Fall 2014

University of New Mexico

Laser Physics I

PHYC/ ECE 464

Optical Science & Engineering

Mansoor Sheik-Bahae

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Phone: 277-2080
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To see me in my office, please make an appointment (call or email).

Class meeting times: Mondays, Wednesdays 17:30- 18:45 am;
Physics and Astronomy, Room 184

Textbook: **Laser Electronics** By Joseph T. Verdeyen

Reference Textbooks:
Optical Electronics in Modern Communications by Amnon Yariv,
Lasers by A. E. Siegman, Laser Fundamentals by William Silfvast

Pre-requisites: E&M, Undergraduate Physics, Modern Physics,
Knowledge of Differential Equations, Linear & Complex Algebra.

Teaching Assistant: **Behnam Abaei**

TA's Office Hours: Mondays 4:30-5:15 pm, PandA Lobby

Homework problem sets will be assigned on a regular basis throughout the semester, most likely one set per week.
Tests: There will be two exams: One Midterm and the Final Exam.

Tentative Test Date (subject to change): **Midterm: Wed. Oct. 15**
Grading: The final grade is weighted as follows:
Midterm: 35%
Final: 50%
Homework: 15%

COURSE SYLLABUS

1- Introduction (*historical overview)* [1 lecture]

2- Review of E&M theory (Chapter 1) [2 lectures]

3-Ray tracing *(ABCD matrix method)* **(Chapter 2) [3 lectures]**

4-Gaussian Beams (Chapter 3) [4 lectures]

5-Optical Cavities (Chapter 5 & 6) [2 lectures]

6-Gain Medium *(field-atom interaction)* **(Chapter 7) [5 lectures]**

7- Laser Oscillation (Chapter 8) [4 lectures]

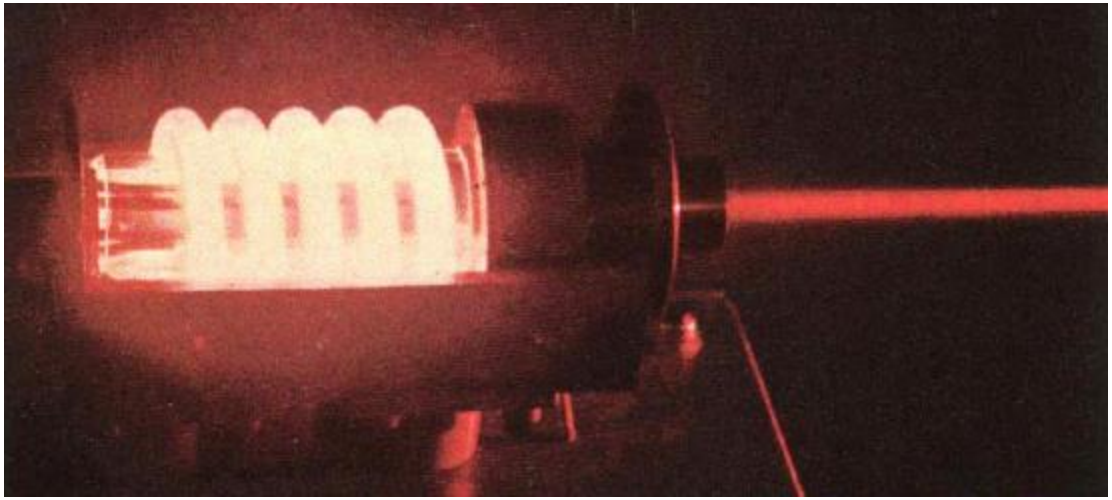
8- General Laser Characteristics (Chapter 9) [6 lectures]

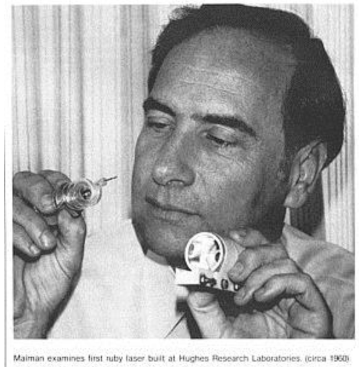
9- Various Laser Systems (Parts of Chapters 10 & 11) [3 lectures]

Introduction (*historical overview*)

Laser Turns ~~50~~ ~~52~~ 54!

