Laserfysik - Laser physics

SK2411, IO2659: 7.5 ECTS points

Lecturers and examiners

Valdas Pasiskevicius, Laser physics, Albanova (Fysikcentrum), Roslagstullsbacken 21 (room A3:1049), vp@laserphysics.kth.se, tel. 5537 8155.

Min Yan, Photonics, KTH, Kista, miya@kth.se, tel. 7904064

Labs: Fredrik Laurell, fl@laserphysics.kth.se Laser physics, Albanova

Assistants

Niels Meiser, Albanova, room A3:1059, nm@laserphysics.kth.se, tel. 5537 8192
Gustav Lindgren, Albanova, room A3:1061, ks@laserphysics.kth.se, tel.5537 8157
Nicky Thilmann, Albanova, room A3:1067, nt@laserphysics.kth.se, tel.5537 8812

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)

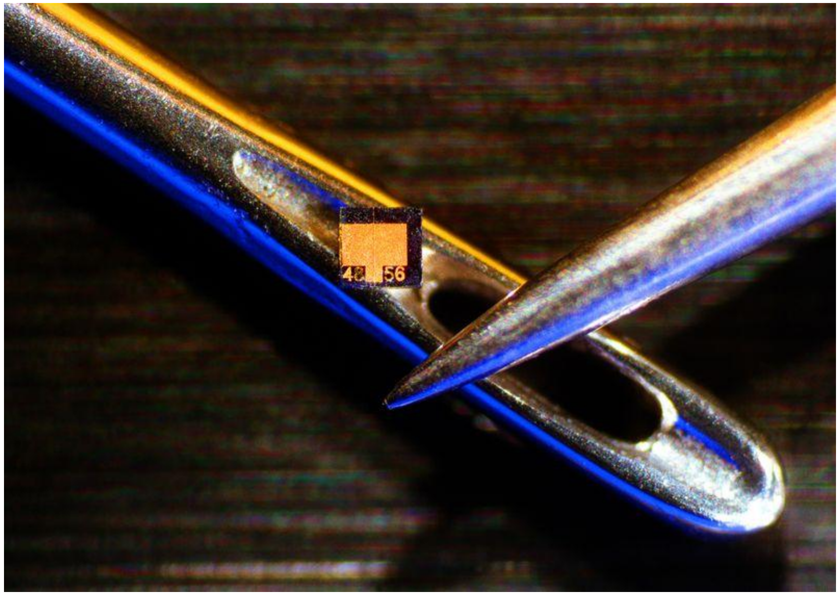
Ch.2: 2.2(2.2.2, 2.2.3), 2.3 (2.3.1-2.3.3), 2.4(2.4.1, 2.4.2*,2.4.3, 2.4.4*), 2.5(2.5.1, 2.5.2)

Applications

- Heavy industry: welding, cutting, marking, cleaning...
- Medicine: surgery, diagnostics…
- Defence: sensing, weapons, targeting…
- Entertainment: CD, DVD, displays, lighting…
- Communications: optical fibre communications, inter-chip communication...
- Research: in all subjects of natural science and medicine...
- Standards: precission frequency measurement, optical clocks (?)…
- Aerospace: Imaging, ranging…

