Department of Physics & Astronomy

PHYC/ECE 464: Laser Physics I

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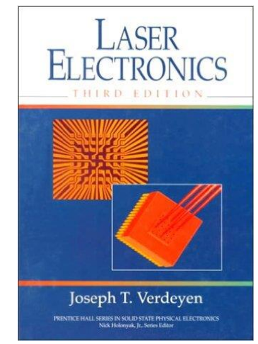
Lectures: Monday and Wednesday, 5:30-6:45 pm
P&A Room 184.



Textbook: Laser Electronics (3rd Edition) by Joseph T. Verdeyen.
Additional resources
Lasers: Anthony E. Siegman .
Introduction to Optics (3rd Edition): Frank L. Pedrotti Leno M. Pedrotti Leno S. Pedrotti.
Optics, 4th Edition: E. Hecht.
Fundamentals of Photonics, 2nd Edition: B. E. A. Saleh, Malvin Carl Teich.

Homework: Problem sets taken from the textbook by E. Verdeyen, about one set per week. They are posted one week before they are due. HW must be turned at the beginning of the class 5:30 pm on the due date.

Office hours: Monday 11:30 am-13:30 pm. You may also arrange a meeting for another time via email.

TA :**Nazanin Mosavian .** office hrs: TBD in the P&A lobby. You may also arrange a meeting for another time via email.

Grading
1. Homework 20%
2. Midterm exams: 25% each
3. Final: 30%

Tentative Exam Dates (subject to change): Midterms, I: TBD and II: November 6. Final Monday, Dec. 11.

Syllabus Topics

Based on textbook by Verdeyen. Chapters 1-11 (some partially covered). Tentative list of topics:

1. **Introduction**- Historical overview
2. **Review of Electromagnetic Theory (Ch 1)**- Maxwell's equations; wave equations; propagation in dielectrics; boundary conditions
3. **Ray Tracing in an Optical System (Ch 2)**- ABCD Matrix method
4. **Gaussian Beams (Ch 3)**- TEM waves; high-order modes
5. **Optical Cavities (Ch 5 & 6)**- Gaussian Beams in stable resonators; resonant optical cavities; finesse and photon lifetime
6. **Atomic Radiation (Ch 7)**- Black body radiation; Einstein coefficients; lineshape; light-matter interaction; line broadening
7. **Laser Oscillation (Ch 8)**- Laser oscillation and amplification; Gain saturation, Amplified spontaneous emission
8. **General Characteristics of Lasers (Ch 9)**- CW lasers; laser dynamics; Q-switching; mode locking
9. **Laser systems (Ch 10 &11)**- Three- and four-level lasers; Ruby lasers; rare earth lasers-amplifiers; gas-discharge lasers; free electron laser; semiconductor lasers
10. **Topics in Laser applications**- If time allows, we will discuss some special topics such as laser cooling, coherence and quantum optics

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Optical Science & Engineering

Class Website: http://physics.unm.edu/Courses/Becerra/Phys464LFa17/

Tentative Schedule

Additional resources

EXAM FORMULA SHEET

Class overview: Lecture 1

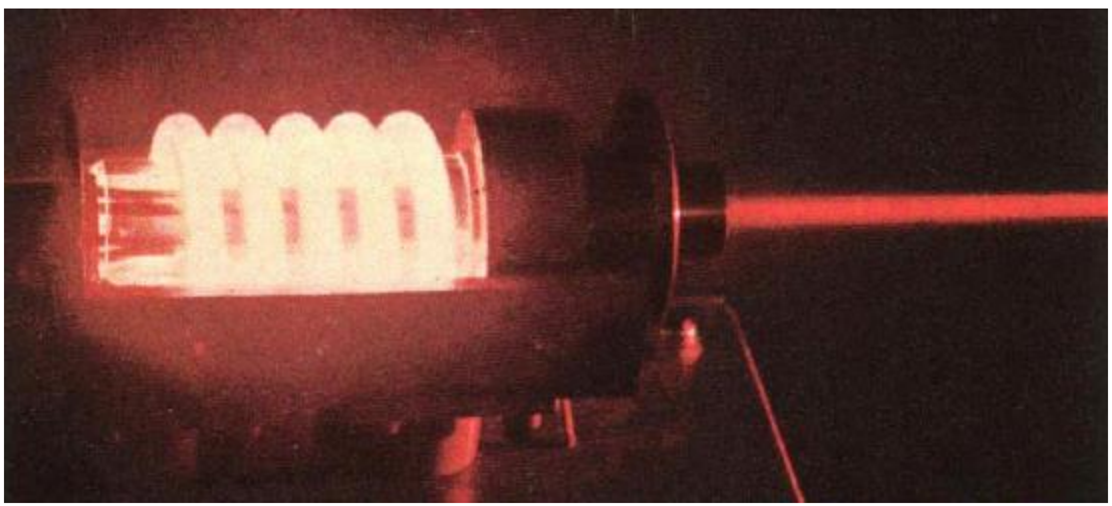
Lasers : Anthony E. Siegman .
Introduction to Optics (3rd Edition): Frank L. Pedrotti Leno M. Pedrotti Leno S. Pedrotti.
Fundamentals of Photonics , 2nd Edition: E. A. Saleh, Malvin Carl Teich.
Optics , 4th Edition: E. Hecht.

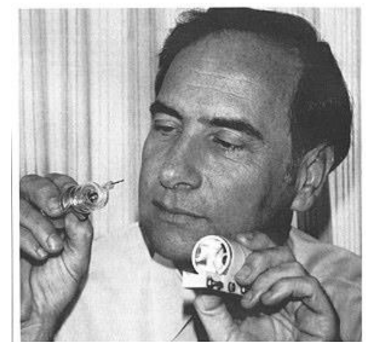
Tentative Schedule

Topic	Date	Subject	Verdeyen Reading	Homework	HW Due	Notes
Introduction	08/18 (M)	Historical Overview; Lasers				
Review of E&M	08/20 (W)	Maxwell's Eqns. and waves in dielectrics	Ch 1	HW1	(R) Aug 27	
	08/25 (M)	Boundary conditions; coherent radiation	Ch 1			

Laser Turns ~~50~~ ~~52~~ ~~54~~ 55(7)!