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

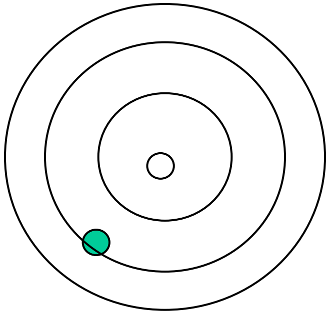




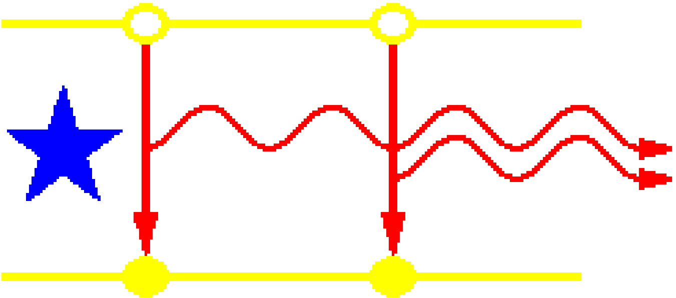
May 17, 1960
Ted Maiman

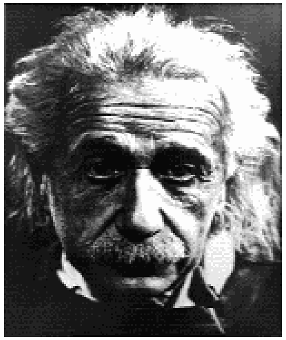
A Brief History of Laser

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

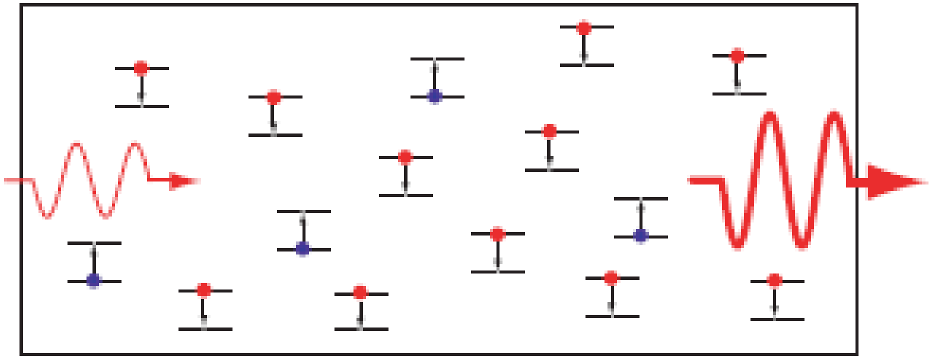


- Einstein postulated the principle of the "stimulated emission" (1917)



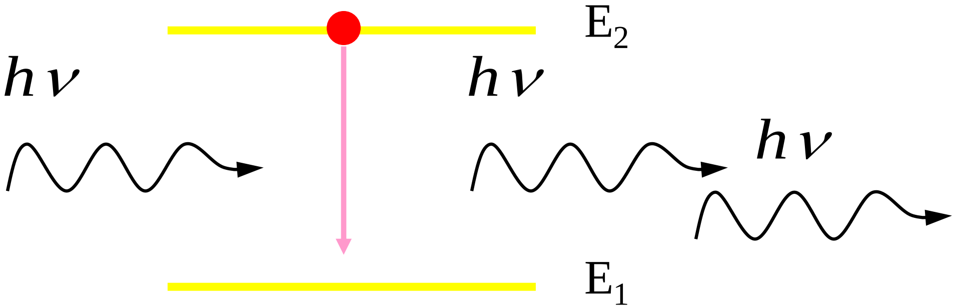


1924: Richard Tolman hints at amplification



"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?)*

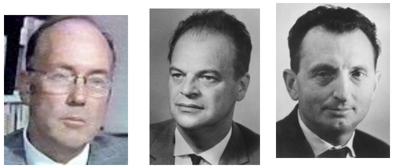
- (1928) Observation of negative absorption or stimulated emission near to resonant wavelengths, **Rudolf Walther Ladenburg**



Stimulated Emission (negative absorption)

