# PHYS 415: OPTICS

# Introduction to the Course

**F. ÖMER ILDAY**

*Department of Physics,*
*Bilkent University, Ankara, Turkey*

I used the following resources in the preparation of almost all these lectures:
Trebino's Modern Optics lectures from Gatech (quite heavily used), and
various textbooks by Pedrotti & Pedrotti, Hecht, Guenther, Verdeyen, Fowles and Das

# General Info 1

**Instructor:** F. Ömer Ilday (http://www.bilkent.edu.tr/~ilday)

**Office:** ARL-Z03 (phone: 1076x)

**Office Hours:** By appointment only

**Lectures:** Tu 13:40 - 15:30 (SAZ-18) and Th 15:40-17:30 (SAZ-18)

**Course page:** http://www.fen.bilkent.edu.tr/~ilday/courses/2006/415/optics.html

Bookmark this page!

You are formally obliged to check this webpage for any announcements…

# General Info 2

**Textbook (required):**

Introduction to Optics, F. L. Pedrotti, L. S. Pedrotti

**Supplementary texts (optional):**

Optics Lectures, R. Trebino
(http://www.physics.gatech.edu/gcuo/lectures/index.html)

Optics, E. Hecht,

Laser Electronics, J. T. Verdeyen,

Modern Optics, G. R. Fowles

Modern Optics, R. D. Guenther

# General Info 3

**Grading (subject to minor changes)**

| | | |
|---|---|---|
| Homeworks/quizes | %15 | |
| Lab work | %20 | |
| Midterm I | %20 | date: end of diffraction (~ last week of October) |
| Midterm II | %20 | date: end of lasers (~first week of December) |
| Final | %25 | |

**Attendance is crucial.** If you follow all of the lectures, do your homework assignments, etc, you will generally receive A's and B's. I reserve the right to add up your grades "nonlinearly" (to your advantage).

If you want, you will be given the option to prepare a term paper or presentation on an advanced topic for extra credit.

There may be unannounced quizes, so come prepared.

# General Info 4

**Homework Assignments**

You are encouraged to work together on your assignments, but you MUST declare with whom on top of the first page. The final write-up must be your own (no carbon copies please). Your lowest homework grade will be dropped.

All assignments to be given to the TA, due by in one week. Electronic submissions are welcome, if you have a scanner and can produce decent output.

The SAPS system has a discussion forum; you are welcome to use this, including homework discussions. However: discussion ≠ posting complete solutions

The TA is not authorized to provide solutions to homework problems, but you can go to him/her with questions.

As a general rule, come to me for conceptual issues and go to the TA for help with problems.

# General Info 5

## Lab Work

Lab work is an important and fun part of this class. Lab hours will be announced once the lab TA is assigned.

Labs are assigned 4 hours each week, in practice you need 2-2.5 hours maximum.

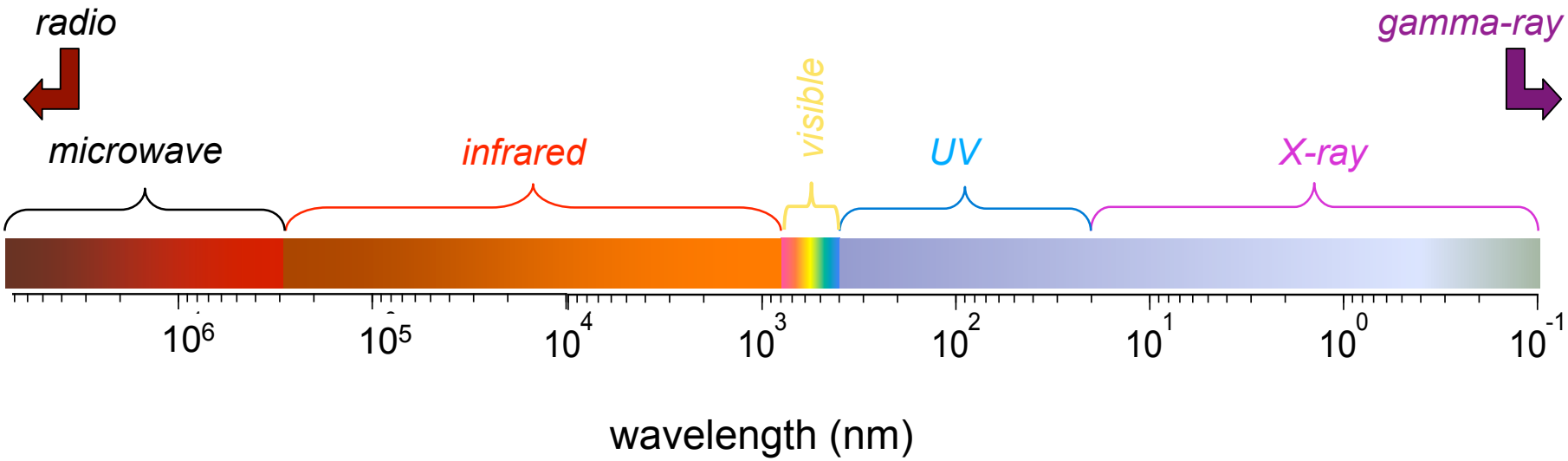
Experiments are designed to intrigue you and to put the lectures on firmer ground. They are relatively easy and they can help you understanding a lot.

