Laserfysik - Laser physics
SK2411: 7.5 ECTS points

Lecturers and examiners
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Course description
Lectures: 24 hours, Exercises: 12 hours.
Lab practice: Diode laser 2 hours, Diode-pumped solid-state laser 4 hours

Examination
Written exam (TEN1;5.5 hp) A/B/C/D/E/Fx/F
Lab reports (LAB1; 2 hp) P/F

Literature
Svelto, Orazio , Principles of Lasers, Fourth edition (Translation by David. C. Hanna)
Kluwer Academic/Plenum Press, Springer (1998 or later) ISBN 0-306-45748-2.

Lecture contents		
1	Introduction, background, history and applications. Interaction of radiation with atoms and ions	Chap. 1, 2
2	Essential spectroscopic characteristics of atomic and molecular media	Chap. 2, 3
3	Semiconductors as laser gain material	Chap. 3
4	Ray and wave propagation, modes of electromagnetic field	Chap. 4
5	Optical resonators	Chap. 5
6	Properties of laser beams	Chap. 11
7	Population inversion, pumping processes	Chap. 6
8	Continuous wave lasers	Chap. 7
9	Transient laser behavior, Q-switching, mode-locking	Chap. 8
10	Transformation of laser radiation: Nonlinear optics	Chap. 12
11	Types of lasers: solid state, semiconductor, dye, gas, chemical	Chap.9,10
12	Types of lasers continued. Summary of the course	

Scope of the Lecture

1. Introduction to main concepts
2. Approach to subject
3. Interaction between radiation and matter:
   3.1 Thermodynamic aspects
   3.2 Electronic transitions
   3.3 Spectroscopic Line-shapes
   3.4 Homogeneous and inhomogeneous broadening
4. Conclusions

<u>Reading</u>
Ch.1: 1.1, 1.2, 1.3, 1.4(1.4.1-1.4.3)
Ch.2: 2.2(2.2.2, 2.2.3), 2.3 (2.3.1-2.3.3), 2.4(2.4.1, 2.4.2*,2.4.3, 2.4.4*), 2.5(2.5.1, 2.5.2)

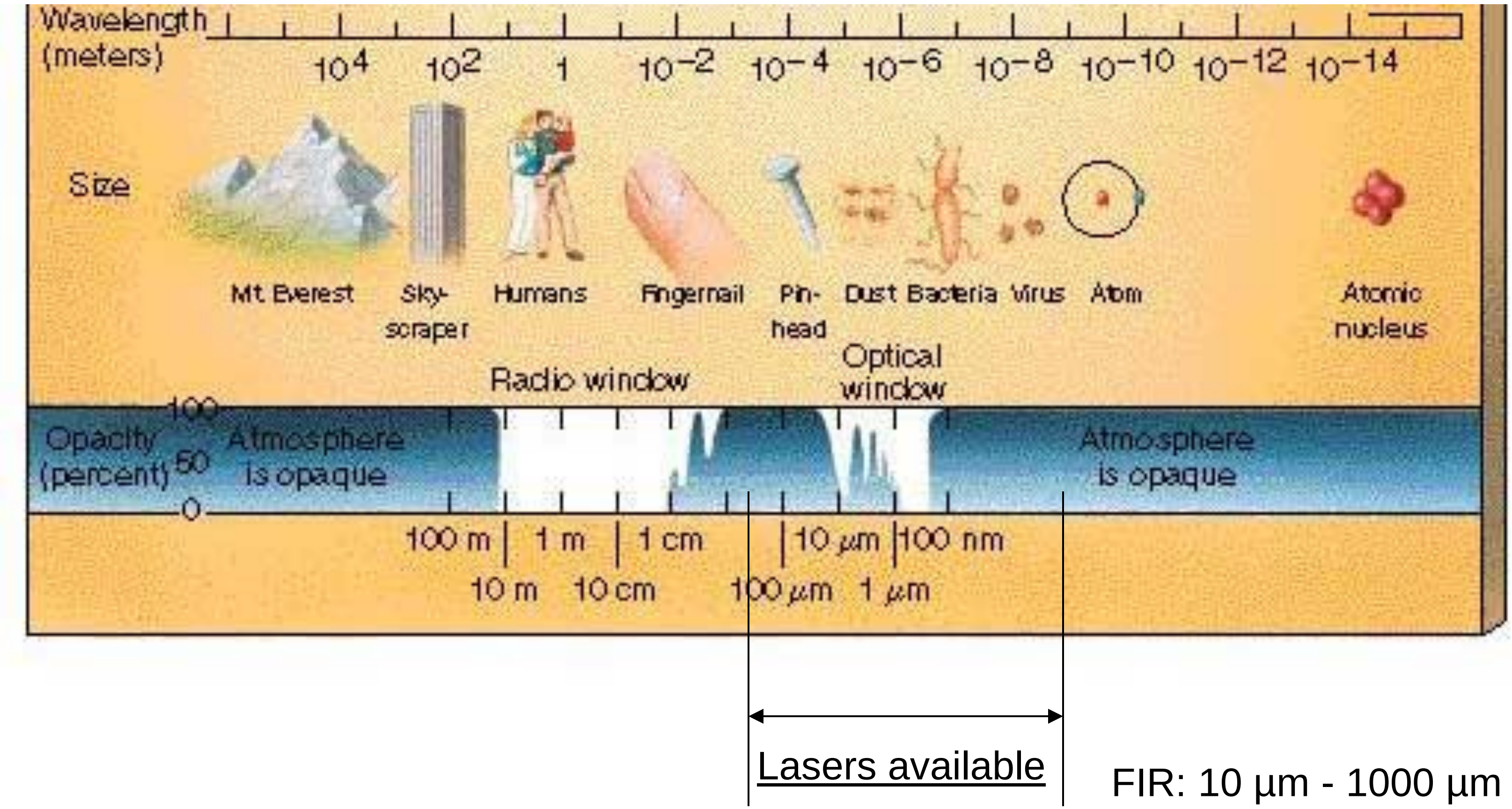
INTERNATIONAL YEAR OF LIGHT 2015

Applications

- **Material processing**: 3D printing, welding, cutting, marking, cleaning...
- **Biomedicine**: imaging, surgery, diagnostics…
- **Defense**: sensing, countermeasures, weapons, targeting…
- **Entertainment**: CD, DVD, displays, lighting…
- **Communications**: optical fibre communications, inter-chip communication...
- **Research**: in all subjects of natural science, material science and medicine...
- **Standards**: precision frequency measurement, optical clocks…
- **Aerospace**: Imaging, ranging…
- **Environmental** monitoring: pollution detection, airborne and spaceborne LIDARs…