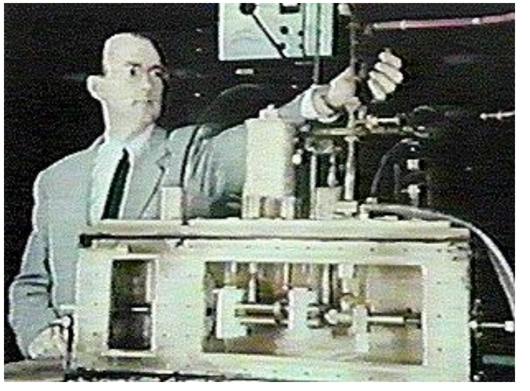
A Brief History of Laser

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



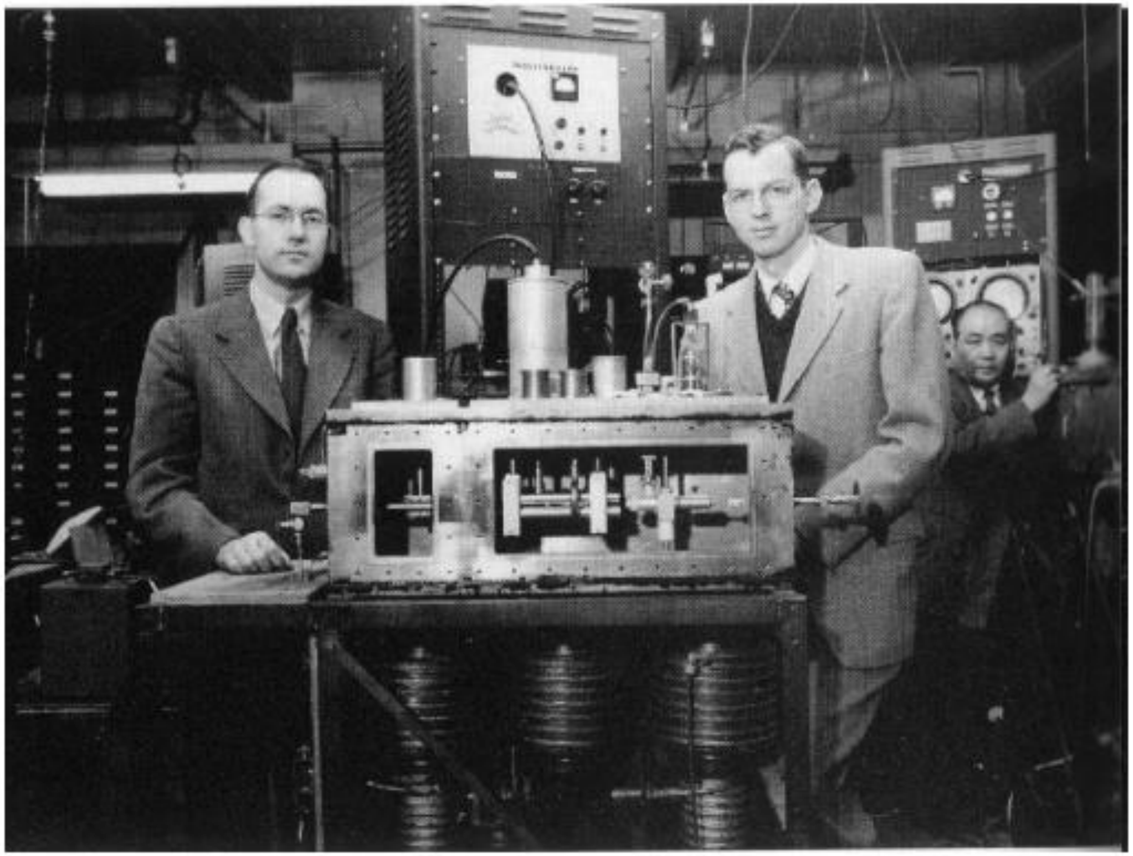
1951–1954: The Ammonia Maser

- 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 !*

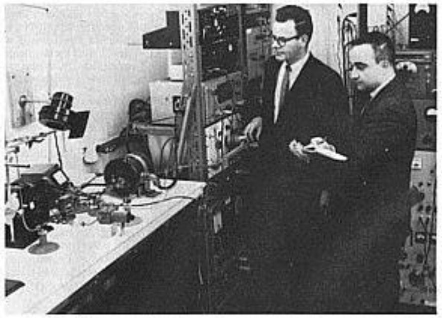
1954: Charles Townes and Jim Gordon: the NH3 maser



- 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*



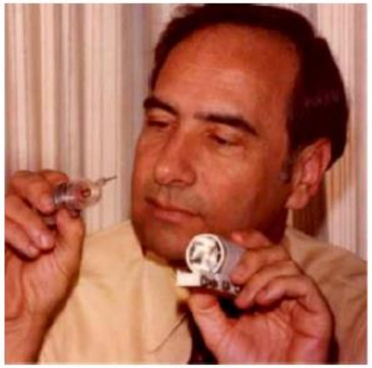
Gordon Gould and colleague in their laboratory.

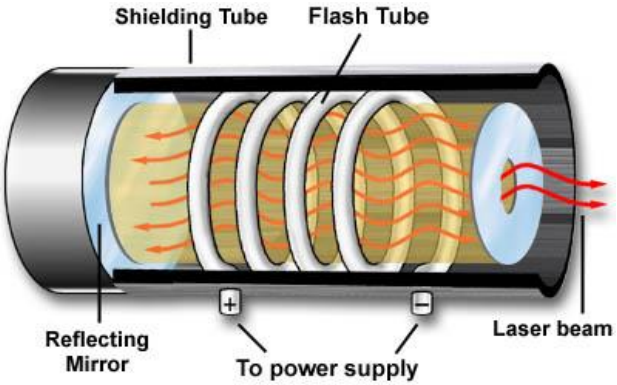
The Laser Happens!

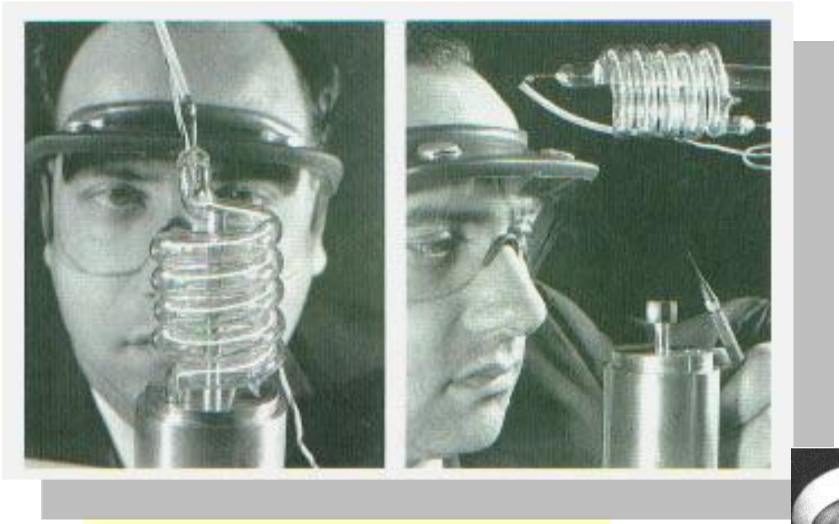
May 17, 1960

Theodore H. Maiman

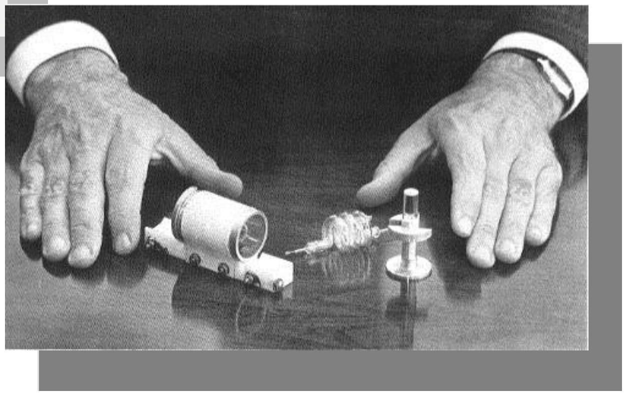
" Stimulated optical radiation in ruby " Nature Vol 187 p. 493 (Aug. 6 , 1960)







.....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."