LASER:



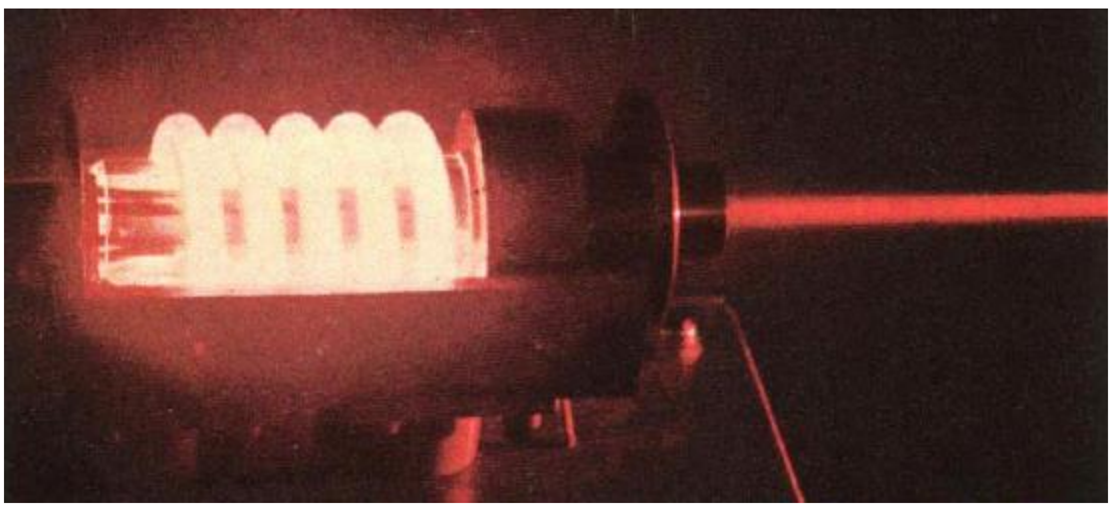


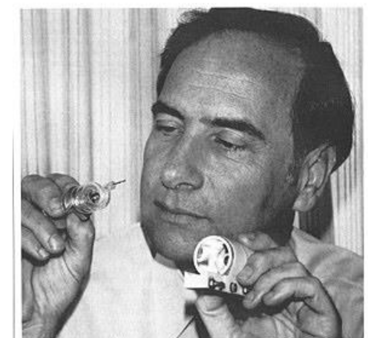
Maiman examines first ruby laser built at Hughes Research Laboratories. (circa 1960)

May 17, 1960
Ted Maiman

Laser Turns ~~50~~ ~~52~~ ~~54~~ 55(7)!

LASER: **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation



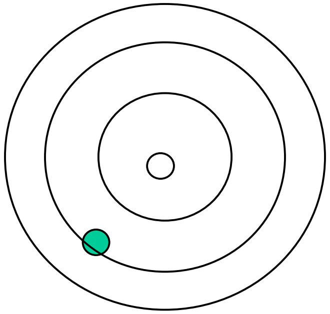


Maiman examines first ruby laser built at Hughes Research Laboratories. (circa 1960)

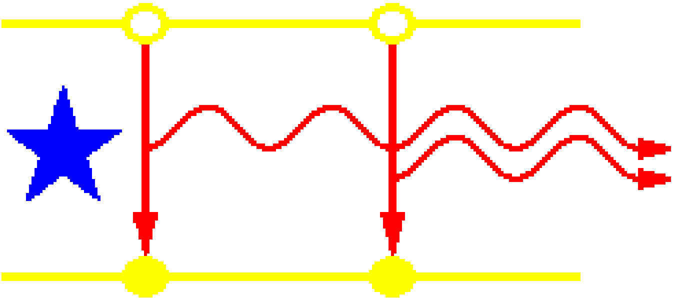
May 17, 1960
Ted Maiman

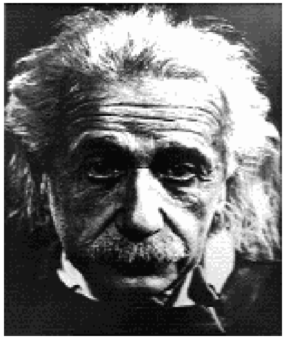
A Brief History of Laser

- Quantum mechanics is born: Planck (1900), Bohr (1913)

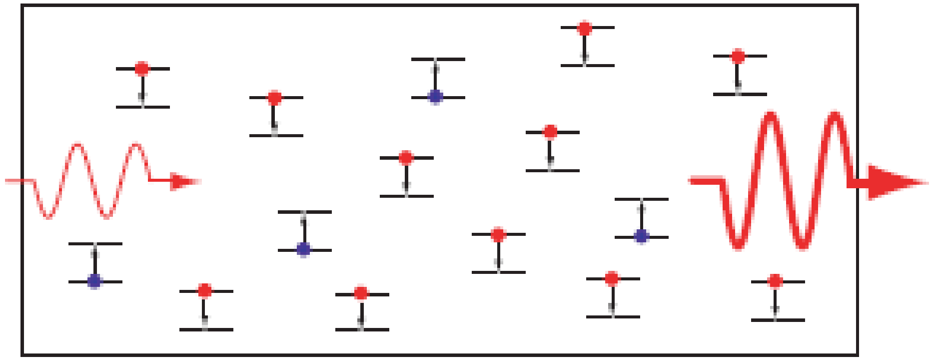


- Einstein postulated the principle of the "stimulated emission" (1917)