# Topics of PHYS415

- **Introduction to optics, EM spectrum, generation of light**
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

# The electromagnetic spectrum

Mostly my lecture notes, very introductory




The transition wavelengths are a bit arbitrary…

# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- **Photon and wave nature of light**
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

# Photon and Wave Nature of Light

Maxwell's equations

Wave equation

Basic math/phys of waves

Diffraction, coherence, interference (all about solving the wave equation)

Photon picture briefly.

Mostly chapters 2 and 3 of Hecht

# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- **Fourier transforms, optical waves, diffraction and Gaussian beams**
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

Review of Fourier transforms, commonly encountered functions.

Overview of diffraction, basic formalism.

My notes, derived from Chapter 9 of Guenther

# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- **Interference and interferometry**
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

Interference and interferometry

Following Pedrotti Chapters 10 and 11 closely.

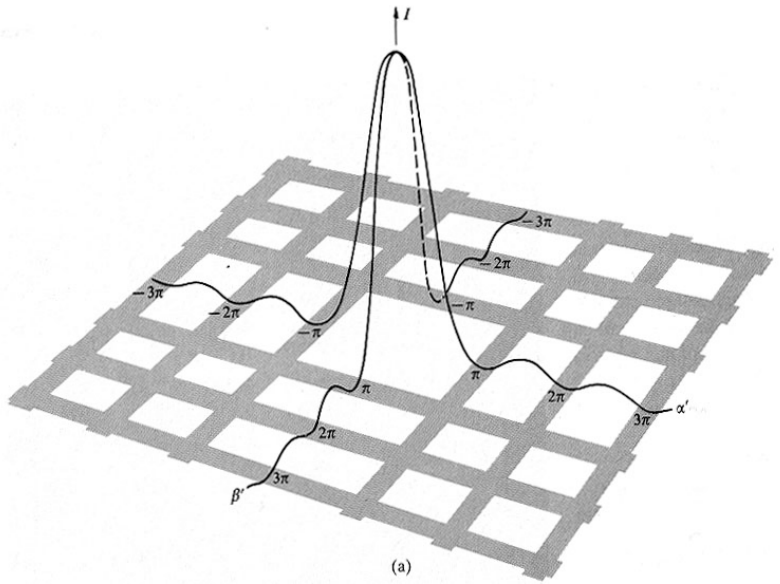
LIGO Project @ CalTech

# Topics of PHYS415

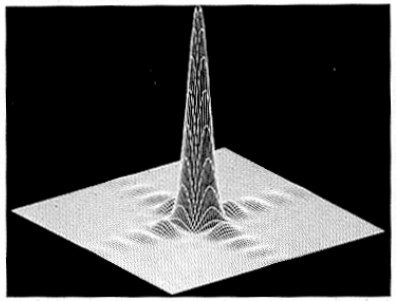
- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- **Diffraction I: Far-field (Fraunhofer) diffraction**
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

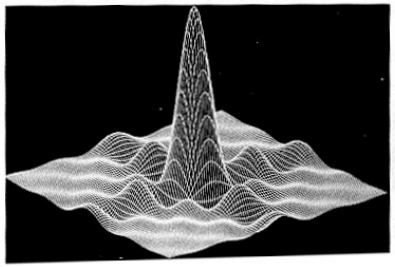
Far-field diffraction, which is the mathematically easier limit:
plane-wave limit, away from the aperture.

Following Pedrotti Chapters 16 closely.



(a)


(b)



# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- **Diffraction II: Near-field (Fresnel) diffraction**
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

Intro to near-field diffraction, this is mathematically challenging, so we will see some easy, special cases. Following Pedrotti Chapter 18.