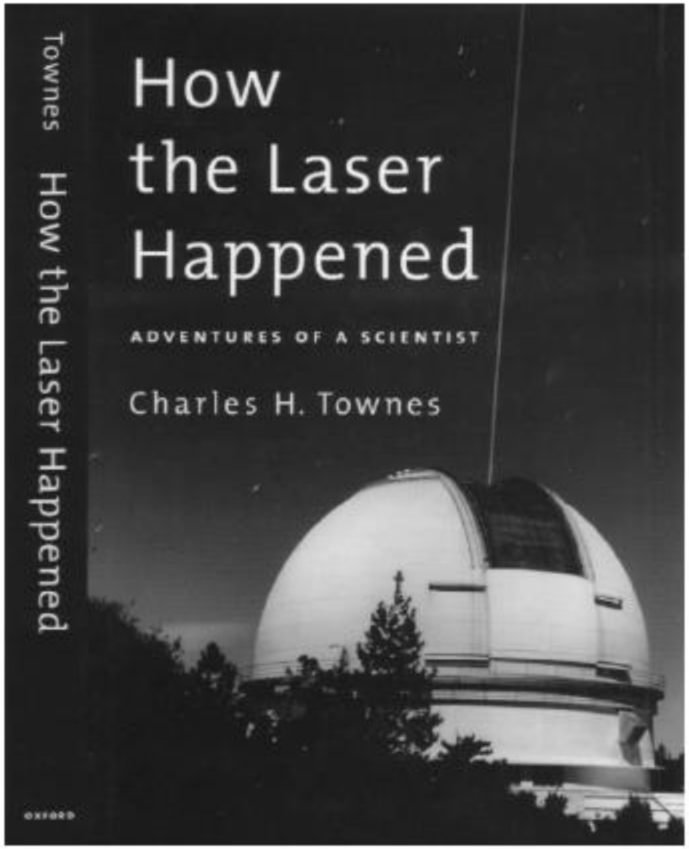
Joan Lisa Bromberg
The Laser in America, 1950—1979
Laser History Project / MIT Press, 1991

Laser was also once called:

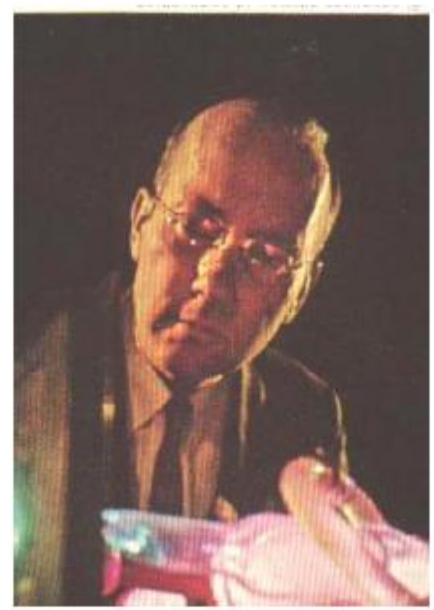
“solution looking for a problem!!”