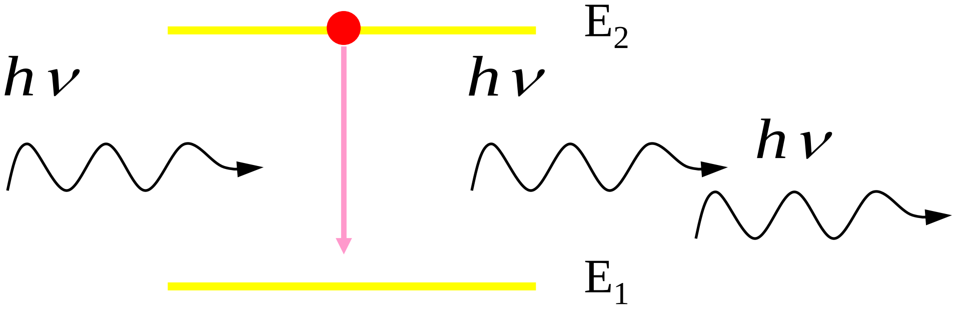
1924: Richard Tolman hints at amplification



"The process of negative absorption… from analogy with classical mechanics would presumably be of such a nature as to reinforce the primary beam." *Phys. Rev.* ***23****, June 1924. (First recognition of the possibility of maser/laser amplification?)*

the second kind. The possibility arises, however, that molecules in the upper quantum state may return to the lower quantum state in such a way as to reinforce the primary beam by "negative absorption." This question will be considered more fully in a later section and it will be pointed out that for absorption experiments as usually performed the amount of "negative absorption" can be neglected.

- (1928) Observation of negative absorption or stimulated emission near to resonant wavelengths, **Rudolf Walther Ladenburg**



Stimulated Emission
(negative absorption)

A Brief History of Laser

- MASER is invented (Townes, Basov and Prokhorov) 1954

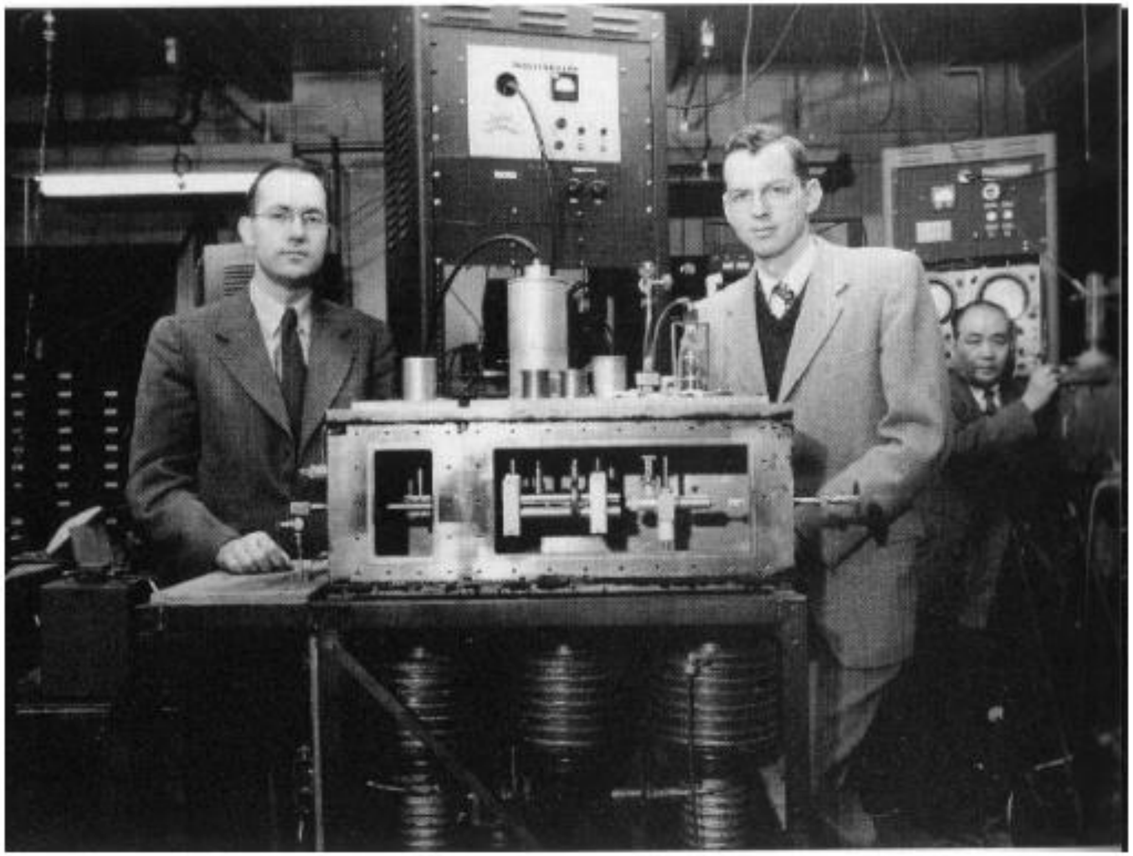
C. Townes, N. Basov and A. Prokhorov (1964)

1951–1954: The Ammonia Maser

- Townes invents the ammonia beam maser 1951
  - The early morning “park bench” invention
- First successful operation by Gordon, Zeiger & Townes April 1954
  - In Townes’ lab at Columbia University
  - A weak narrowband 22 GHz oscillator / amplifier / atomic clock
  - Townes and students coin the name MASER
  - Basov and Prokhorov achieve similar results in the Soviet Union

•*Some critics (then) called it(the MASER) : **M**eans of **A**cquiring **S**upport for **E**xpensive **R**esearch !*

1954: Charles Townes and Jim Gordon: the NH_3 maser



➢Laser operation is predicted by Shawlow and Townes (1957)

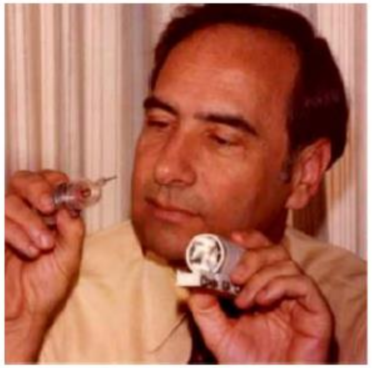
Late 1950s: Evolving toward the laser . . .