The list is growing fast

Spectral ranges



$$\mu m = 10^{-6} m$$

$$nm = 10^{-9} m$$

$$\AA = 10^{-10} m$$

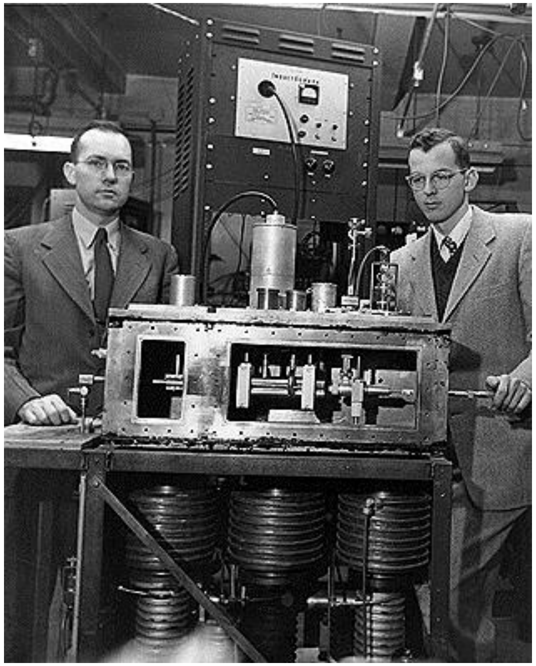
FIR: 10 µm - 1000 µm
MIR: 2 µm - 10 µm
NIR: 0.7 µm - 2 µm
VIS: 400 nm - 700 nm
UV: 200 nm - 400 nm
VUV: 100 nm - 200 nm
EUV: 10 nm -100 nm
Soft X rays: 1 nm -30 nm

Highlights of laser development story

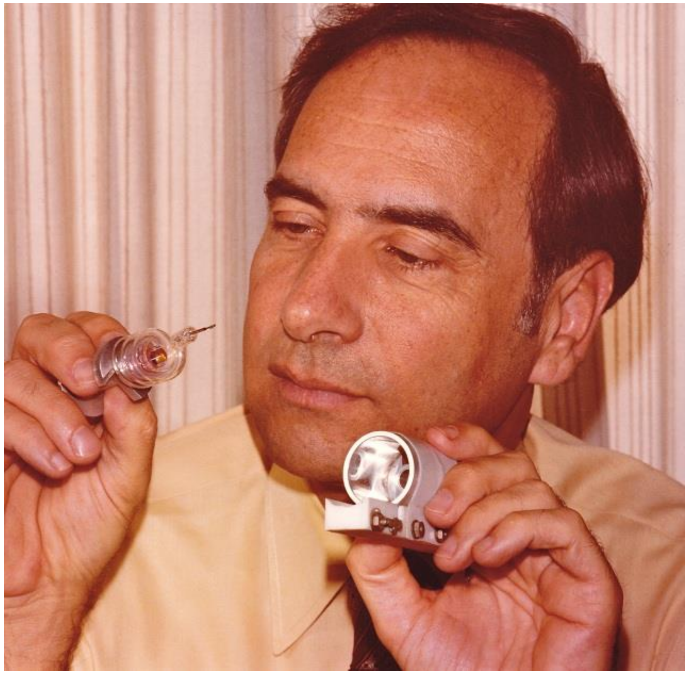
<u>Pioneering work:</u>

- Infrared and Optical Masers
  A. L. Schawlow and C. H. Townes
  Bell Telephone Laboratories, Murray Hill, New Jersey
Received 26 August 1958 Phys. Rev., 112, p.1940-1949.

- T. Maiman, "Stimulated Optical Radiation in Ruby," Nature (London) 187, 493 (1960)