http://www.imdb.com/video/wab/vi1636107033/

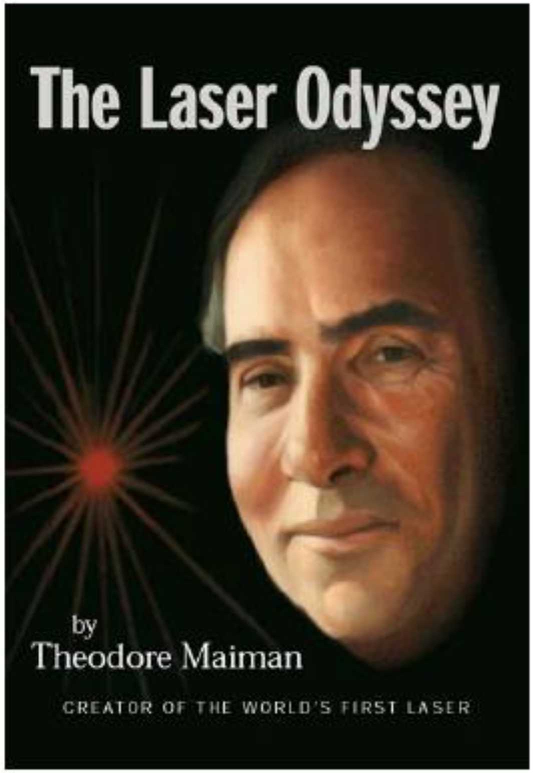
By: Lawrence Sutherland



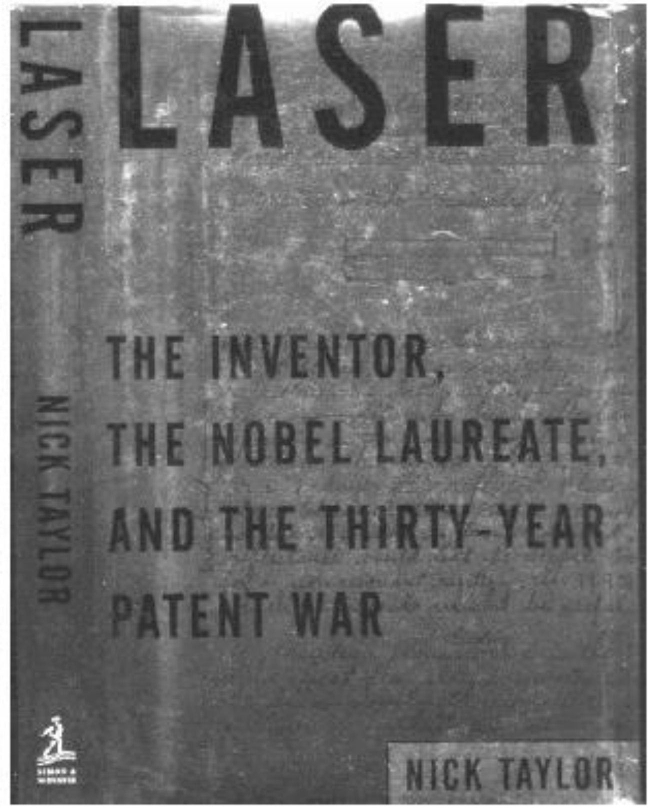
Charles Townes, *How the Laser Happened: Adventures of a Scientist* (1999)

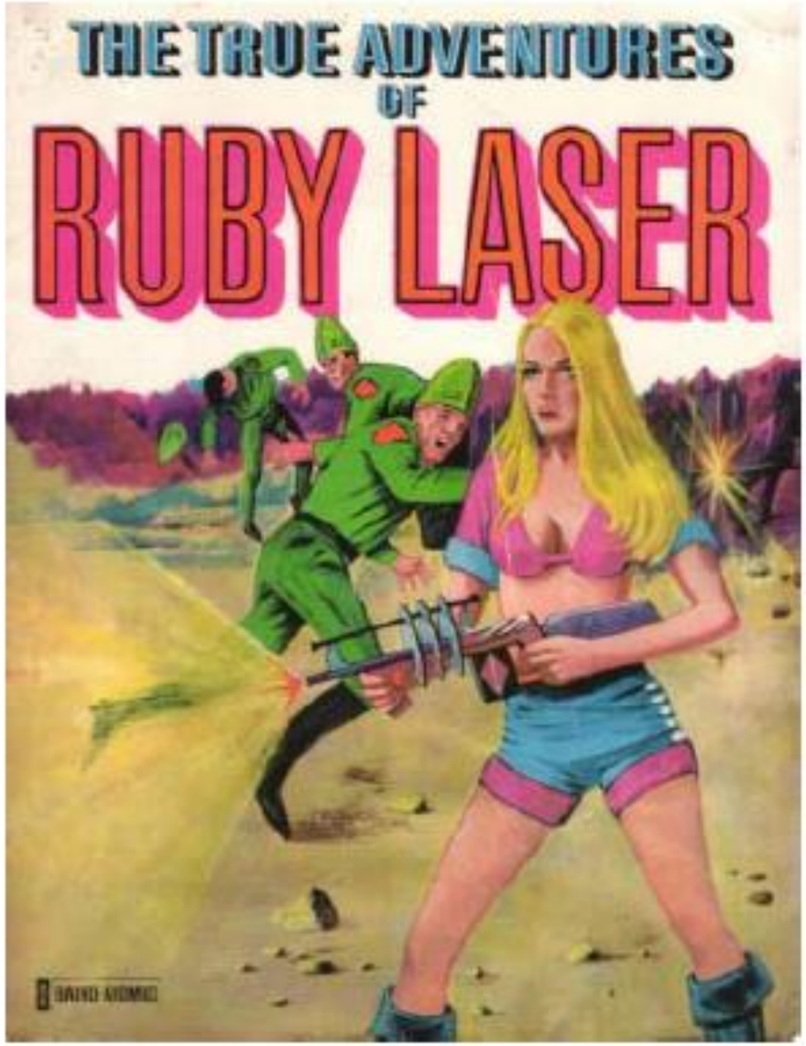


Theodore Maiman, *The Laser Odyssey (2000)*



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




THE TRUE ADVENTURES
OF
RUBY LASER

2.5 Main Components of a Laser

1. **Power Supply or Pump Source**

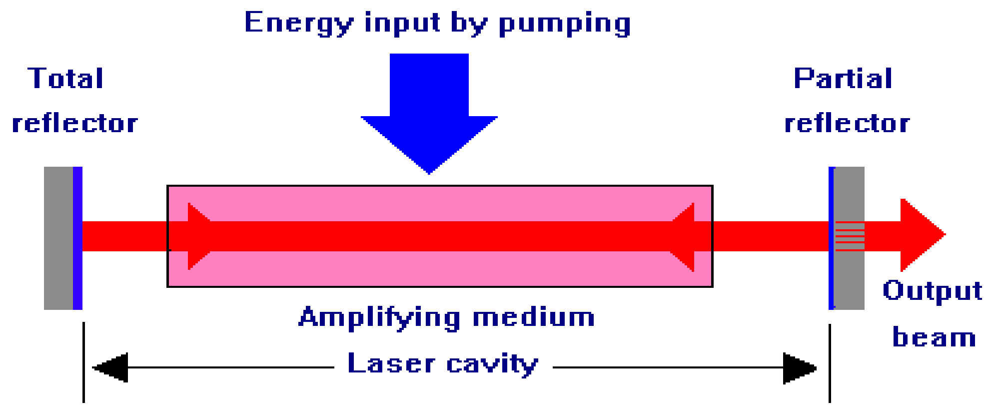
Examples are arc-lamp, another laser, electric discharge, chemical reaction, electrical current,