- Schawlow & Townes' proposals 1957–1958
  - *Detailed analysis of laser theory and requirements*
  - *Published as lengthy Phys Rev paper in Dec 1958*
  - *Stimulated much interest among other workers*
- The First QE Conference (Shawanga Lodge) Sept 1959
  - *Organized by Townes, published by Columbia*
  - *Brought together all the active people in the field*
- Gordon Gould & his ideas Late 1957
  - *The notebook, the candy store notary,*
    and the Thirty-Year Patent Wars

Gordon Gould and colleague in their laboratory.

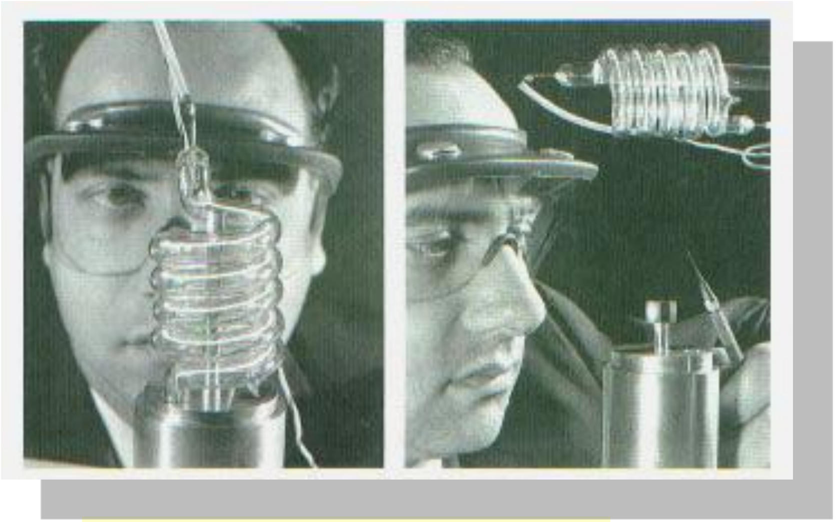
The Laser Happens!

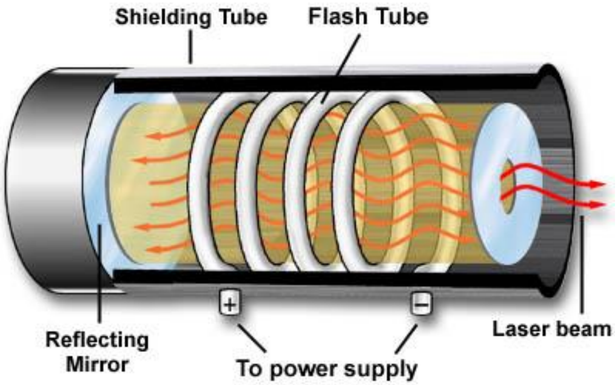
May 17, 1960



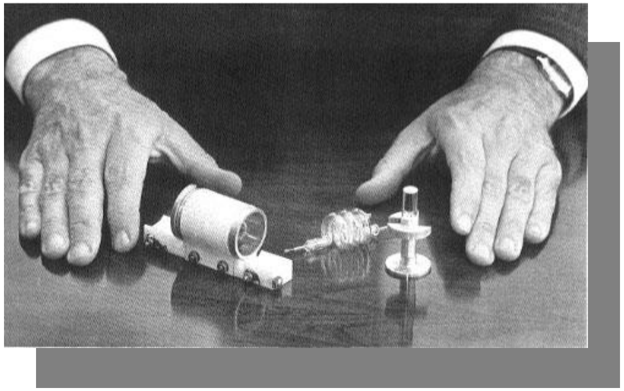
Theodore H. Maiman (HRL)

" Stimulated optical radiation in ruby " Nature Vol 187 p. 493 (Aug. 6 , 1960)





…..just another maser !!??



1960: The Laser Era opens . . .

- The ruby laser (6943 A)
  - Maiman, Asawa and D'Haenens, Hughes Res Labs May 1960
  - Immediately reproduced by numerous laboratories
- Trivalent uranium in cooled CaF2 (2.5 μm)
  - *Sorokin and Stevenson, IBM Res Labs mid–1960*
  - *First four-level solid-state laser*
- Divalent samarium in CaF2 (7085 A)
  - *Also Sorokin and Stevenson, IBM ~Nov 1960*
- First He-Ne gas laser (1.15 μm)
  - *Javan, Bennett & Herriott, Bell Labs ~Dec 1960*
  - *RF excitation, "collisions of the second kind"*

Ali Javan and the He-Ne Laser

First continuous-wave (CW), gaseous laser

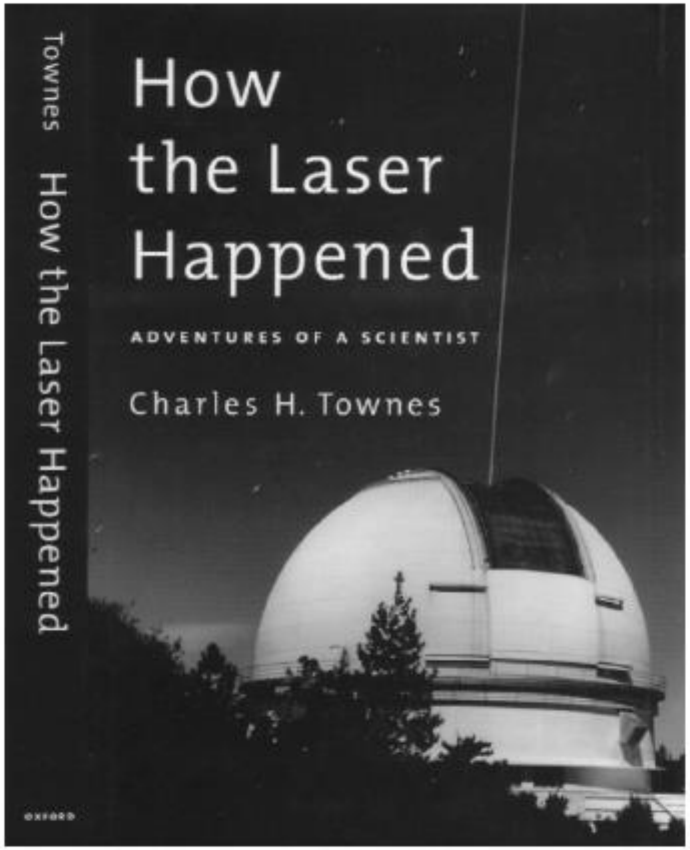
1963–1966: The immensely rapid evolution continues