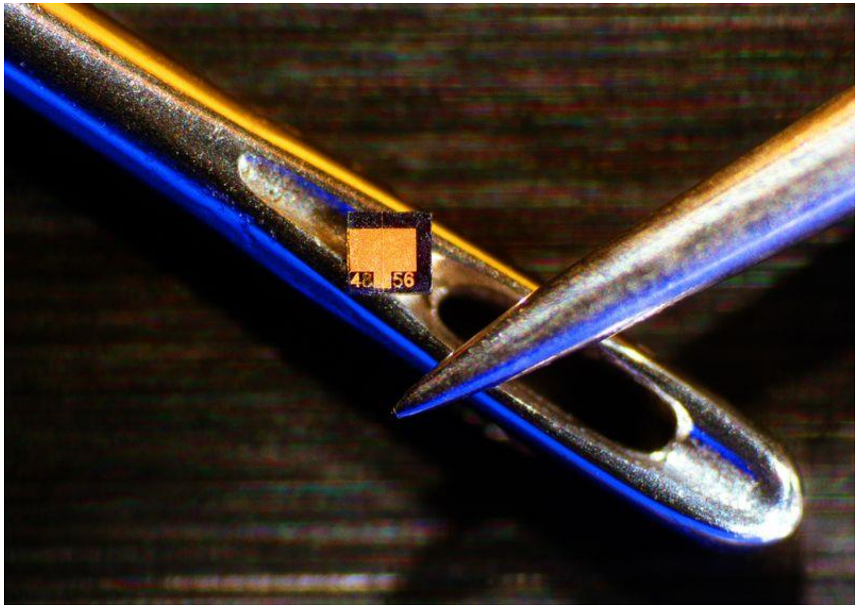


Ch. Townes, J. Gordon, Columbia U., 1953



Th. Maiman, 1985

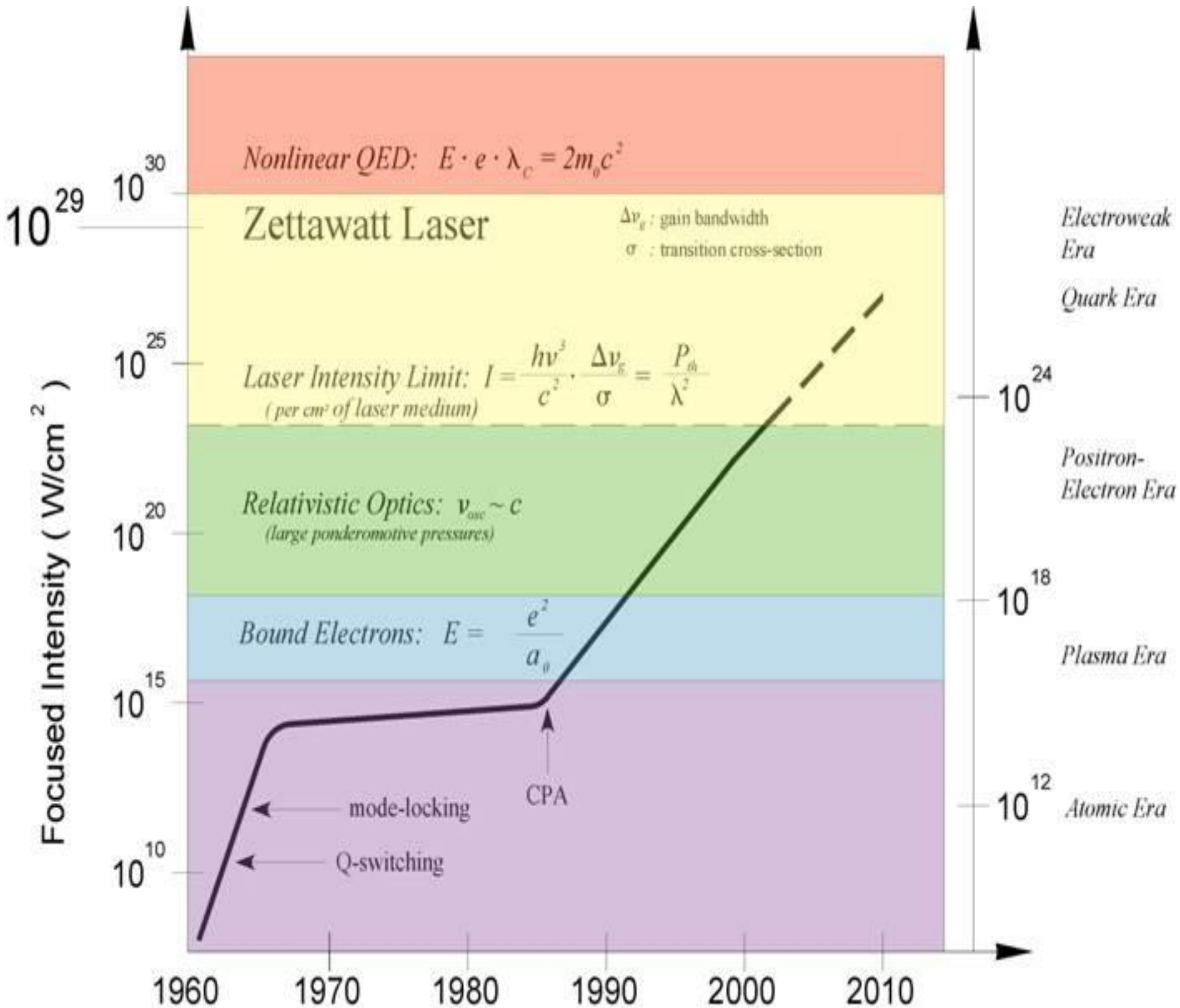
Range of energies and sizes



Laser diode: 10 pJ (10^{-11} J), <10€

LLNL NIF:
192 beams 4 MJ (NIR), 1.85 MJ (UV), 500 TW (2012), 3.5 b$

Story of Intensities



$$Power = \frac{Energy}{Pulselength}$$

$$Intensity = \frac{Power}{Beam\ Area}$$

$$\mu s = 10^{-6}\, s$$

$$ns = 10^{-9}\, s$$

$$ps = 10^{-12}\, s$$

$$fs = 10^{-15}\, s$$

$$as = 10^{-18}\, s$$

Highlights of laser success story

11 Nobel prizes:

• 2018 Arthur Ashkin: Optical tweezers, Gerard Mourou, Donna Strickland: Chirped pulse amplification.