The list is growing fast

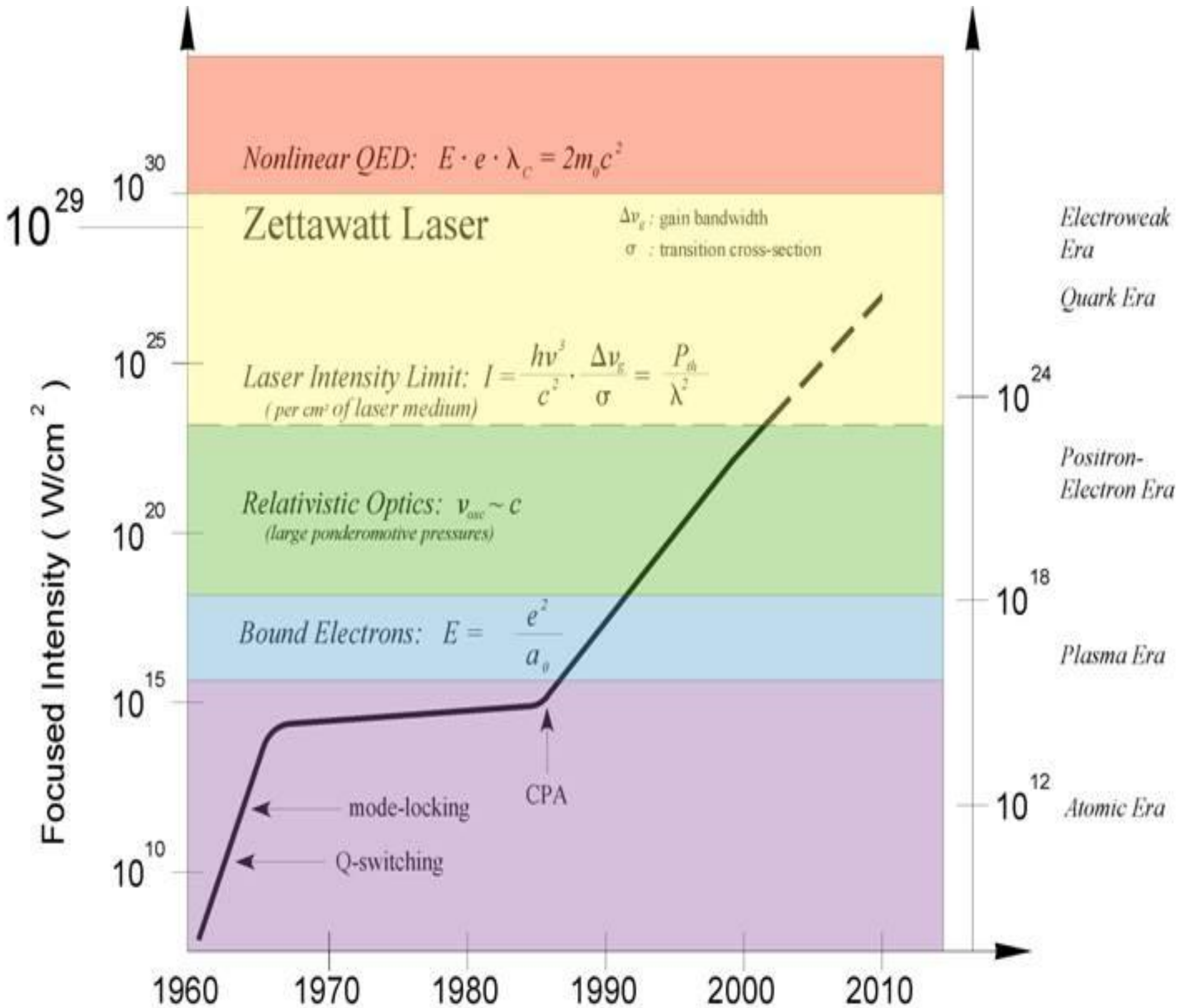
Range of energies and sizes



Laser diode: 10 pJ (10^{-11} J)