• *Liquid lasers*	*Lempicki & Samelson 1963*
• *Laser mode locking*	*Various groups 1963*
• *CO2 laser*	*Kumar Patel 1964*
• *Nd:YAG laser*	*Joe Geusic et al 1964*
• *Ion lasers*	*Bill Bridges, Gene Gordon 1964*
• *Iodine photodissociation laser*	*Kasper & Pimentel 1964*
• *HCl chemical laser*	*Kasper & Pimentel 1965*
• *Organic dye lasers*	*Peter Sorokin, Fritz Schaefer 1966*

1961: First laser medical treatments

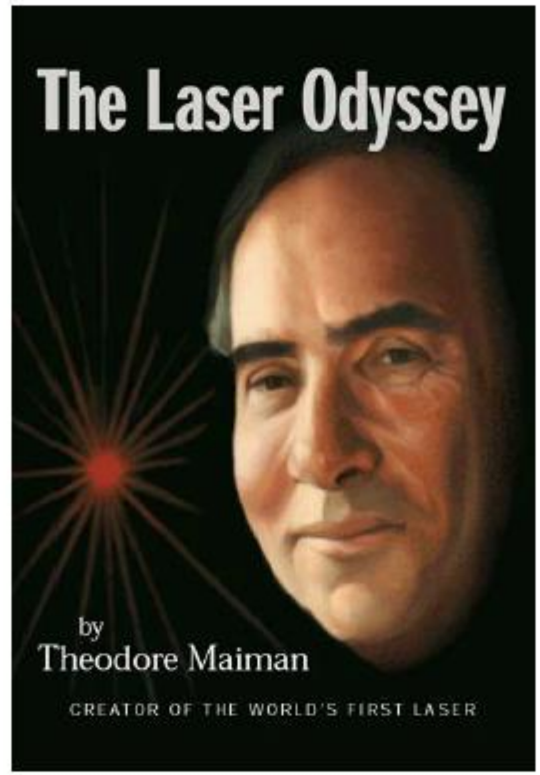
"In December 1961 the Columbia-Presbyterian Hospital used a laser on a human patient for the first time, destroying a retinal tumor with the American Optical [ruby laser] photocoagulator."

Joan Lisa Bromberg
The Laser in America, 1950—1979
Laser History Project / MIT Press, 1991

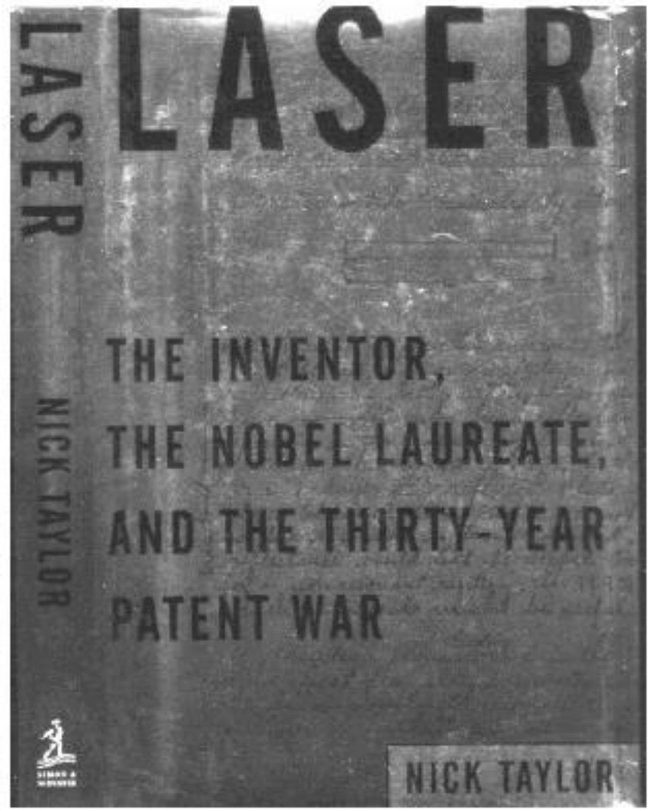


Charles Townes, *How the Laser Happened: Adventures of a Scientist* (1999)

Theodore Maiman, *The Laser Odyssey (2000)*



LASER: The Inventor, the Nobel Laureate, and the Thirty Year Patent War (biography of Gould by Nick Taylor; 2000)



1. Main Components of a Laser

1. **Power Supply or Pump Source**

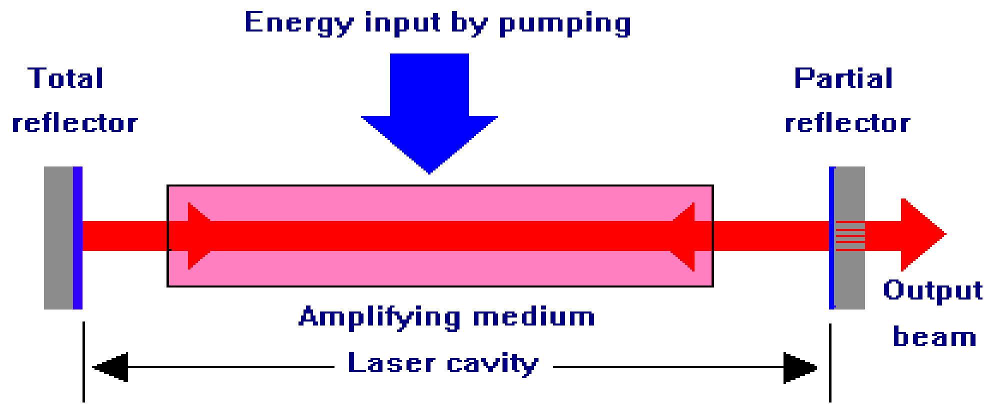
   Examples are arc-lamp, another laser, electric discharge, chemical reaction, electrical current,

