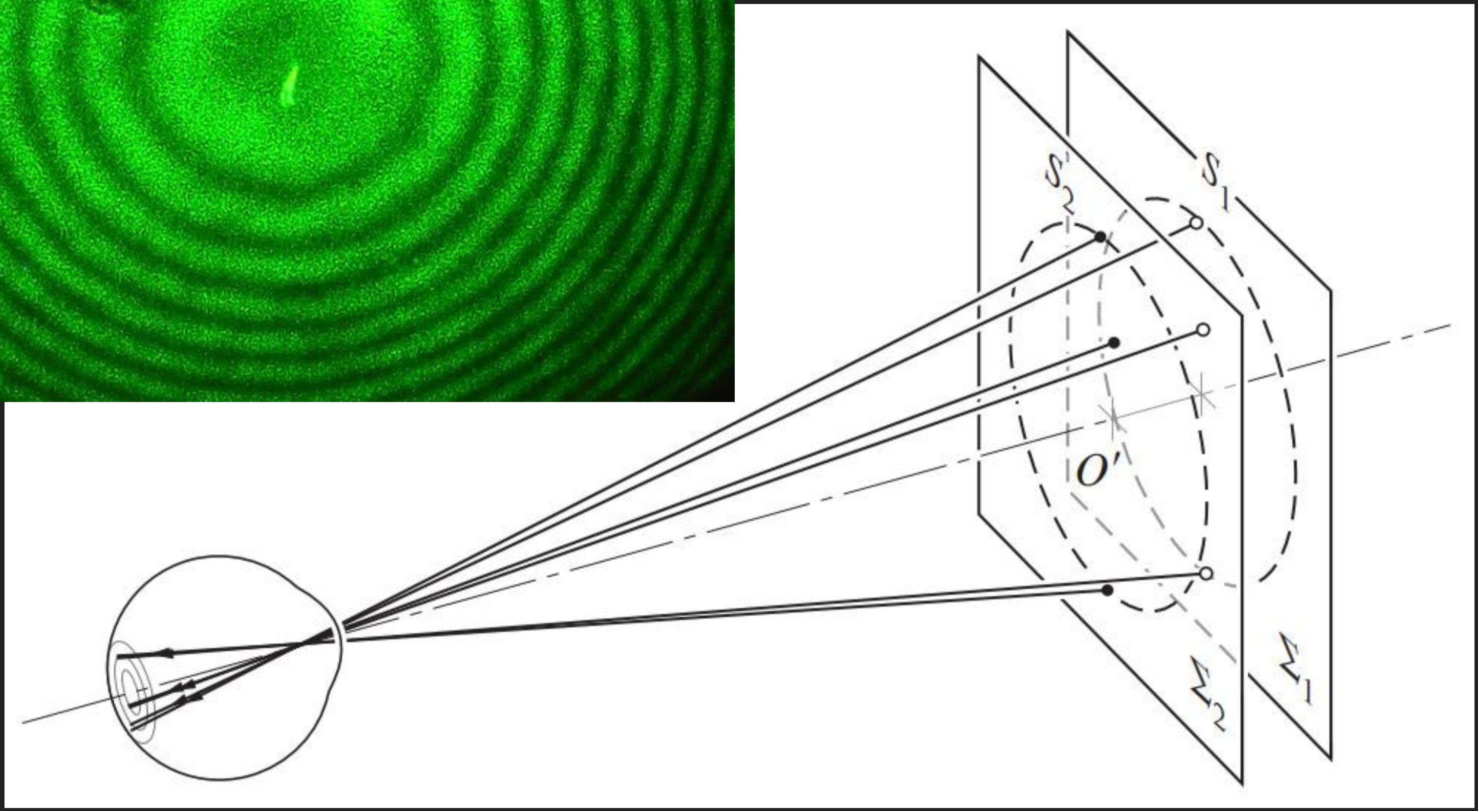


Michelson interferometer II

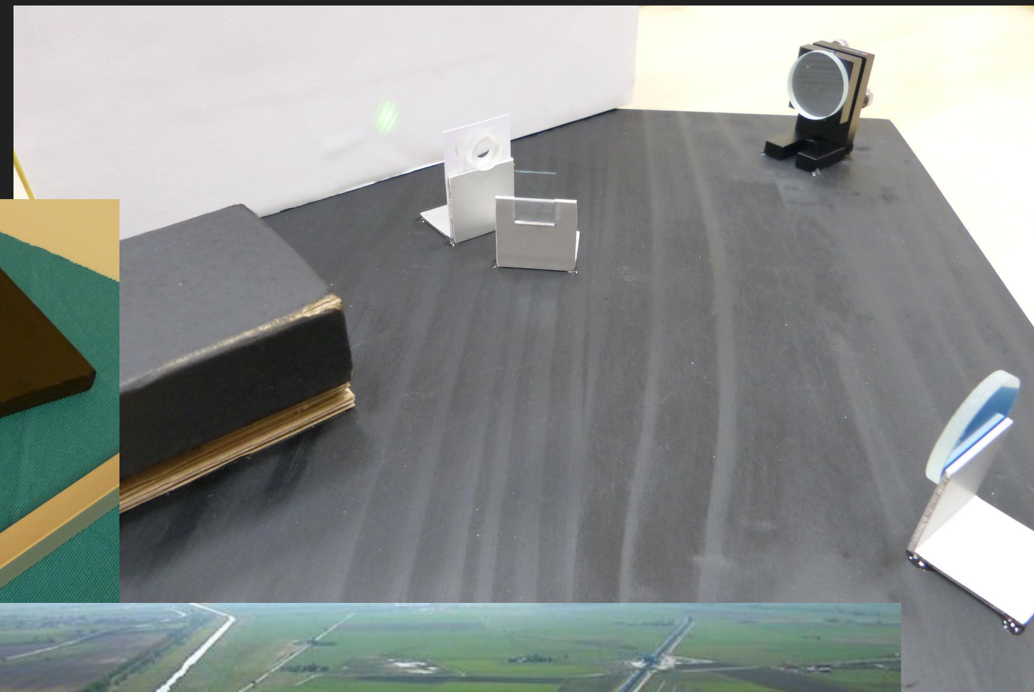