LLNL NIF: 4 MJ ($4x10^6$ J) planned
Record: 152 kJ

Story of Intensities



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

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

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

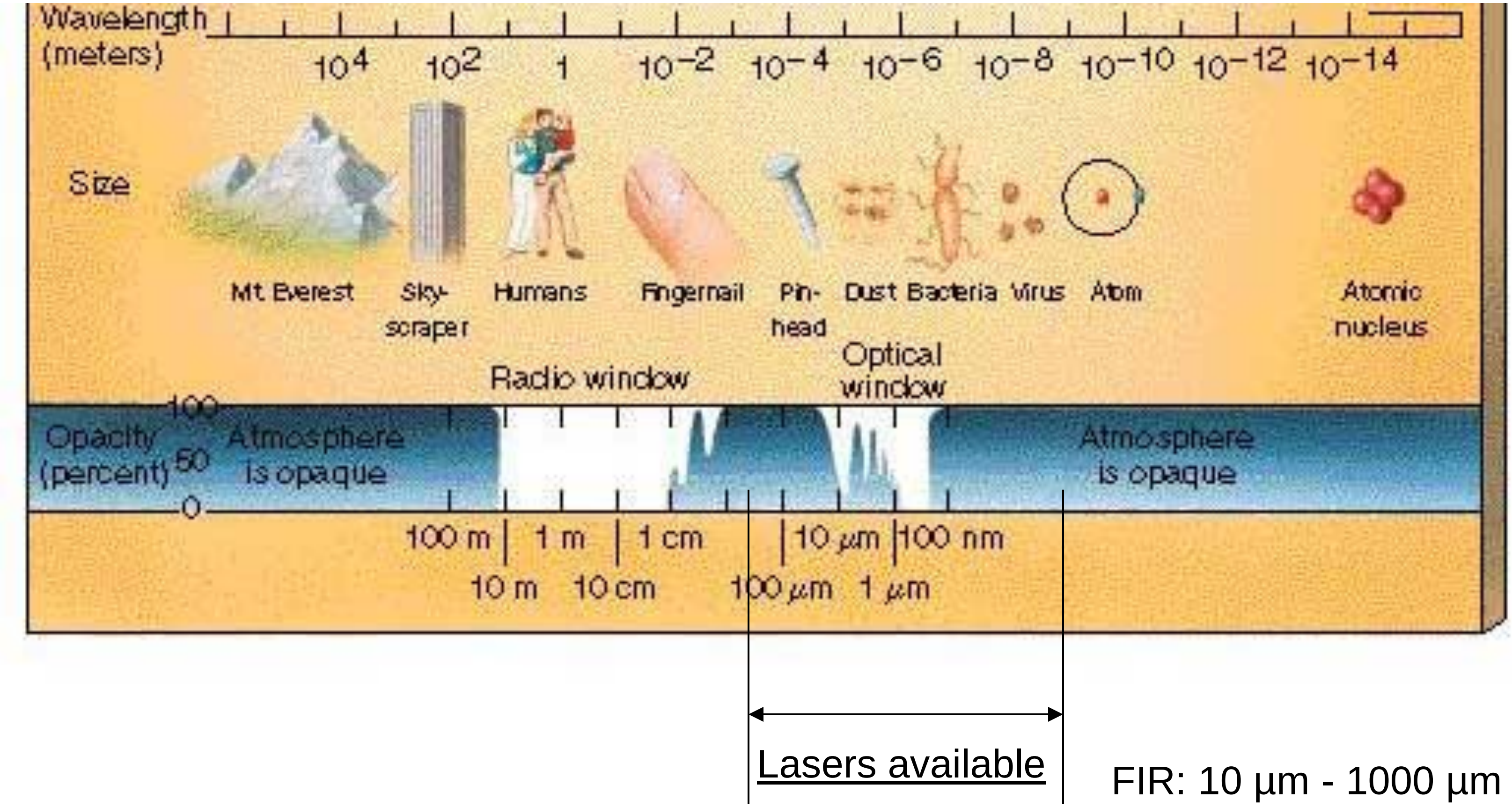
$$ns = 10^{-9} s$$

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

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

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

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

Pioneering work:

• 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)

Nobel prizes:

• 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:

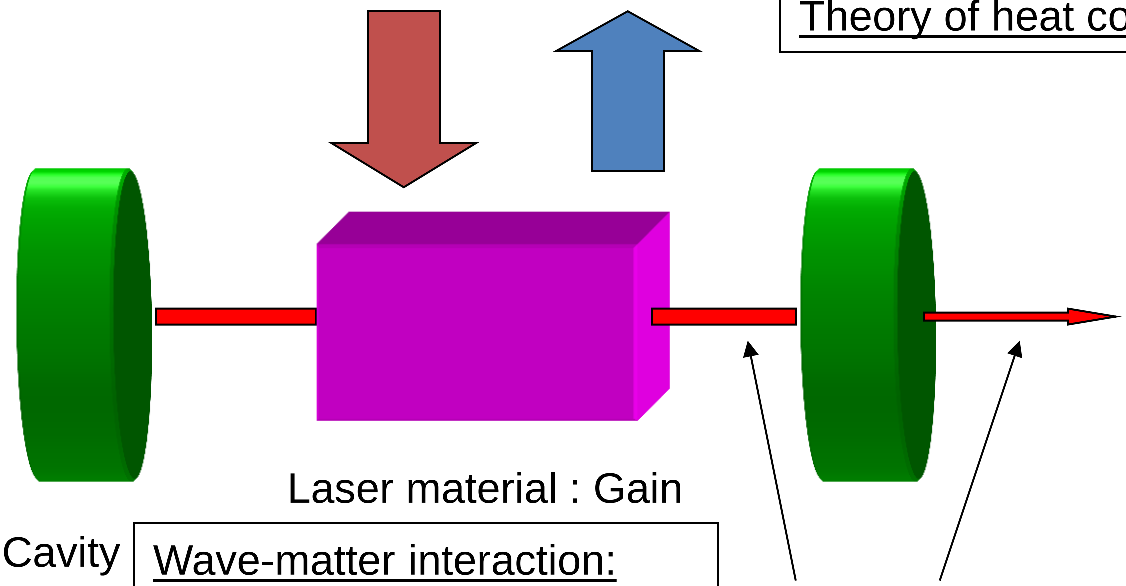
"for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle"