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

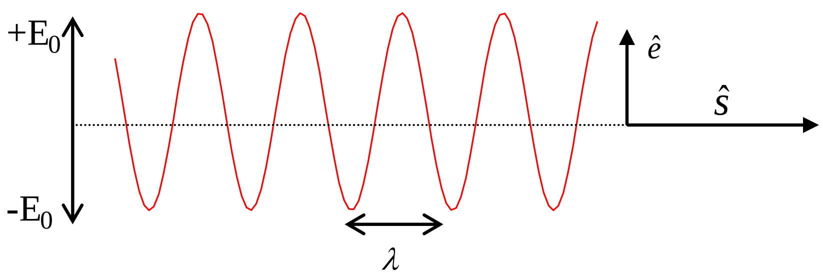
$\hat{e}$ = polarization vector

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

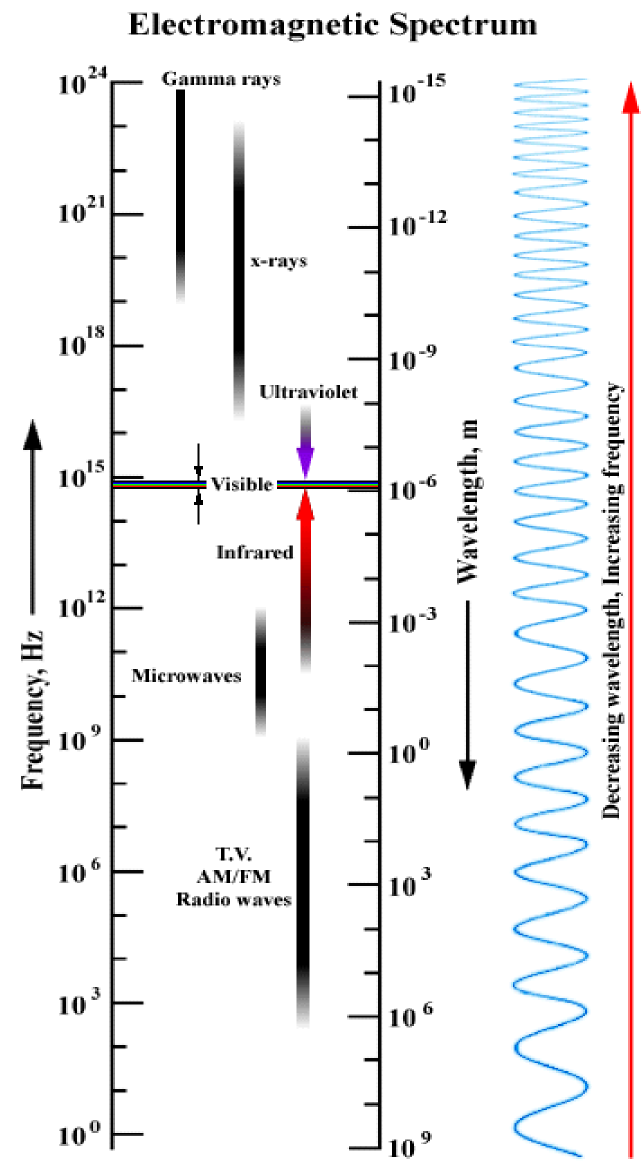
$\vec{k} = \frac{2\pi}{\lambda}\hat{s} = \frac{\omega}{c}\hat{s}$ = wavevector