2. **Gain (Amplifying) Medium**

   Can be solid, gas or liquid

3. **Laser Cavity (Resonator)**

   Example: two mirrors



2. What is a laser?

2.1 What is light?!

❖Electromagnetic radiation:

$$E = \hat{e}E_0 \cos(\omega t - kz + \varphi)$$

E = instantanous electric field

E_0 = amplitude

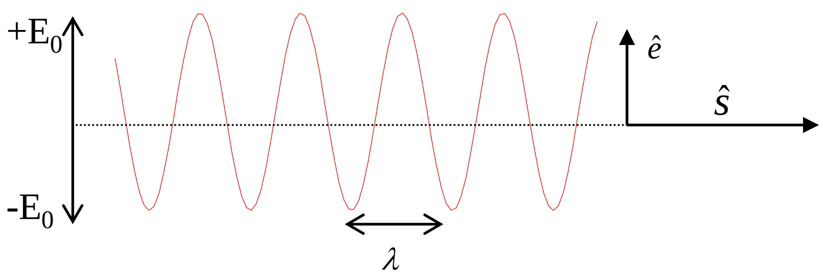
$\hat{e}$ = polarization vector

$\omega = 2\pi\nu = 2\pi c/\lambda$ = frequency

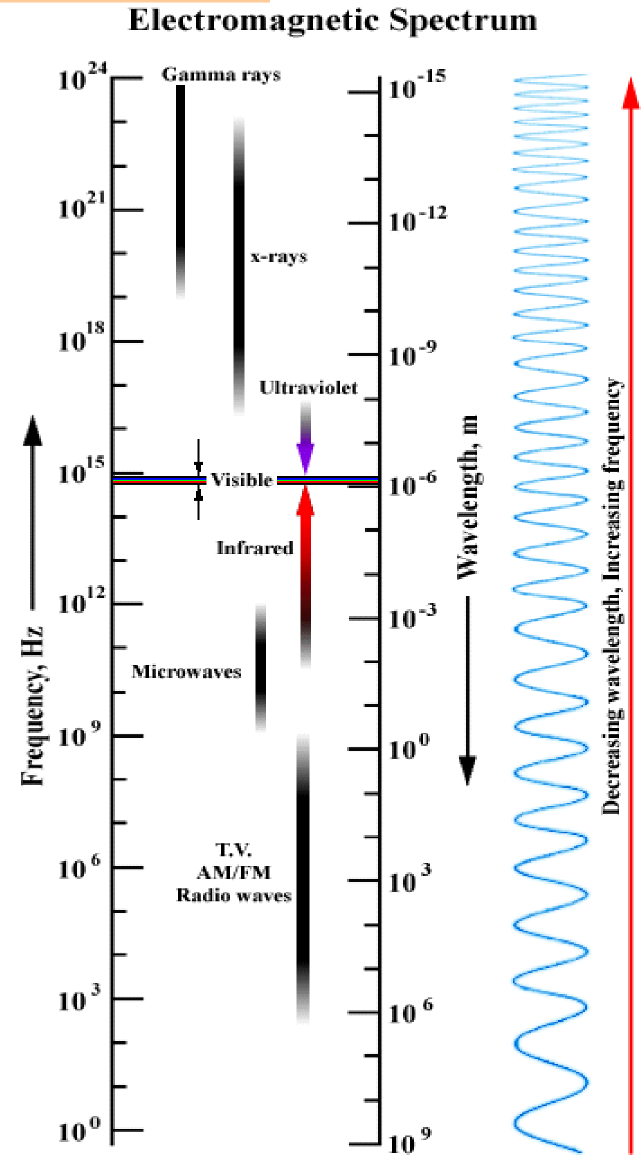
$\vec{k} = \frac{2\pi}{\lambda}\hat{s} = \frac{\omega}{c}\hat{s}$ = wavevector