• 2017 Kip Thorne, Rainer Weiss, Barry Barish: Gravitational wave detection with laser interferometer

• 2014 - Eric Betzig, Stefan W. Hell, William E. Moerner: Super-resolution fluorescence microscopy

• 2014 - Isamu Akasaki, Hiroshi Amano, Shuji Nakamura: Blue light emitting diodes

• 2009 - Charles K. Kao: ground-braking research in fibers for optical communications

• 2005 - Roy J. Glauber: quantum theory of optical coherence

• 2005 - John L. Hall,Theodor W. Hänsch: frequency comb generation with mode-locked lasers

• 2000 - Zhores I. Alferov,Herbert Kroemer: heterojunction semiconductor devices (lasers)

• 1997 - Steven Chu, Claude Cohen-Tannoudji, William D. Phillips: laser cooling of atoms

• 1981 - Nicolaas Bloembergen, Arthur Leonard Schawlow: precision laser spectroscopy

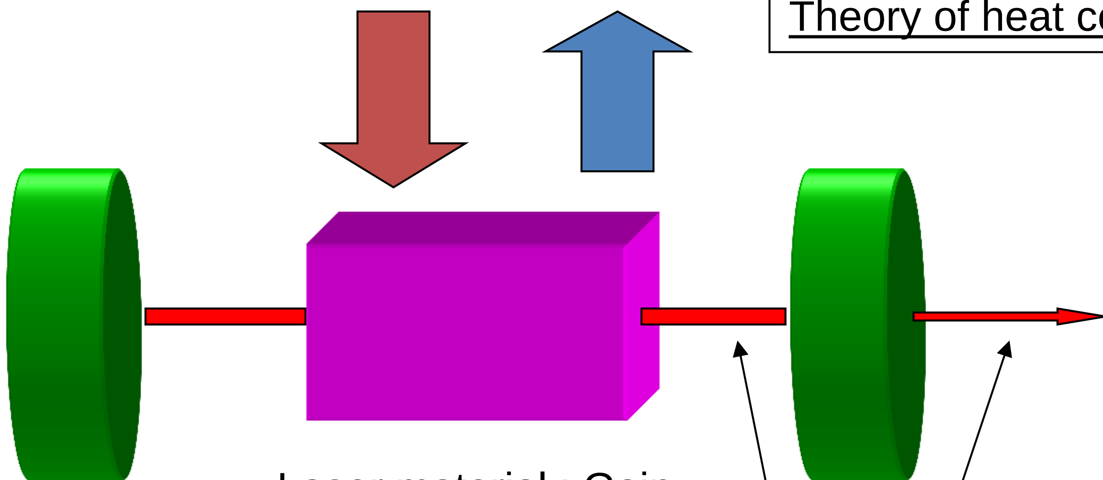
• 1964 - Charles H. Townes, Nicolay G. Basov, Aleksandr M. Prokhorov:
"for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle"

Field overview

Energy in: Pump

Energy out: Heat

Theory of heat conduction



Laser material : Gain

Feedback: Cavity

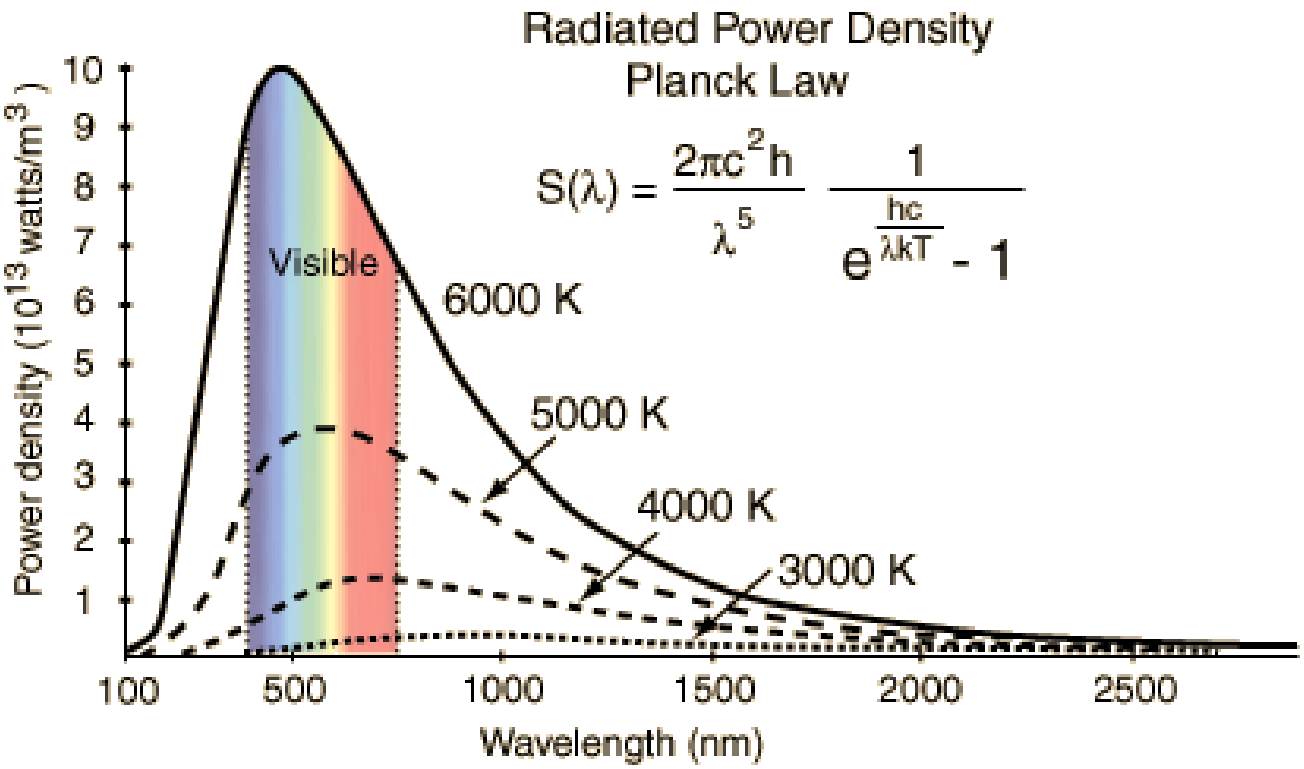
Radiation

Boundary conditions:
- Longitudinal modes
- Spatial modes
- Coherence

Light-matter interaction:
- Quantum mechanics:
  Electronic, vibrational, rotational transitions
- Quantum theory or light

Theory of electromagnetic radiation:
- Maxwell equations
- Wave equations
- Nonlinear coupled wave equations

