What is Optics?

Arthur L. Schawlow, best known for his work on laser, for which he share the 1981 Nobel Prize in Physics.
[source: Credible (and Edible) Lasers: The Life of Arthur L. Schawlow]

PHY 431 Optics
Course Description

Cover the fundamental properties of light propagation and interaction with matter under the approximations of geometrical optics and scalar wave optics, emphasizing physical intuition and underlying mathematical tools.

Topics

- Geometrical optics
  - Basic ray-tracing
  - Image formation and imaging systems
  - Optical system design
- Wave optics
  - Scalar linear wave propagation
  - Wave properties of light
  - Polarization
  - Interference and interferometers
  - Fourier Optics (a more systematic approach to light propagation)
  - Spatial filtering, resolution, coherent & incoherent image formation, space-bandwidth product
  - Wavefront modulation, holography, diffractive optics
- Modern Optics
  - Lasers
  - Optical Trapping

What you need

- Necessary
  - Euclidean geometry
  - calculus with complex variables
  - Taylor series approximation
- Helpful if you know but we will cover here
  - basic electrodynamics
  - basic wave propagation
  - Fourier analysis

What is Optics? Photonics?

- Think of optics as the science of light. It's a branch of physics that describes the behavior and properties of light and the interaction of light with matter. It's about what light is made of and how it behaves.

- Light allows us to see, but it also transmits sound, cuts things, and controls electrical circuits. That's where photonics comes in.
- Photonics is the science and technology of generating and harnessing light. This includes the emission, transmission, amplification, detection, modulation, and switching of light—much of which is centered around the use of lasers and photodetectors. Light sensors, telecommunications equipment, holographs, CDs, laser surgery, fiber optics, and the Internet are all based on photonics.

Among photonics-based technologies we take for granted today are:

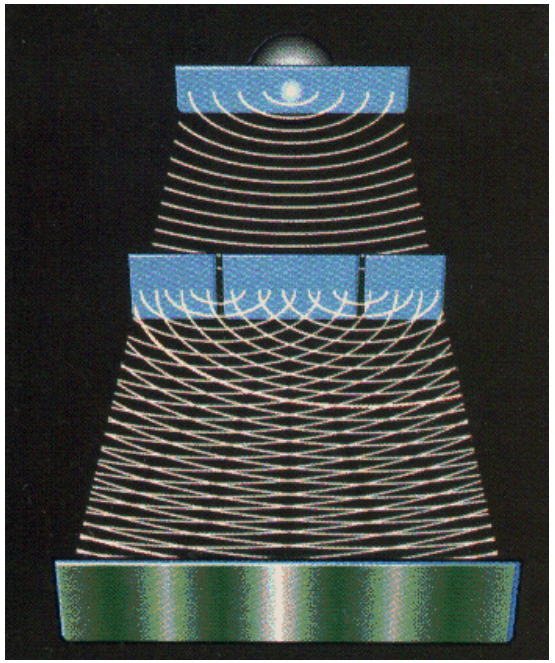
- Barcode scanners, printers, remote control devices;
- Laser surgery, drilling, and surface modification;
- Range finding, navigation;
- Computer networking, circuit boards, and chips;
- CDs, DVDs; and
- Digital cameras.

Brief (*western*-)History of Optics

A legend of Archimedes (no evidence) link

- Ancient Greeks (~5-3 century BC)
  - Pythagoras (rays emerge from the eyes)
  - Democritus (bodies emit "magic" substance, simulacra)
  - Plato (combination of both of the above)
  - Aristotle (motion transfer between object & eye)
- Middle Ages
  - Alkindi, Alhazen defeat emission hypothesis (~9-10 century AD)
  - Lens is invented by accident (northern Italy, ~12thcentury AD)
  - Della Porta, da Vinci, Descartes, Gallileo, Kepler formulate geometrical optics, explain lens behavior, construct optical instruments (~15thcentury AD)
- Beyond the middle ages:
  - Newton (1642-1726) – "Particle"
  - Huygens (1629-1695) – "Wave"

Brief History of Optics



- 18^{th} –19^{th} centuries
  - Fresnel, Young experimentally observe diffraction, question Newton's particle theory
  - Maxwell formulates electro-magnetic equations, Hertz verifies antenna emission principle (1899)
- 20^{th} century
  - Quantum Mechanics (Black-body radiation, Plank's constant, photoelectric effects, atoms)
  - Quantum theory explains wave-particle duality
    Quantum Electrodynamics (QED)
  - Invention of holography (1948)
  - Invention of laser (1956)
  - Optical applications proliferate: computing, communications, fundamental science, medicine, manufacturing, entertainment.