Field overview

Energy in: Pump

Energy out: Heat

Theory of heat conduction



Laser material : Gain

Feedback: Cavity

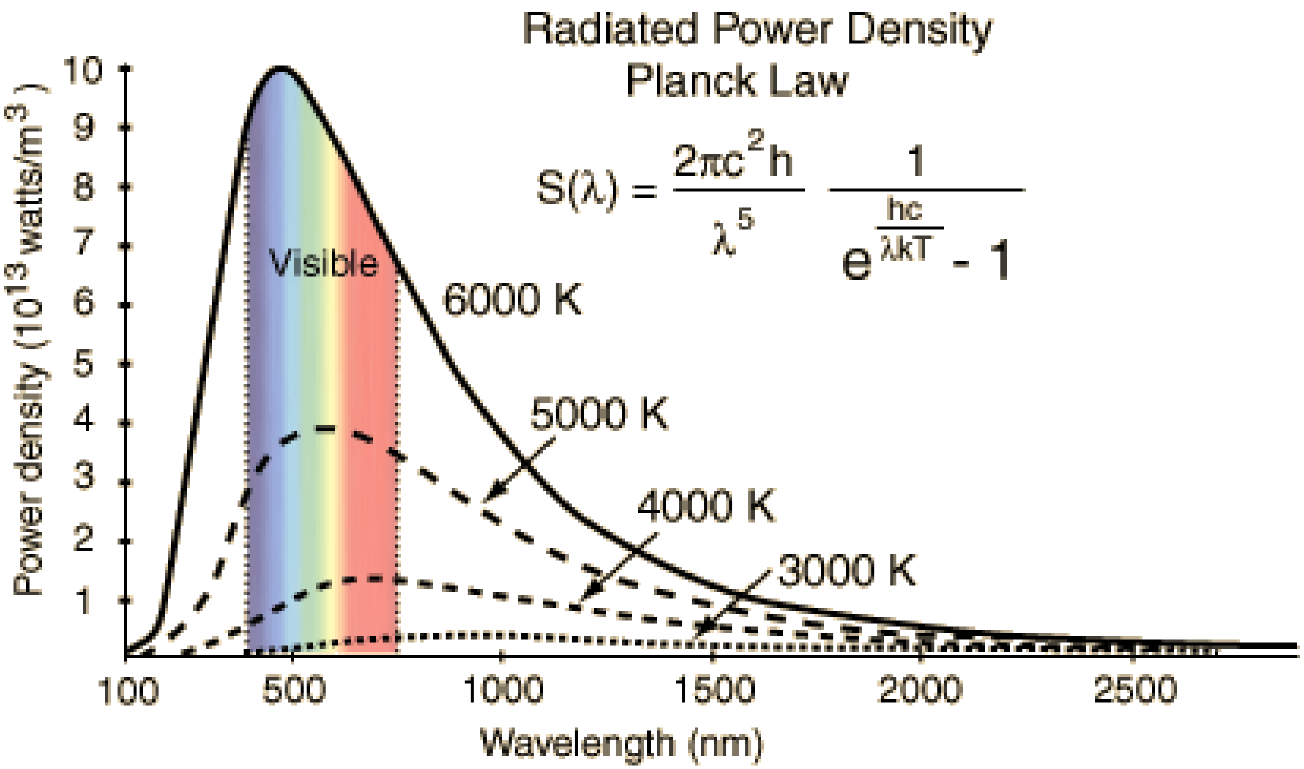
Radiation

Boundary conditions:
- Longitudinal modes
- Spatial modes
- Coherence

Wave-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



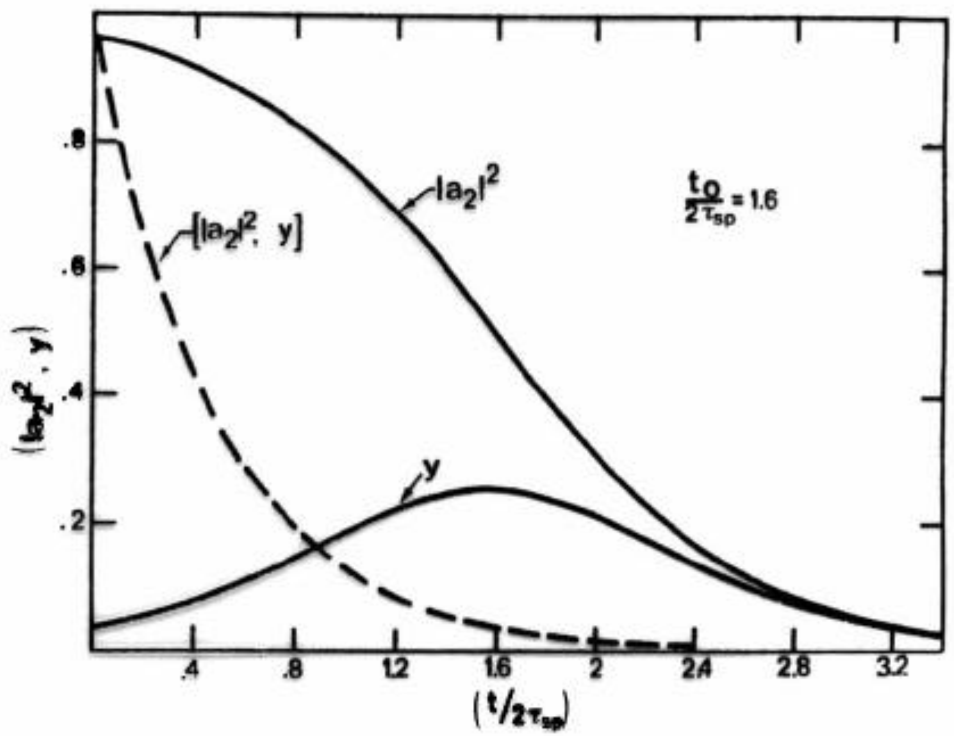