Blackbody radiation



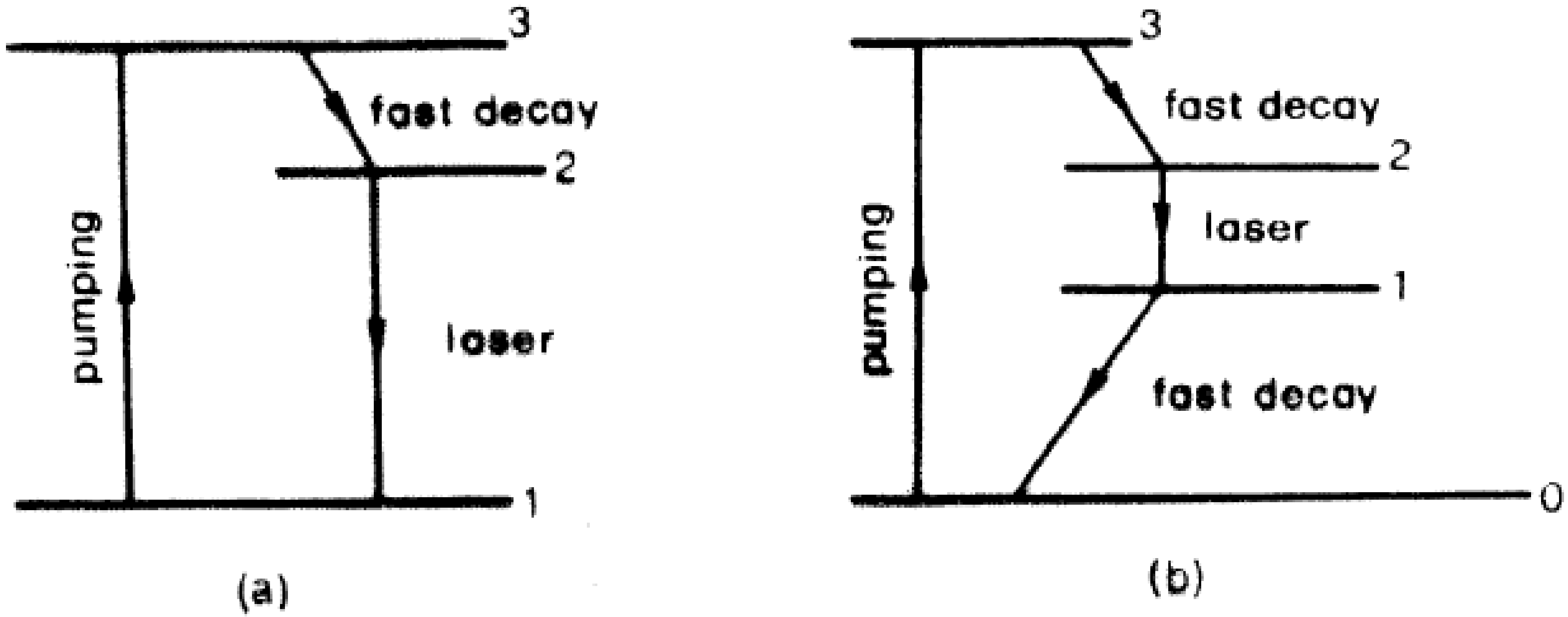
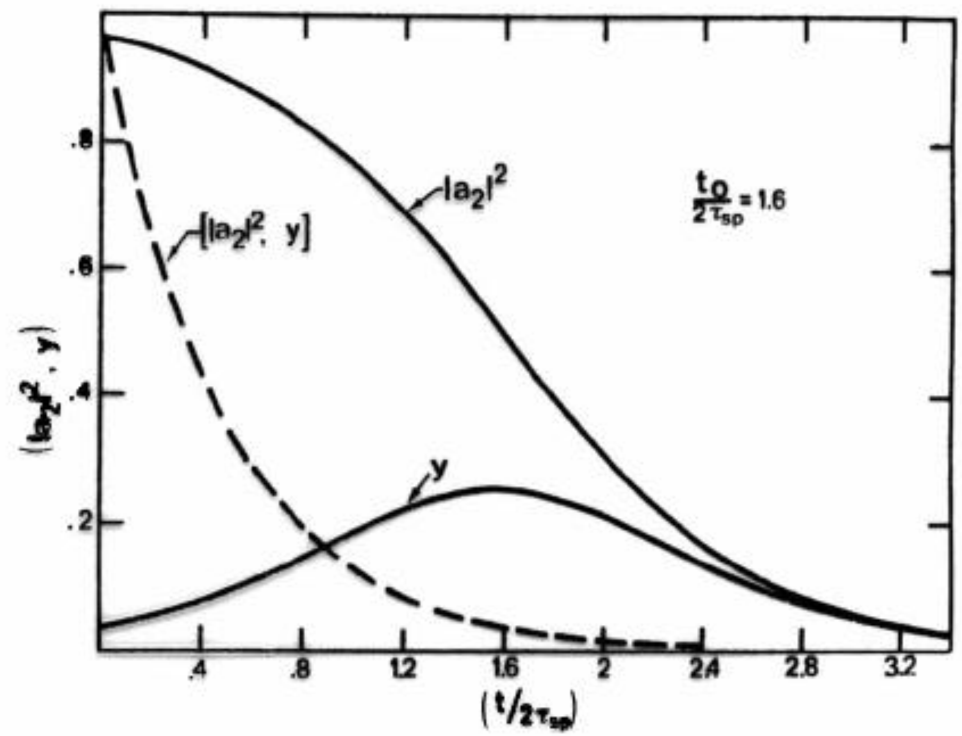
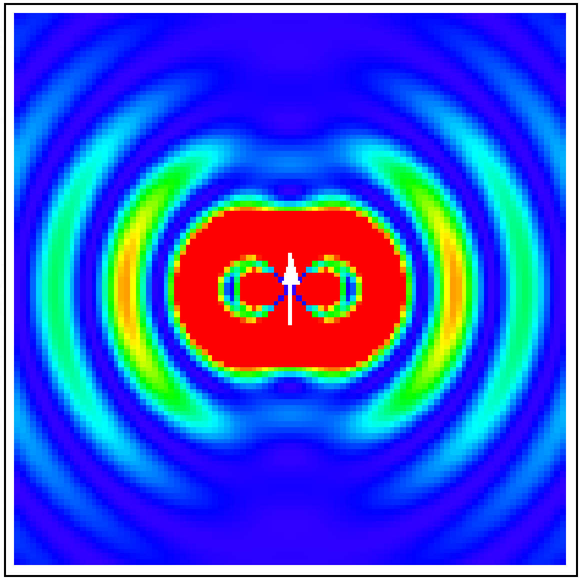


FIG. 1.4. (a) Three-level and (b) four-level laser schemes.