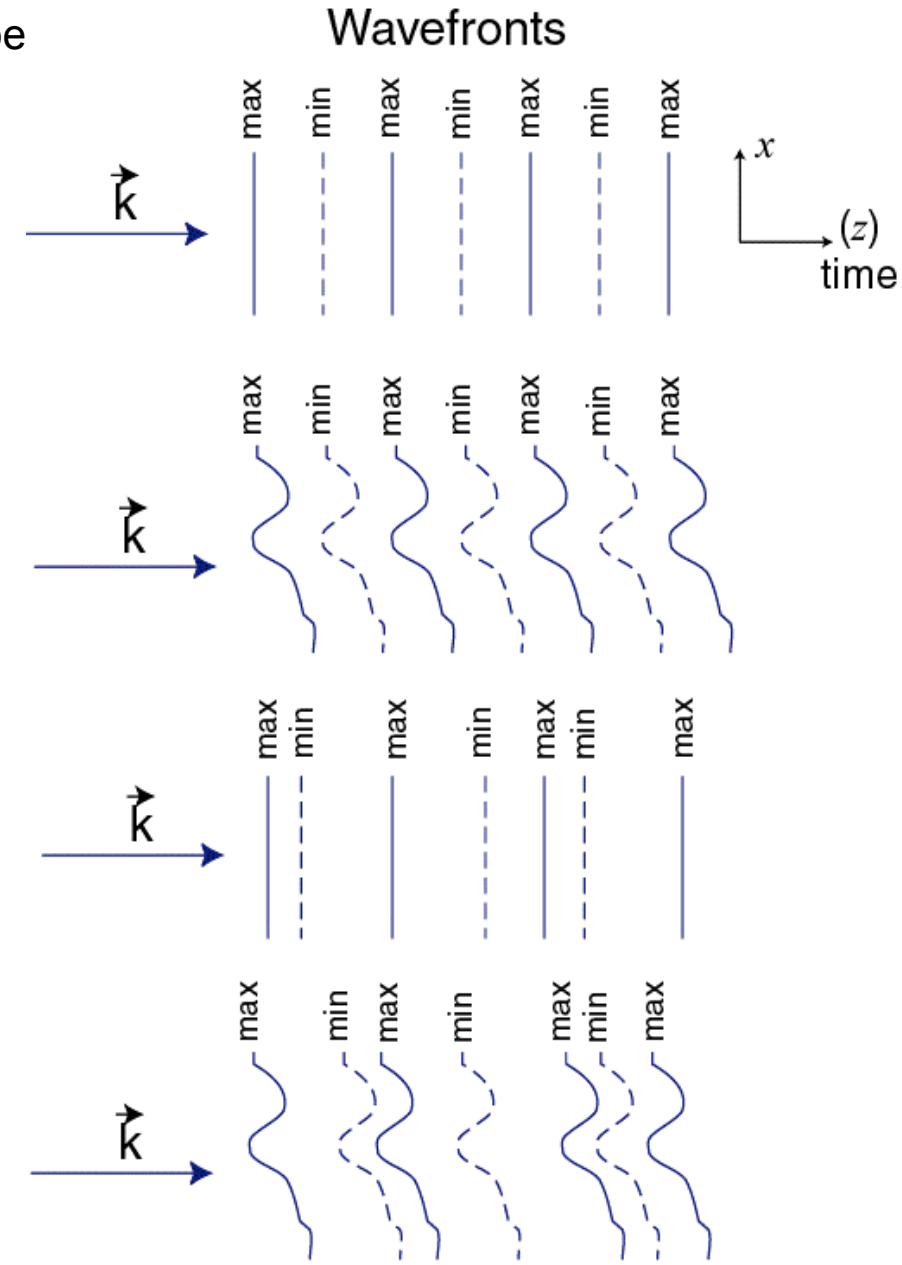
In this case, we are not so far from the source/aperture and sort of in the spherical wave limit.

# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- **Coherence**
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

The concept of coherence, distinction be incoherent sources.

Following Pedrotti Chapter 12.