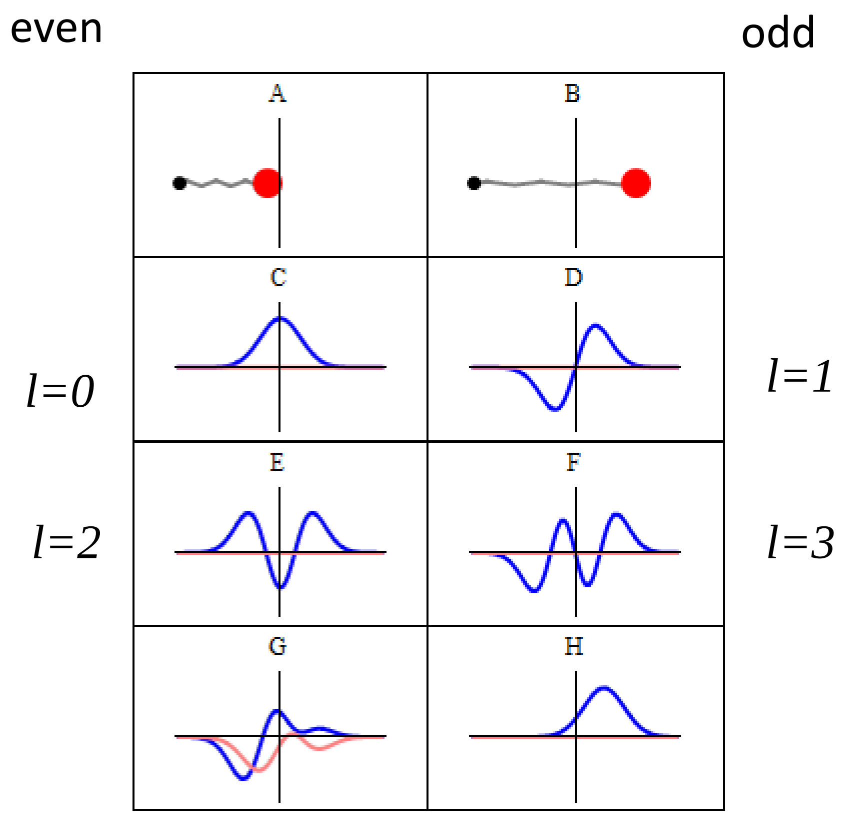


Fig. 2.5. Time behavior of the upper state occupation probability $|a_2|^2$ and of the normalized radiated power $\tau_{sp}P_r/h\nu_0$. Continuous lines: semiclassical results. Dashed line: quantum result.

Transitions, parity, dipole approximation



Transition rate (Fermi Golden Rule):