Michelson interferometer III

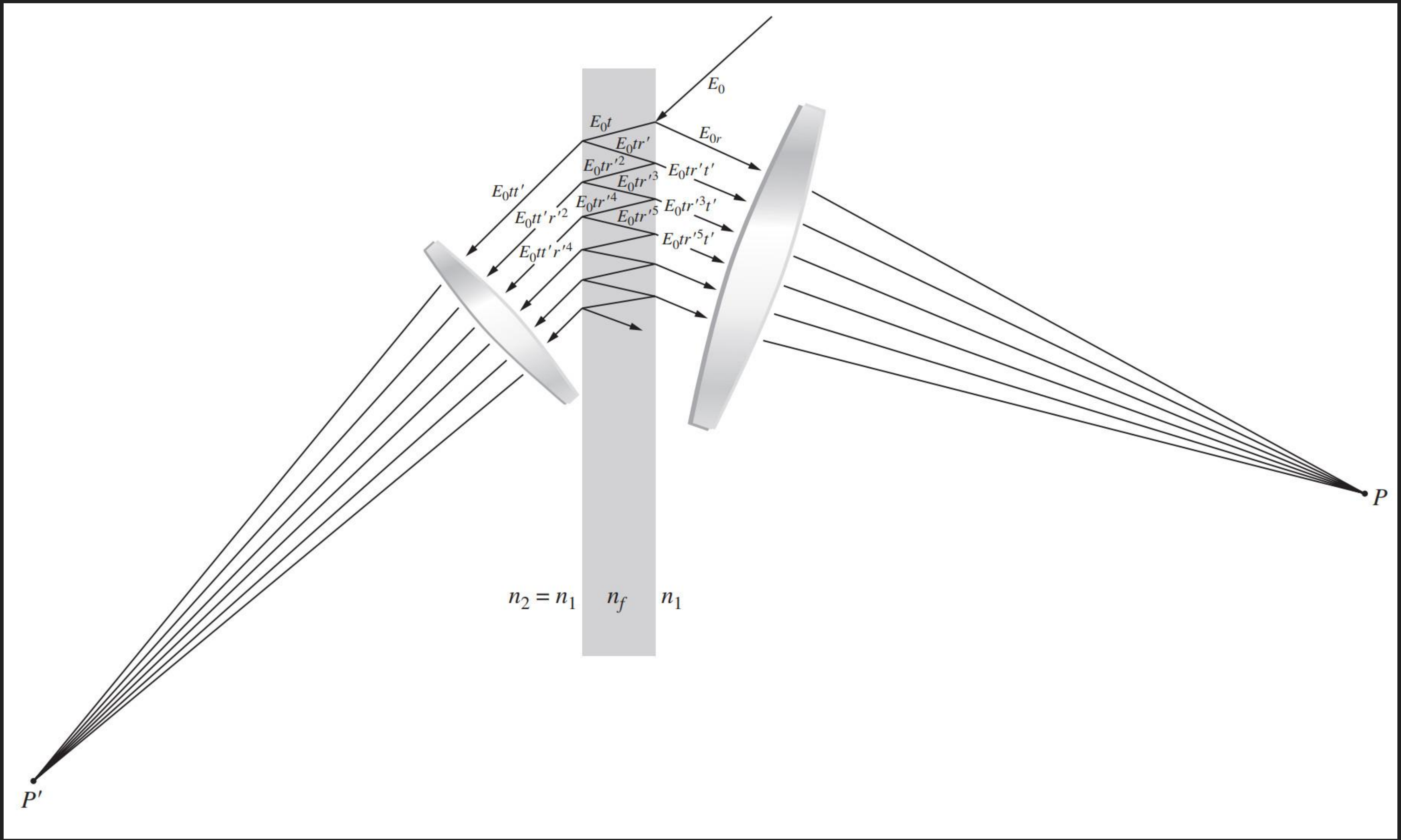




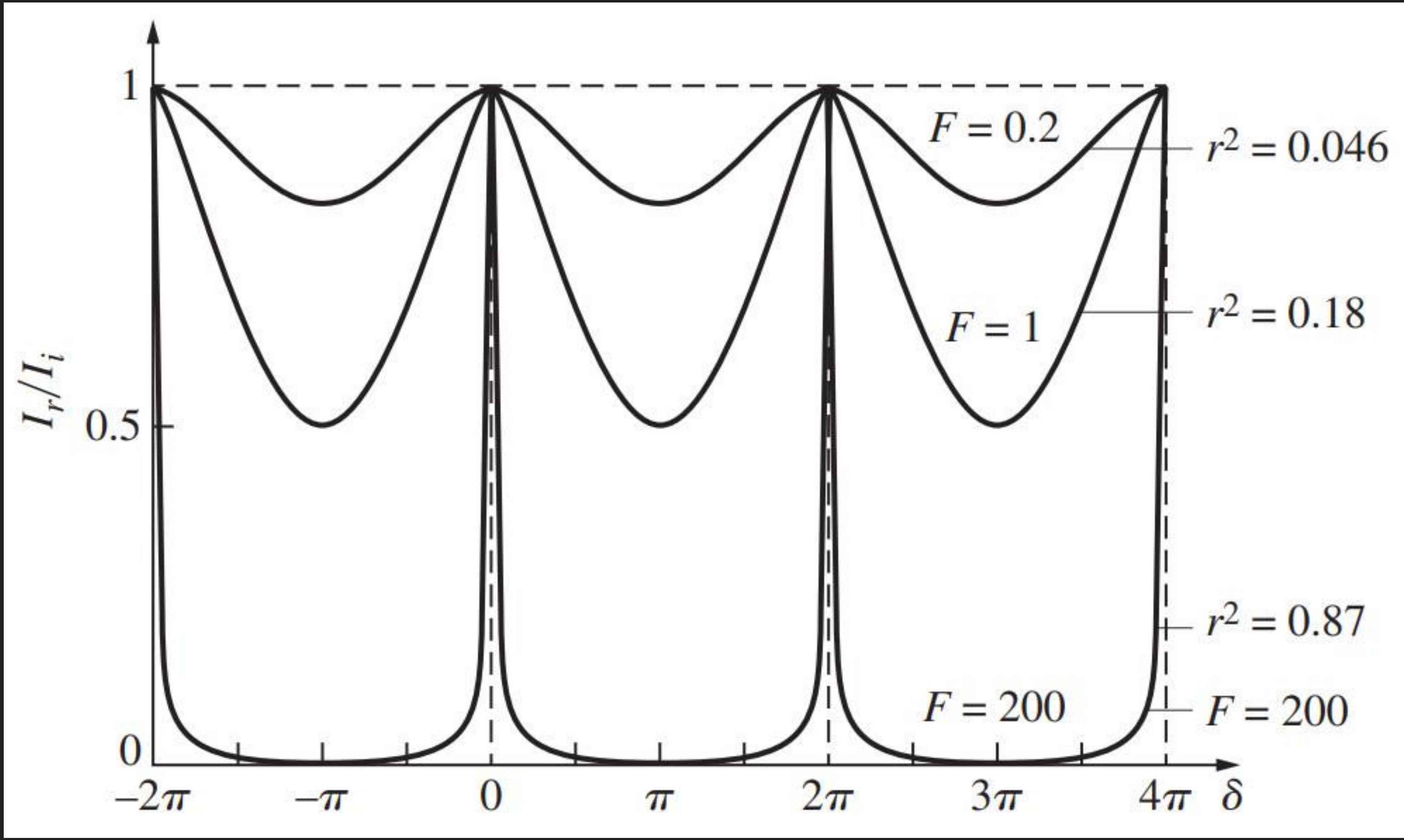
Michelson interferometer IV



Multi-beam interference



Airy function



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.