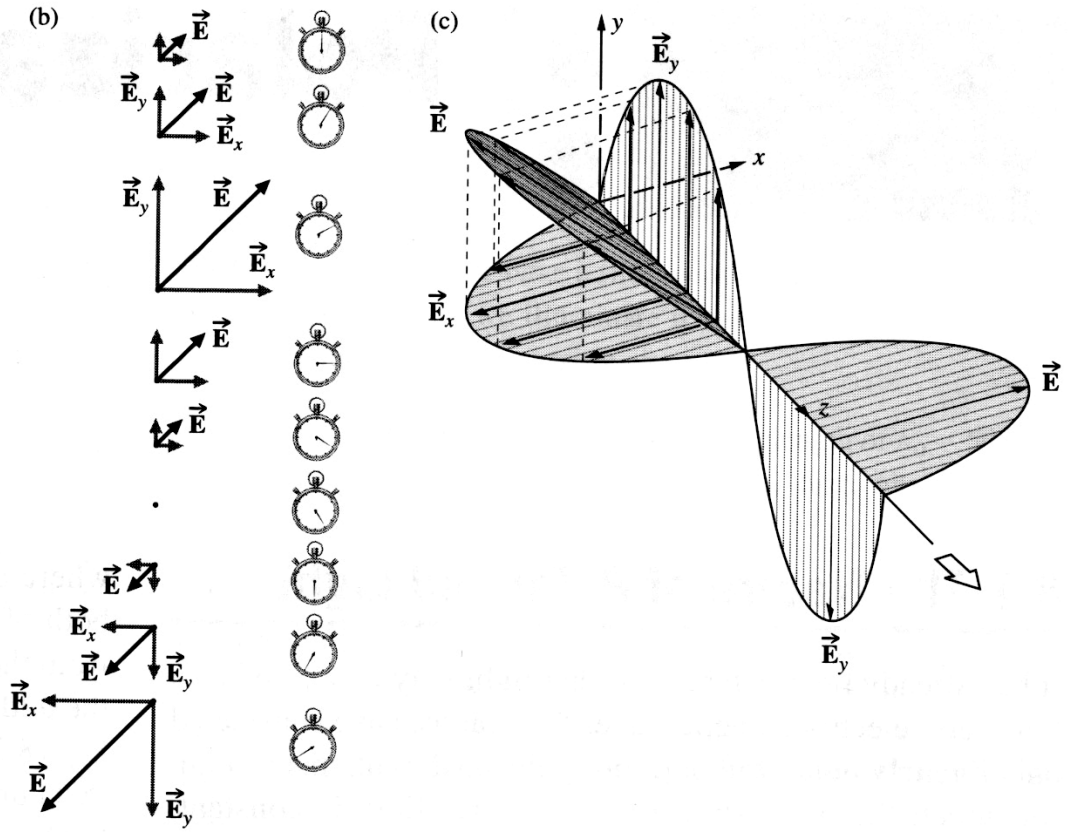


# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- **Polarization**
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

Light has two degrees of freedom, ever wonder why?

Well, these two degrees correspond to polarization. We will have an intro into the matrix treatment of polarization. Complex polarization rotations and modulations are crucial for many modern applications.



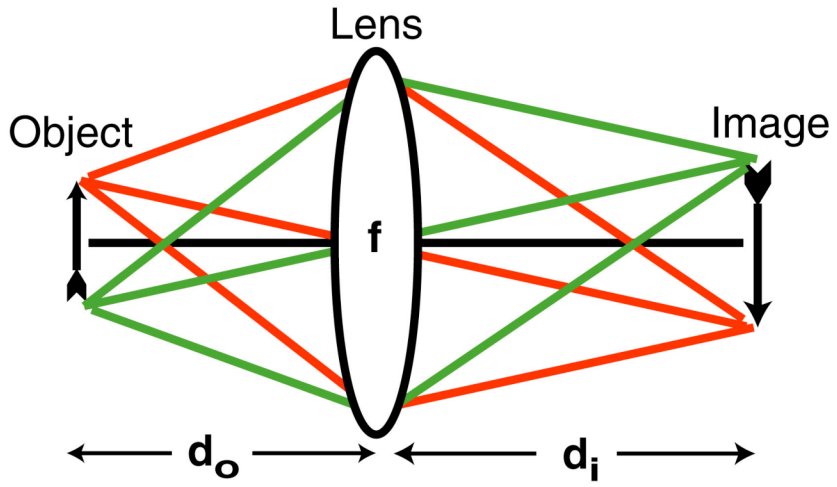
# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- **Geometrical and paraxial optics**
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

Basic geometrical optics: refraction, lenses, focusing elements… Following mostly my notes from Verdeyen Chapters 2 and 3.

The paraxial limit and the paraxial equations.

This week will prepare you for the upcoming treatment of optical cavities as well as basics of optical delivery systems.



# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- **Optical cavities and resonators**
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

Treatment of optical cavities. Stability of the cavities. Mostly following my notes from Verdeyen Chapters 5 and 6.