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

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

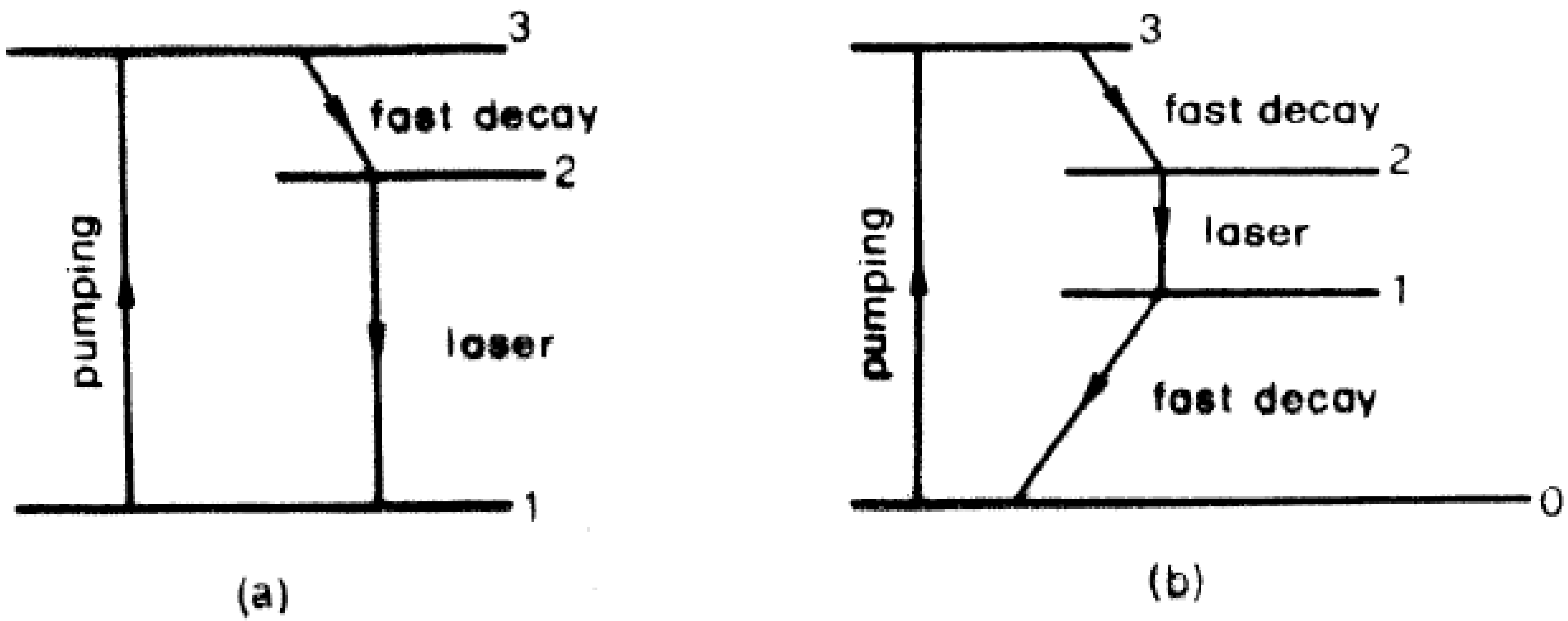


FIG. 1.4. (a) Three-level and (b) four-level laser schemes.

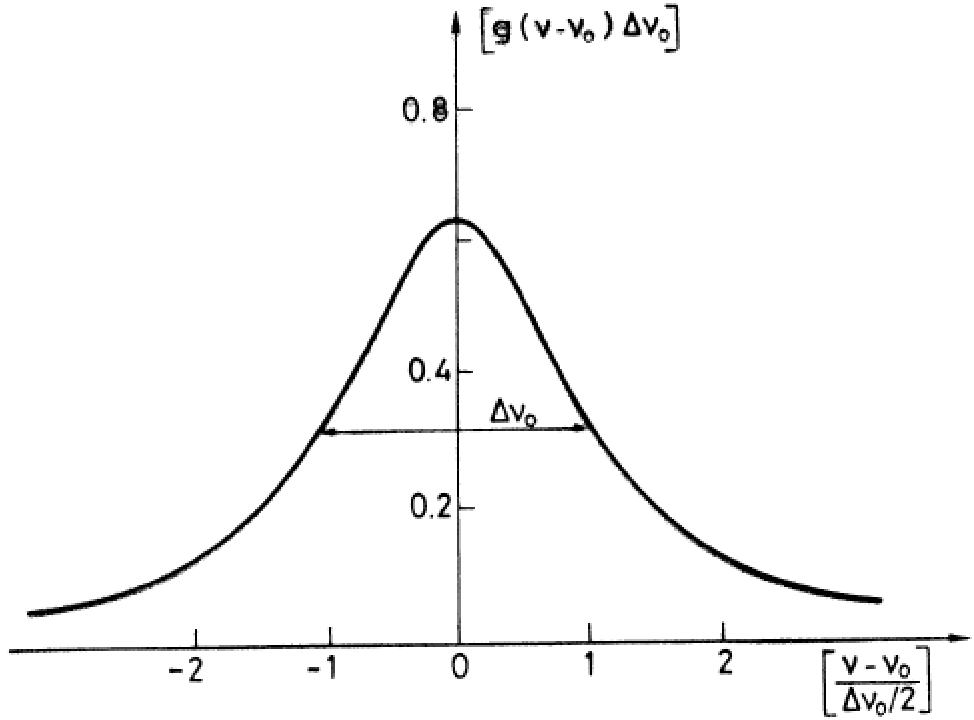


FIG. 2.6. Normalized plot of a Lorentzian line.