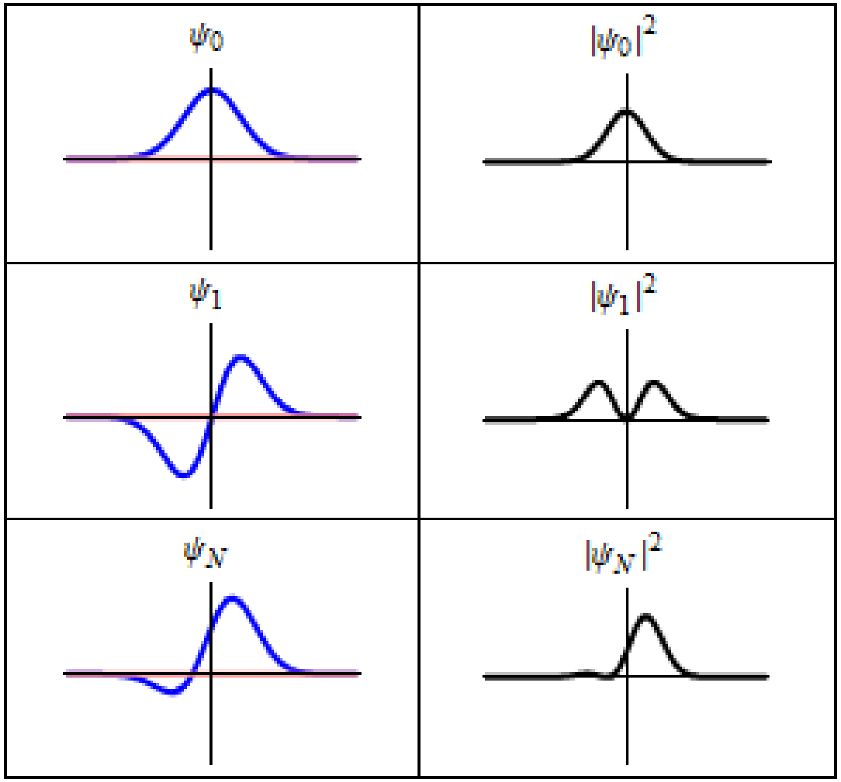
2.5. Time behavior of the upper state occupation probability $|a_2|^2$ and of the normalized radiated power $t_{sp}P_r/h\nu_0$. Continuous lines: semiclassical results. Dashed line: quantum result.

Transitions, parity, dipole approximation

even $l=0$

odd $l=1$

Superposition



Transition rate (Fermi Golden Rule):

$$W_{if} = \frac{2\pi}{\hbar} \left| M_{if} \right|^2 \rho_f$$

$$M_{if} = \int \psi_f^* e\vec{r}\, \psi_i d\vec{r}$$

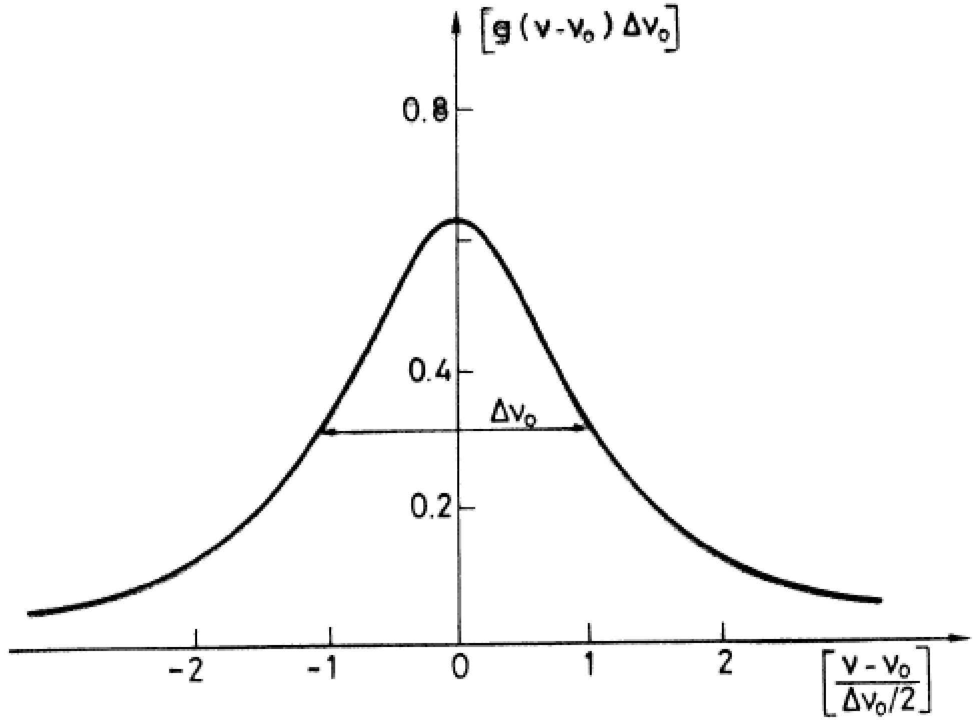


FIG. 2.6. Normalized plot of a Lorentzian line.