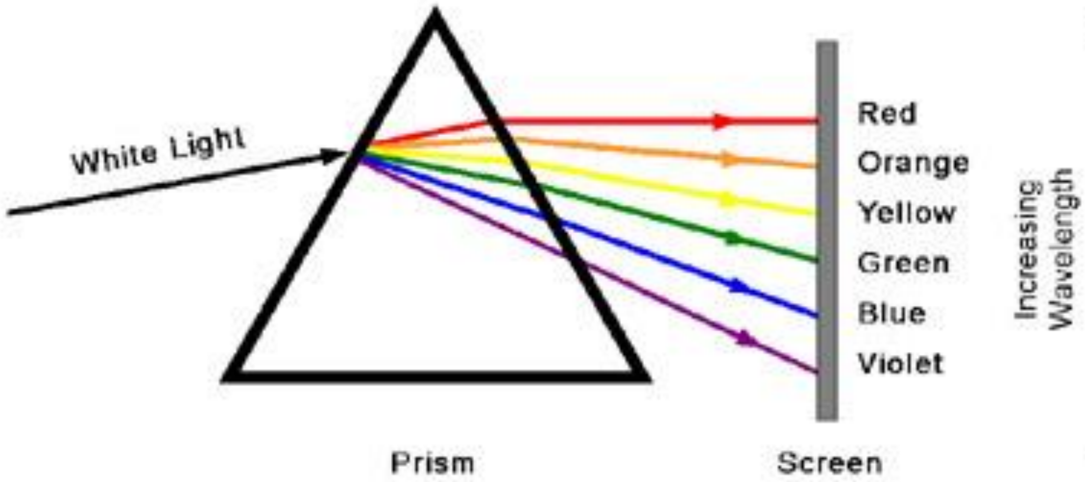
λ = wavelength

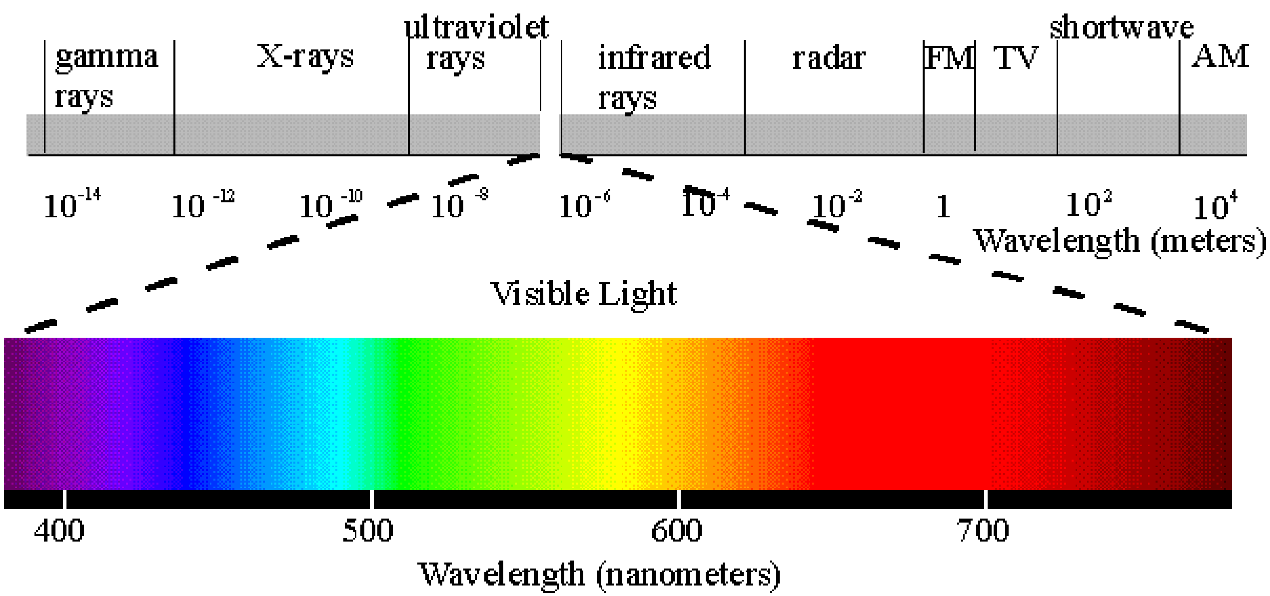
φ = phase



❖Propagation is governed by Maxwell's equations





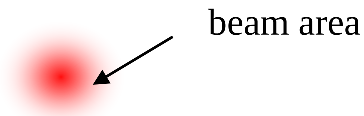


The electromagnetic spectrum
from "The Joy of Visual Perception: A Web Book"
http://www.yorku.ca/eye/

Light Intensity (I) and Power (P)

Since optical frequencies are very high (>10^{14} Hz), the detectors measure a time average of the flux density contained in the electromagnetic field. This is called the light intensity and has units of power per unit area:

$$I = \frac{nc\varepsilon_0}{2} E_0^{\ 2} = \frac{P(power)}{A(area)}$$



$$E_0(V/cm) \approx 27\sqrt{I(W/cm^2)/n}$$

- ***n***= refractive index (depends on wavelength: dispersion)
- ***c***= speed of light in vacuum (3x10^{10} cm/sec)
- $\boldsymbol{\varepsilon_0}$= permittivity of free space (8.85x10^{-12} F/m)

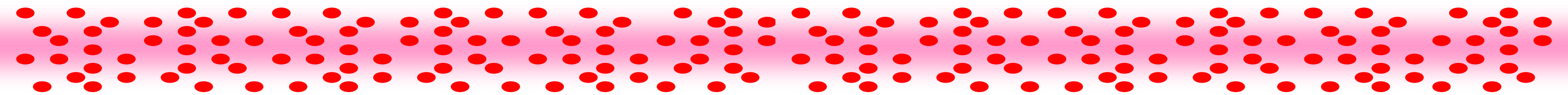
Another commonly used attribute of light:
Brightness= *Power/(Solid Angle.Frequency)*

2.2 What is a Photon?

In addition to the wave nature, light (electromagnetic waves) also can be viewed as stream of quantum particles with energy of each particle is given:

$$E=h\nu=hc/\lambda$$

where $h=6.63\times10^{-34}$ ***J-sec*** is the ***Plank's constant***.



Photon density in an optical beam (number of photons per unit volume):

$$N_p = \frac{I}{h\nu c/n}$$

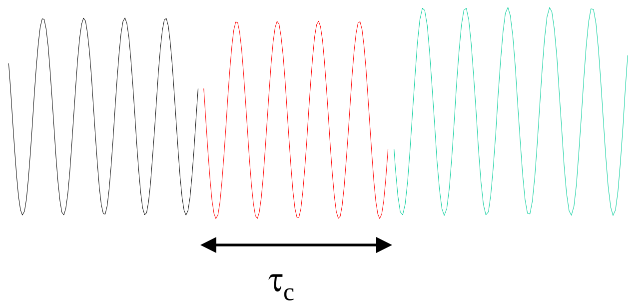
useful formulas: $\lambda(\mu m)\approx 1.24/E(eV)$

$\lambda(\mu m)=10000/E(cm^{-1})$

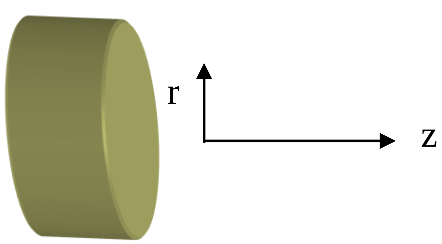
2.3 Temporal and Spatial Coherence

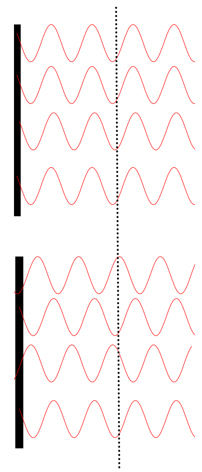
➢Temporal Coherence: The phase φ(t) can vary randomly with time.