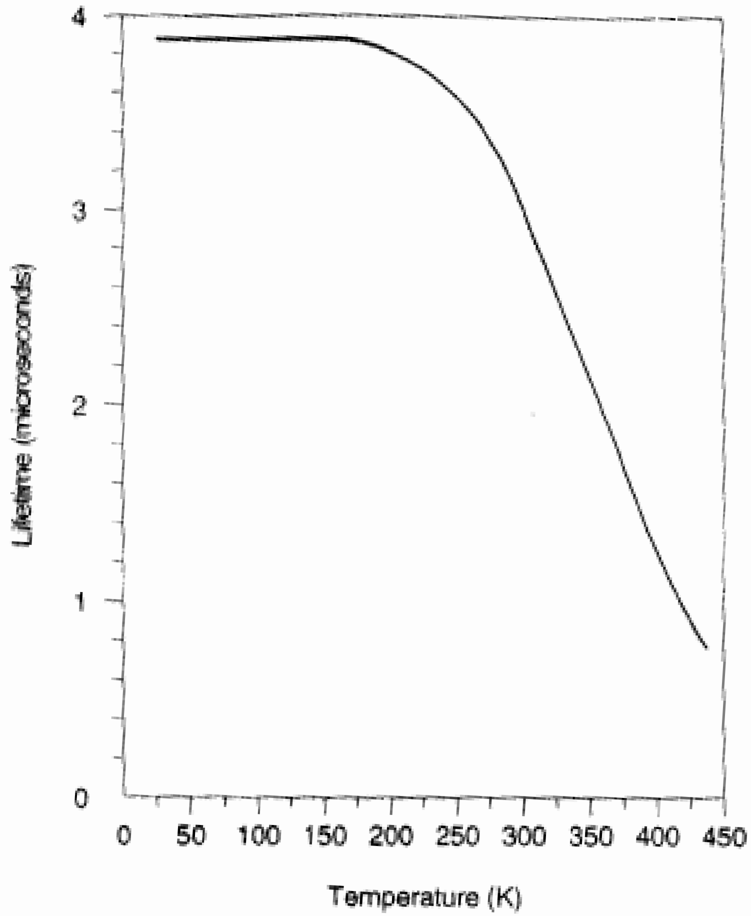


Figure 4-6 Decay time of the upper laser level of a titanium sapphire laser material as a function of temperature (K)

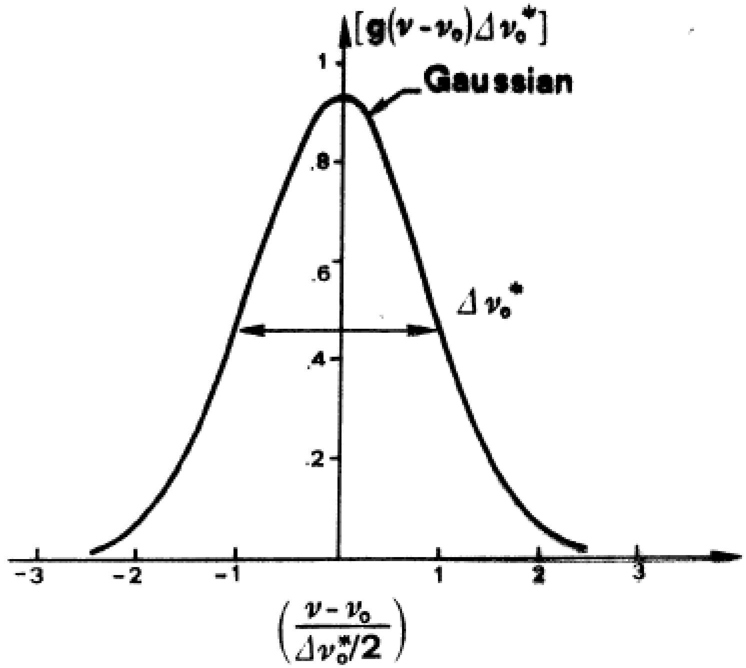
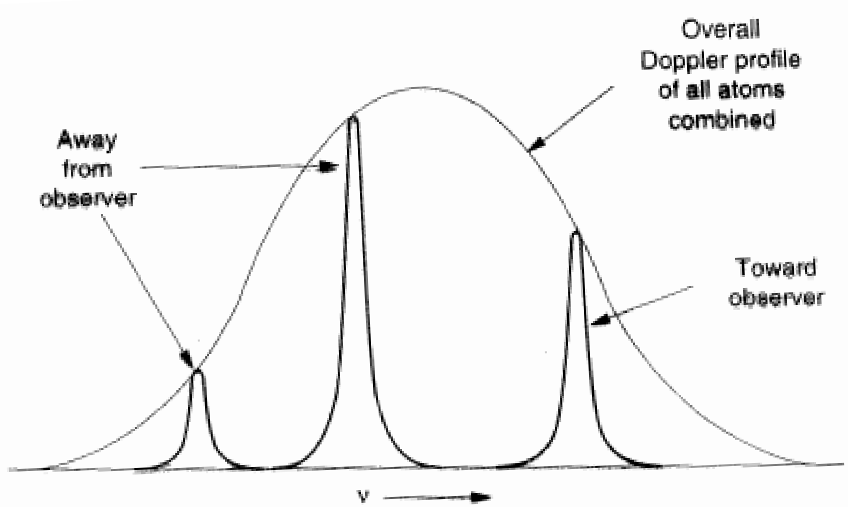
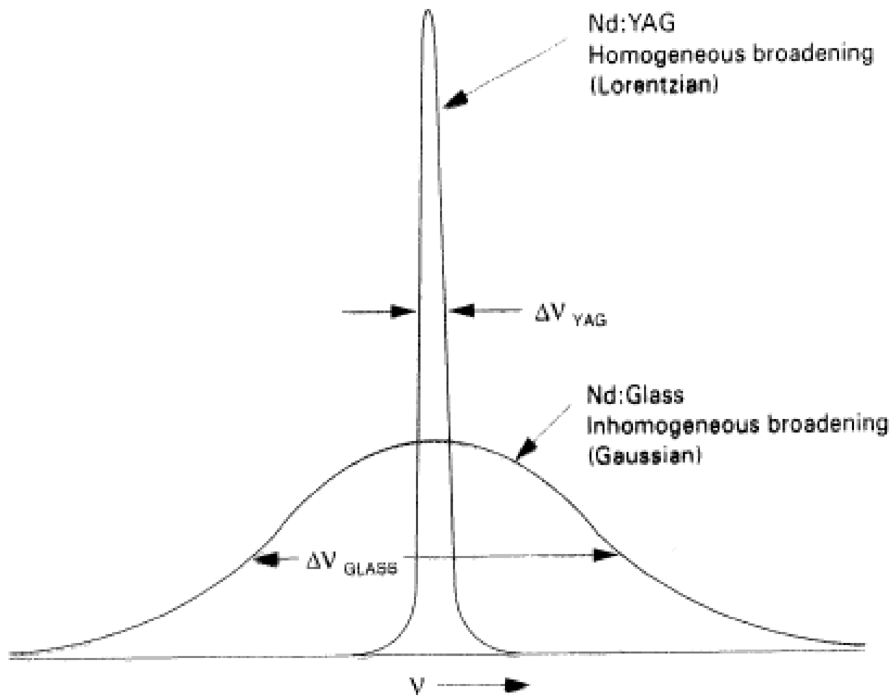