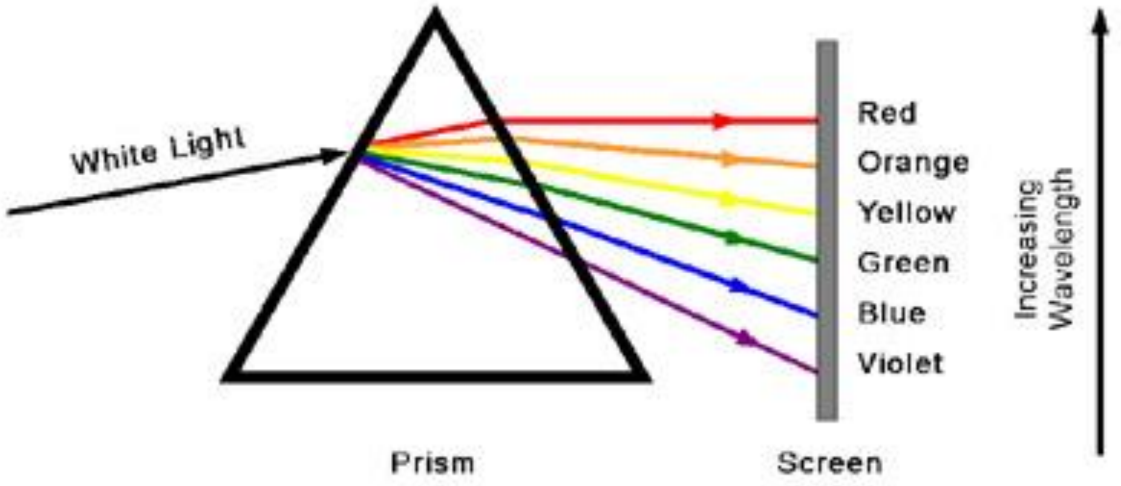
λ = wavelength

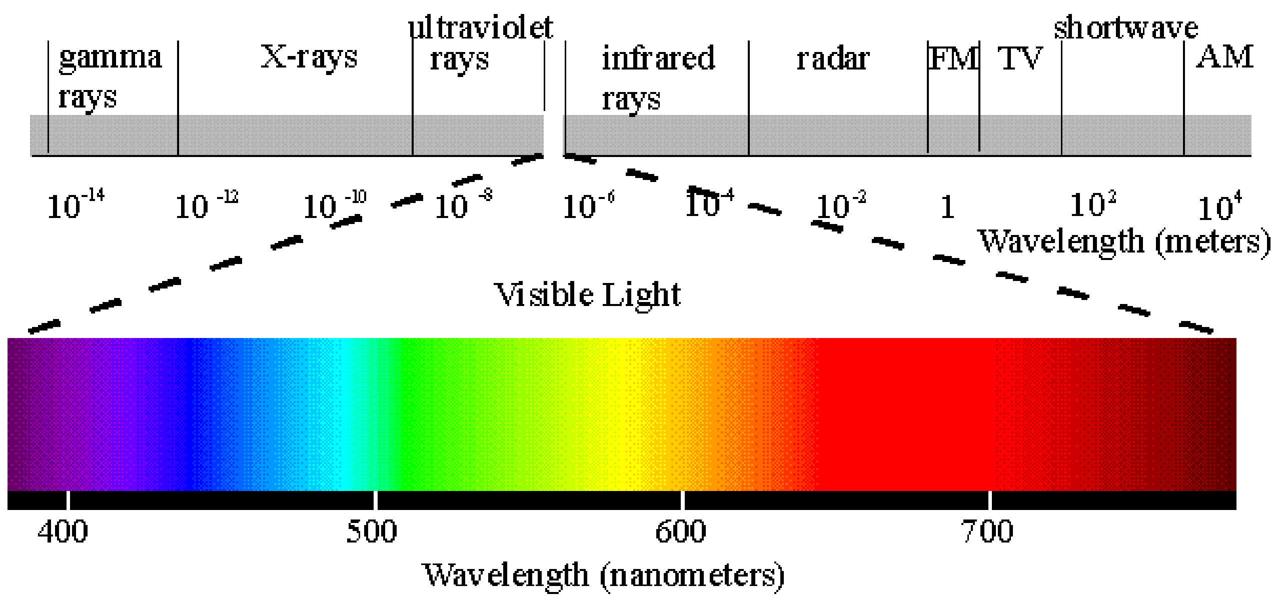
φ = phase



❖Propagation is governed by Maxwell's equations





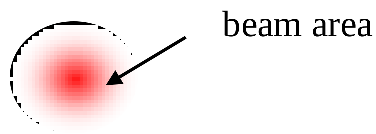


The electromagnetic spectrum
from "The Joy of Visual Perception: A Web Book"
http://www.yorku.ca/eye/

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)

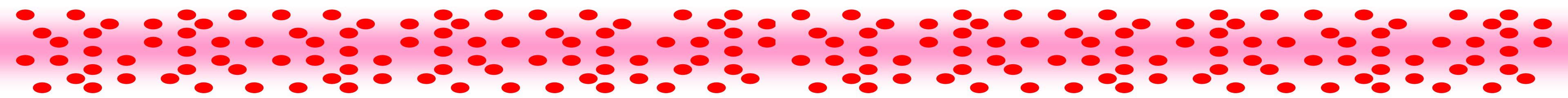
Another commonly used attribute of light:
Brightness= *Power/(Solid Angle.Frequency)*

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=6.63x10^{-34} J-sec*** *is the* ***Plank's constant.***



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

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

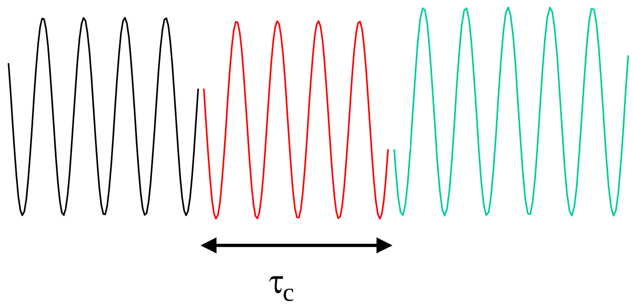
useful formulas: $\lambda(\mu m) \approx 1.24/E(eV)$

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

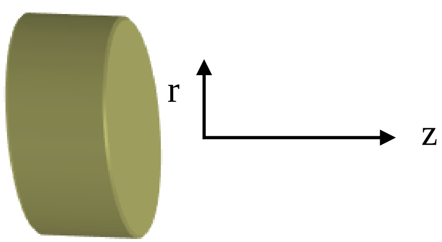
2.3 Temporal and Spatial Coherence

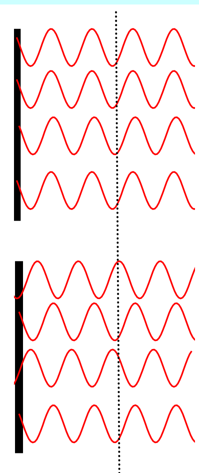
➢ Temporal Coherence: The phase φ(t) can vary randomly with time.