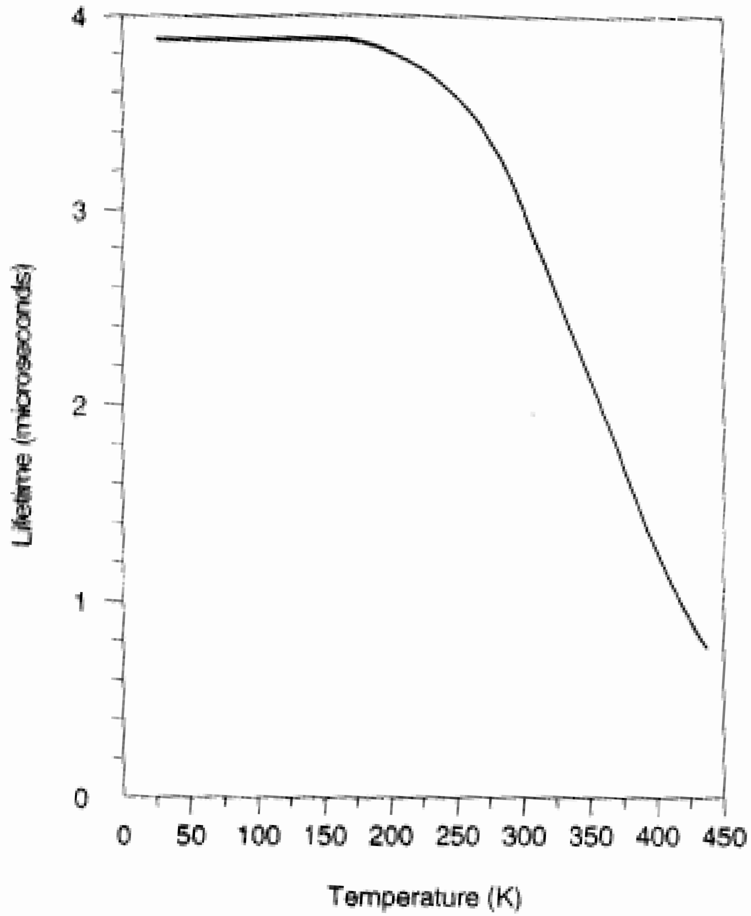


Figure 4-6 Decay time of the upper laser level of a titanium sapphire laser material as a function of temperature (K)

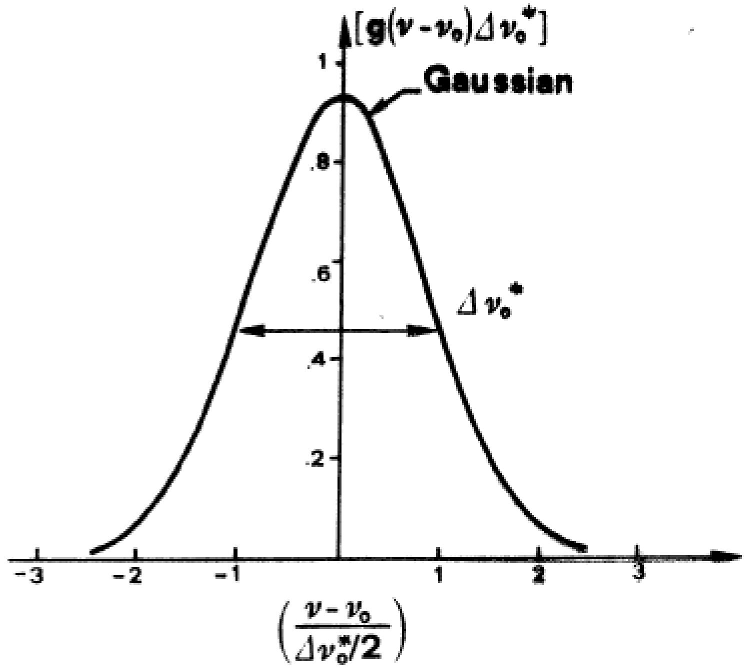


FIG. 2.8. Normalized plot of a Gaussian line.

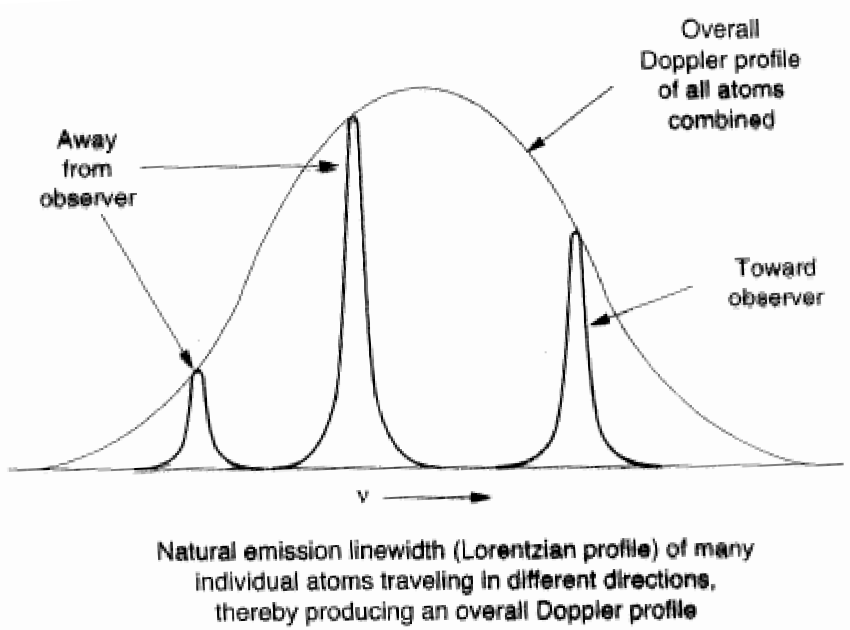


Figure 4-12 Shape of a Doppler-broadened emission line, indicating the natural emission linewidths of individual atoms radiating while traveling in various directions