The coherence time (τ_c) is defined as the mean interval between such random variations.



➢Spatial Coherence: The phase φ(r) can vary randomly with transverse distance of an extended source



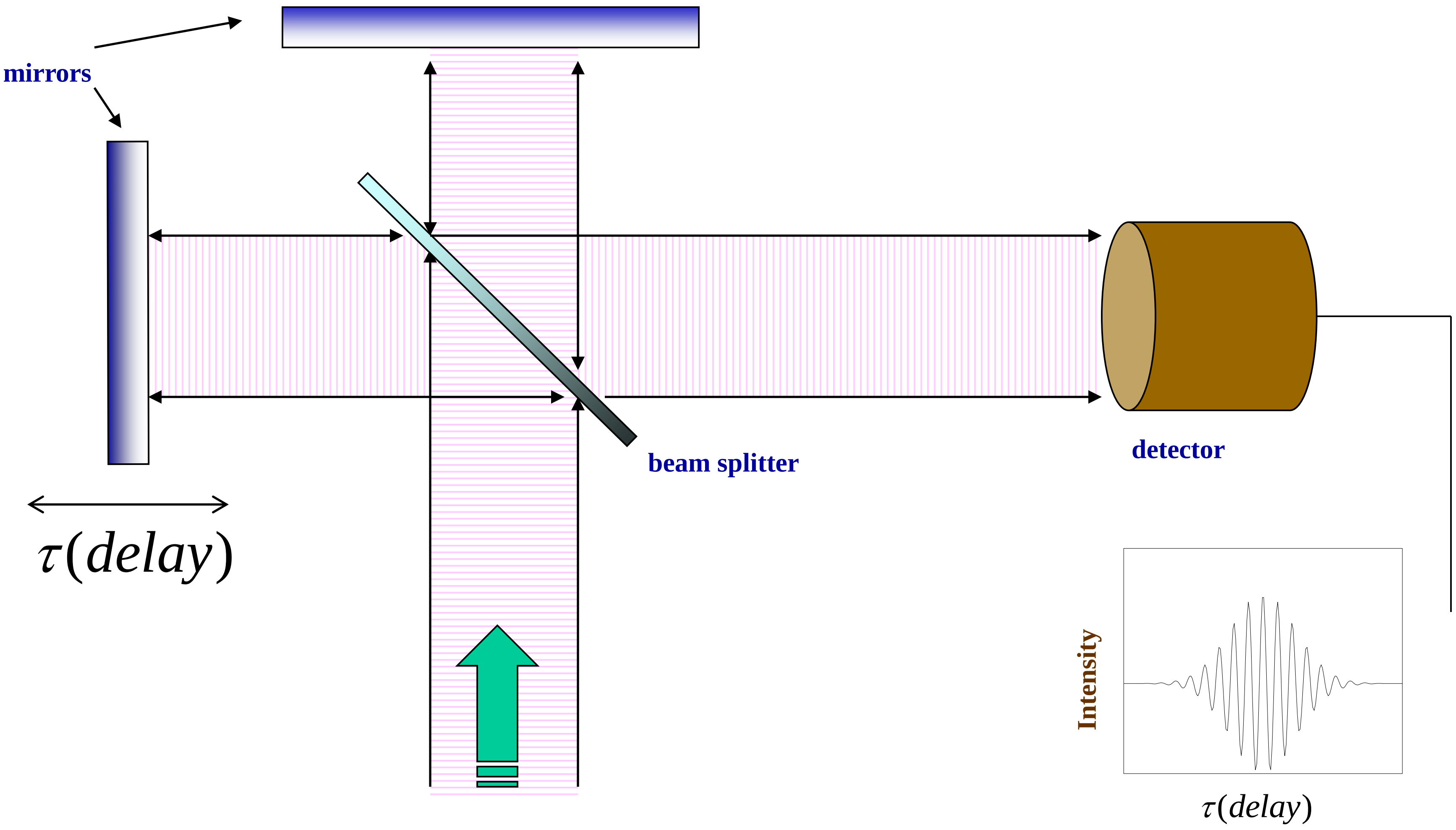


Spatially coherent

Spatially incoherent

Interferometers

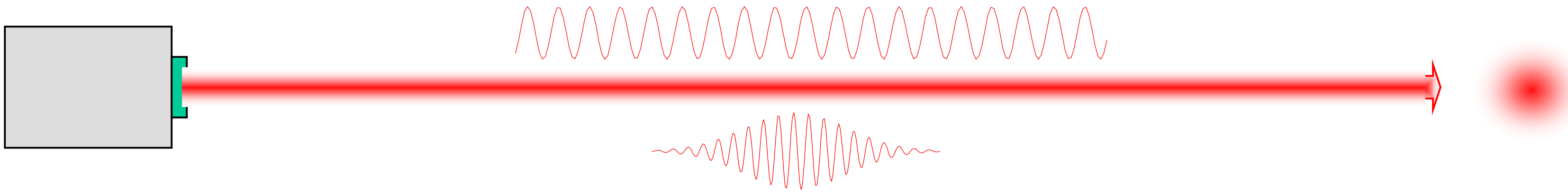
(Measuring the Coherence Properties of Light)



Example: ***Michelson Interferometer***

2.4 Properties of Laser Radiation

- High degree of temporal coherence (almost single wavelength)
- High degree of spatial coherence (highly directional, low divergence)
- Efficient (e.g., wall plug efficiencies of 50% in semiconductor lasers)
- Very very short pulses (<10 fs) have been generated
- High average (e.g. > 100 kW!) and peak powers (e.g. > 10 TW!) can be achieved



Laser versus white light bulb: a comparison