At the end of these lectures, you should be able to make basic calculations of laser and passive optical cavities.

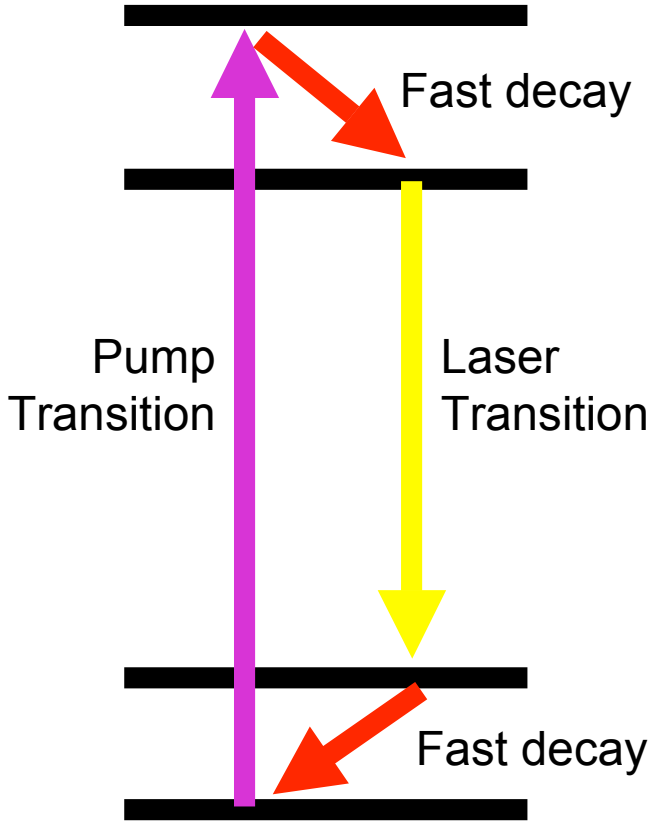
# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- **Lasers**
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

Introduction to laser amplification, laser oscillation. Continuous-wave lasers and pulsed lasers. Commonly used laser types.

At the end of these lasers, you should be equipped well enough to determine on your own the optimum laser type and its crucial parameters for a given laser application.

Mostly my notes and Pedrotti Chapter 21.



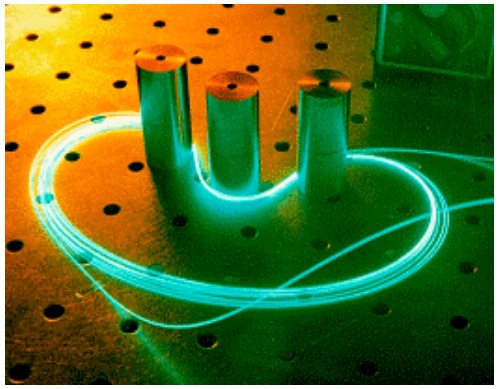
# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- **Fiber optics and telecommunications**
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- Optical properties of materials, laser-material interactions

Fibers are “light pipes”: how do we guide light through these pipes? Total internal reflection, of course.

Today, fiber optics underlies modern communication networks. We will learn about how data are transmitted using light propagating vast distances in optical fiber.

Mostly my notes and Pedrotti Chapter 24.



# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- **Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics**
- Optical properties of materials, laser-material interactions

We can modulate light (streams of photons) with electrical signals (streams of electrons), using the electro-optic effect. This is crucial for optical information processing today, including optical communications.

We can even modulate light using intense light: photons modulated by other photons, through the coupling of a nonlinear medium. This is nonlinear optics; responsible for all frequency conversions. Possibly the future of ultra-high-speen optical information processing and communications.

Mostly my notes and Pedrotti Chapter 26.

# Topics of PHYS415

- Introduction to optics, EM spectrum, generation of light
- Photon and wave nature of light
- Fourier transforms, optical waves, diffraction and Gaussian beams
- Interference and interferometry
- Diffraction I: Far-field (Fraunhofer) diffraction
- Diffraction II: Near-field (Fresnel) diffraction
- Coherence
- Polarization
- Geometrical and paraxial optics
- Optical cavities and resonators
- Lasers
- Fiber optics and telecommunications
- Modulation of photons by electrons and other photons: Electro-optic modulation and nonlinear optics
- **Optical properties of materials, laser-material interactions**

Optical properties of materials: absorption and dispersion, dielectric media, metals... Crucial for all optics development and research.

Processing of materials with laser light: a very large market

Following Pedrotti Chapter 27 and my notes.