FIG. 2.8. Normalized plot of a Gaussian line.



Natural emission linewidth (Lorentzian profile) of many individual atoms traveling in different directions, thereby producing an overall Doppler profile

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



$$\frac{\Delta V_{GLASS}}{\Delta V_{YAG}} \sim 40 - 60$$

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

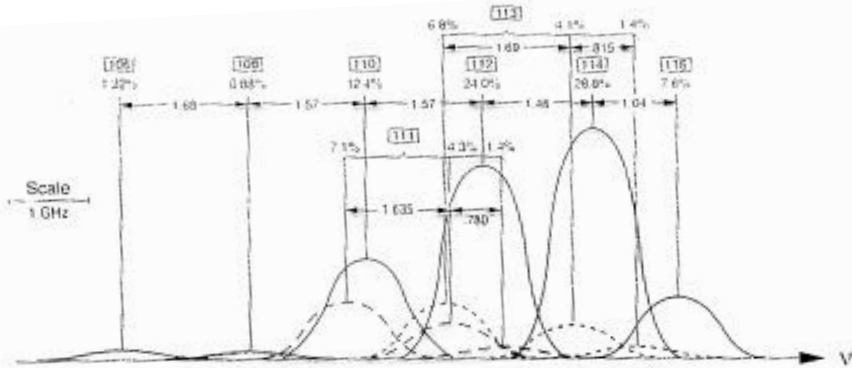


Figure 4-15(a) Emission lineshapes of the various isotopes of the cadmium 441.6-nm laser transition from a naturally occurring isotopic mixture

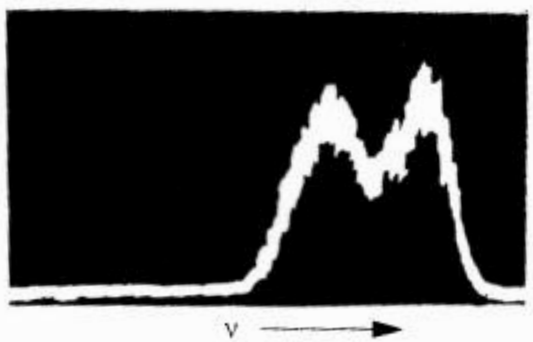


Figure 4-15(b) Laser output at 441.6 nm from a natural isotopic mixture of Cd

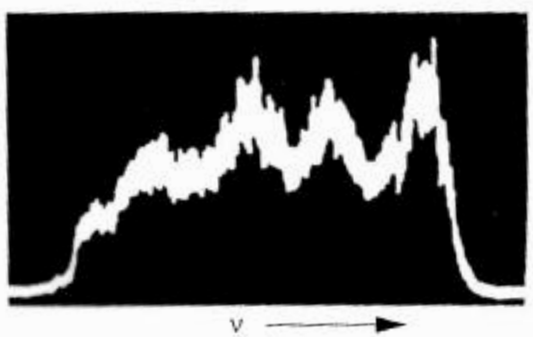


Figure 4-15(c) Laser output at 441.6 nm from a special isotopic mixture of Cd in which the contributions from the various isotopes are uniform

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