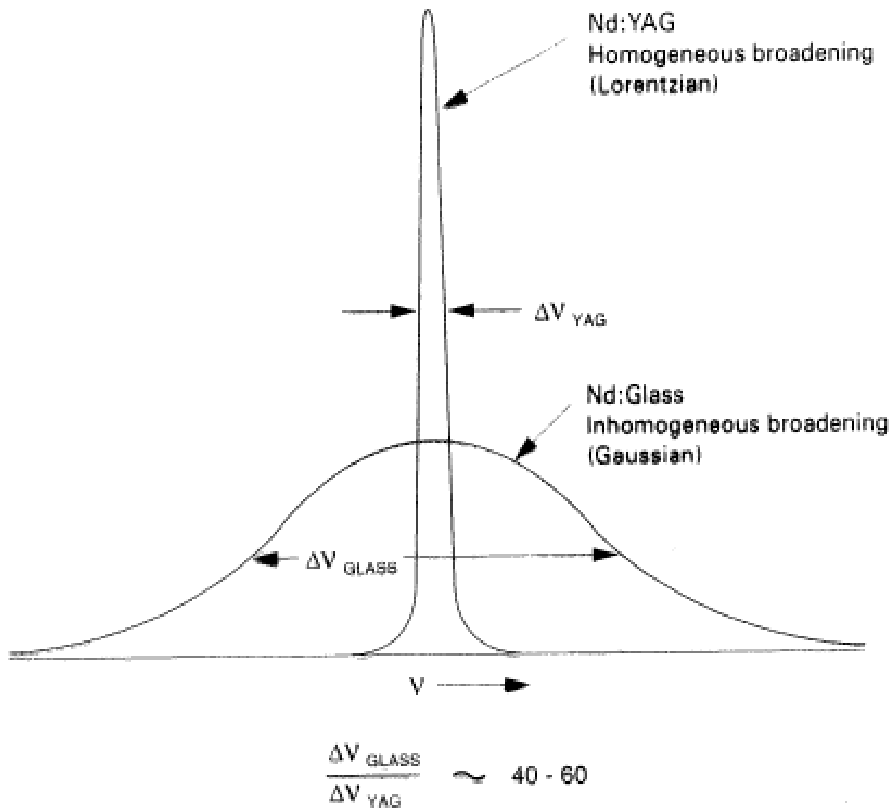


Figure 4-11 Relative emission linewidths of a radiating Nd ion doped into either a YAG crystal or a glass material

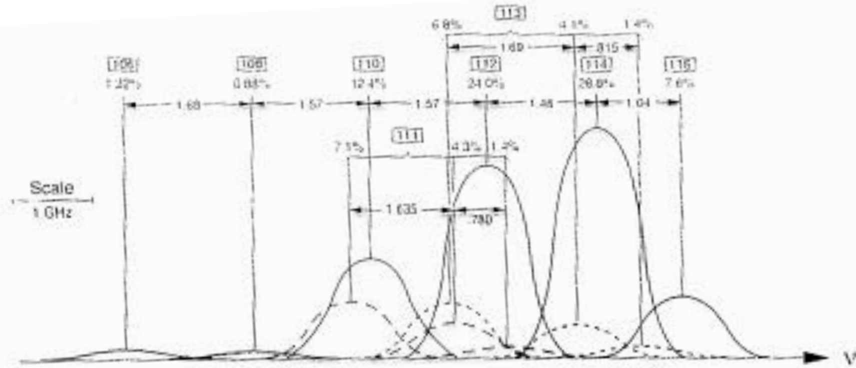


Figure 4-15(a) Emission lineshapes of the various isotopes of the cadmium 441.6-nm laser transition from a naturally occurring isotopic mixture

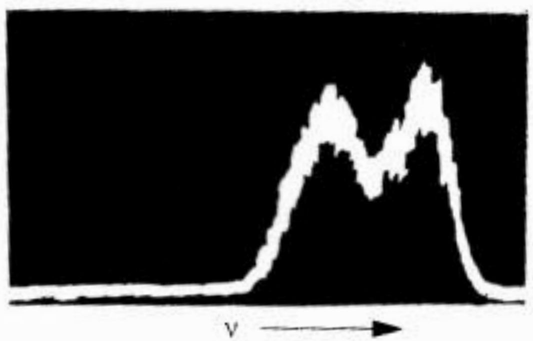


Figure 4-15(b) Laser output at 441.6 nm from a natural isotopic mixture of Cd

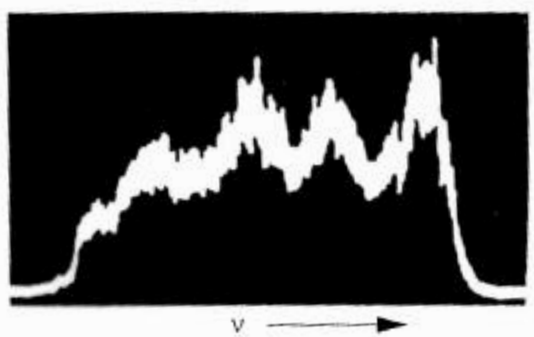


Figure 4-15(c) Laser output at 441.6 nm from a special isotopic mixture of Cd in which the contributions from the various isotopes are uniform

Main keywords from the Lecture1:

Absorption, speontaneous and stimulated emission,
Absorption and emission cross sections,
Population inversion,
Laser cavity loss, laser oscillation threshold,
Four-level and three-level lasers,
Coherence, brightness, directionality, monochromaticity,
Cavity modes of the em field,
Allowed and forbidden electric dipole transitions,
Natural linewidth,
Homogeneously and inhomogeneously broadened linewidths,
Gain

Problems

1.3, 1.4, 1.5, 1.7, 2.3, 2.7
Examples 2.1, 2.4