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



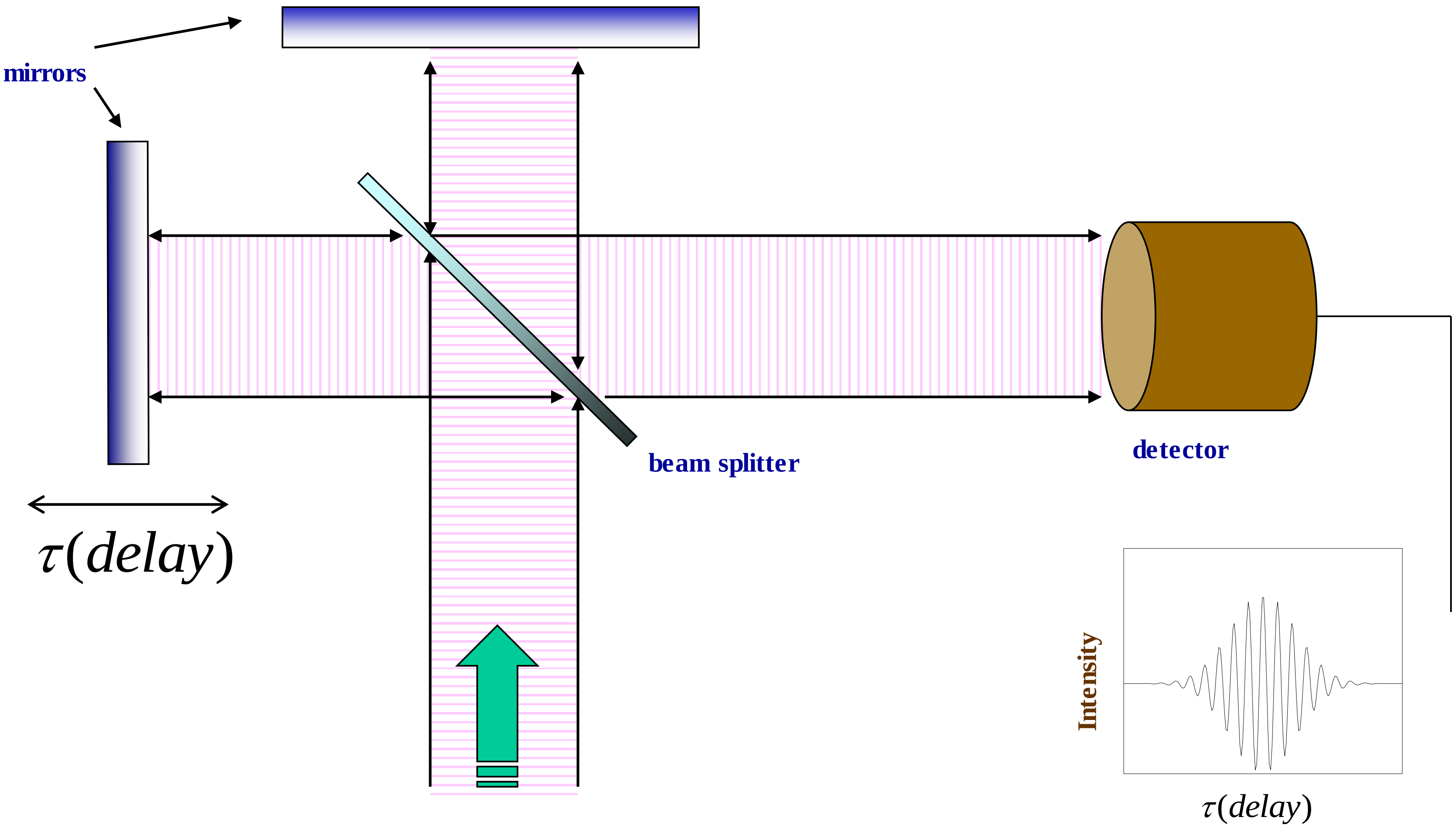


Spatially coherent

Spatially incoherent

Interferometers

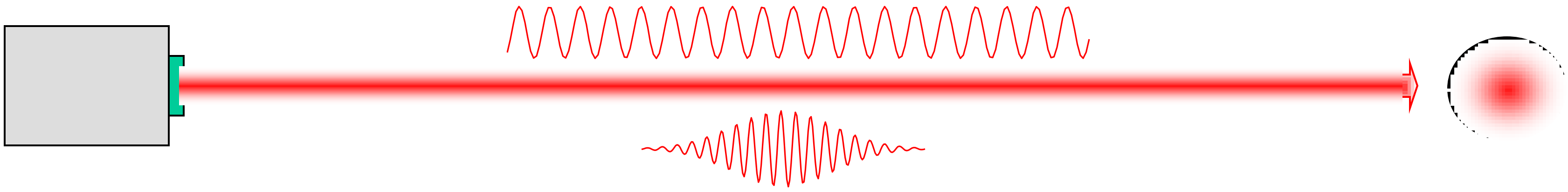
(Measuring the Coherence Properties of Light)



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