Example Applications

- Confocal microscopy
  - optical slicing
  - Fluorescence
  - two-photon
  - real-time
  - Holographic
  - Spectroscopic
  - bio-imaging, imaging through turbulence
- Super-resolution
  - apodizing filters
  - hybrid (optics+signal processing) approaches
  - information-theoretic viewpoint
  - meta-materials (invisible cloak?)
- Optical data storage
  - optical disks (CD's, DVD's, MO disks)
  - holographic memories

- Optical Communication
  - Fiber Optics
  - Optical switching and modulation
    - optical MEMS
    - electro-optics
    - acousto-optics
- Statistical optics
  - Coherence imaging (van Cittert-Zernicketheorem, radio astronomy)
  - Optical coherence tomography
  - X-ray tomography
- Lasers Spectroscopy
- Laser cooling of atoms/molecules
- Laser trapping (optical tweezers) of atoms/molecules

Nobel Laureates in the field of Optics

The Nobel Prize in Physics 2009 was divided, one half awarded to Charles K. Kao *"for groundbreaking achievements concerning the transmission of light in fibers for optical communication"*, the other half jointly to Willard S. Boyle and George E. Smith *"for the invention of an imaging semiconductor circuit – the CCD sensor"*.

- **R. Galuber, J. Hall, T. Haensch (Physics 2005)**
- **W. Ketterle, E. Cornell, C. Wieman Physics 2001**
- **Z. Alferov, H. Kroemer, J. Kilby –Physics 2000**
- **A. Zewail – Chemistry 1999**
- **S. Chu, C. Cohen-Tannoudji, W. Phillips –Physics 1997**

E. Ruska –Physics 1986 N. Bloembergen, A. Schawlaw, K. Siegbahn –Physics 1981 A. Cormack, G. Housefield –Biology or Medicine 1979 M. Ryle, A. Hewish – Physics 1974•D. Gabor –Physics 1971•A. Kastler –Physics 1966•C. Townes(MIT), N. Basov, A. Prokhorov–Physics 1964 •F. Zernicke–Physics 1953•C. Raman – Physics 1930•W. H. Bragg, W. L. Bragg –Physics 1915•G. Lippman–Physics 1908•A. Michelson –Physics 1907•J. W. Strutt(Lord Rayleigh) –Physics 1904•H. Lorentz, P. Zeeman–Physics 1902•W. Röntgen–Physics 1901

An Anecdotal History of Optics from Aristophanes to Zernike http://www.ece.umd.edu/~taylor/optics.htm

- I. ANCIENT HISTORY: Aristophanes, Democ ritus, Aristotle, Archimedes, Seneca, Nero, Ptolemy, Alhazan.
- II. SPECTACLES: Bacon, Keppler, Franklin, Airy, Fick.
- III. THE TELESCOPE: Lippershey, Galileo, Newton, Gregory, Cassegrain, Hall, Dolland, Schmidt.
- IV. THE MICROSCOPE: Jansen, Hooke, Huygens, van Leeuwenhoek, Lister, Gauss, Abbe.
- V. RAY OPTICS , CORPUSCLES AND WAVELETS: Snell, Descartes, Fermat, Hamilton, Bradley, Euler.
- VI. WAVE OPTICS: Young, Fresnel, Arago, Laplace, Fourier, Poisson, Malus, Brewster, Foucault, Fizeau, Doppler.
- VII. OPTICS, ELECTROMAGNETIC WAVES AND QUANTA: Maxwell, Hertz, Luneburg, Fraunhofer, Planck, Einstein, Bohr.
- VIII. SOME ROOTS OF MODERN OPTICAL SYSTEMS: Chappe, Niepce, Wheatstone, Baird, Gabor, Zernike.