Types of Lasers

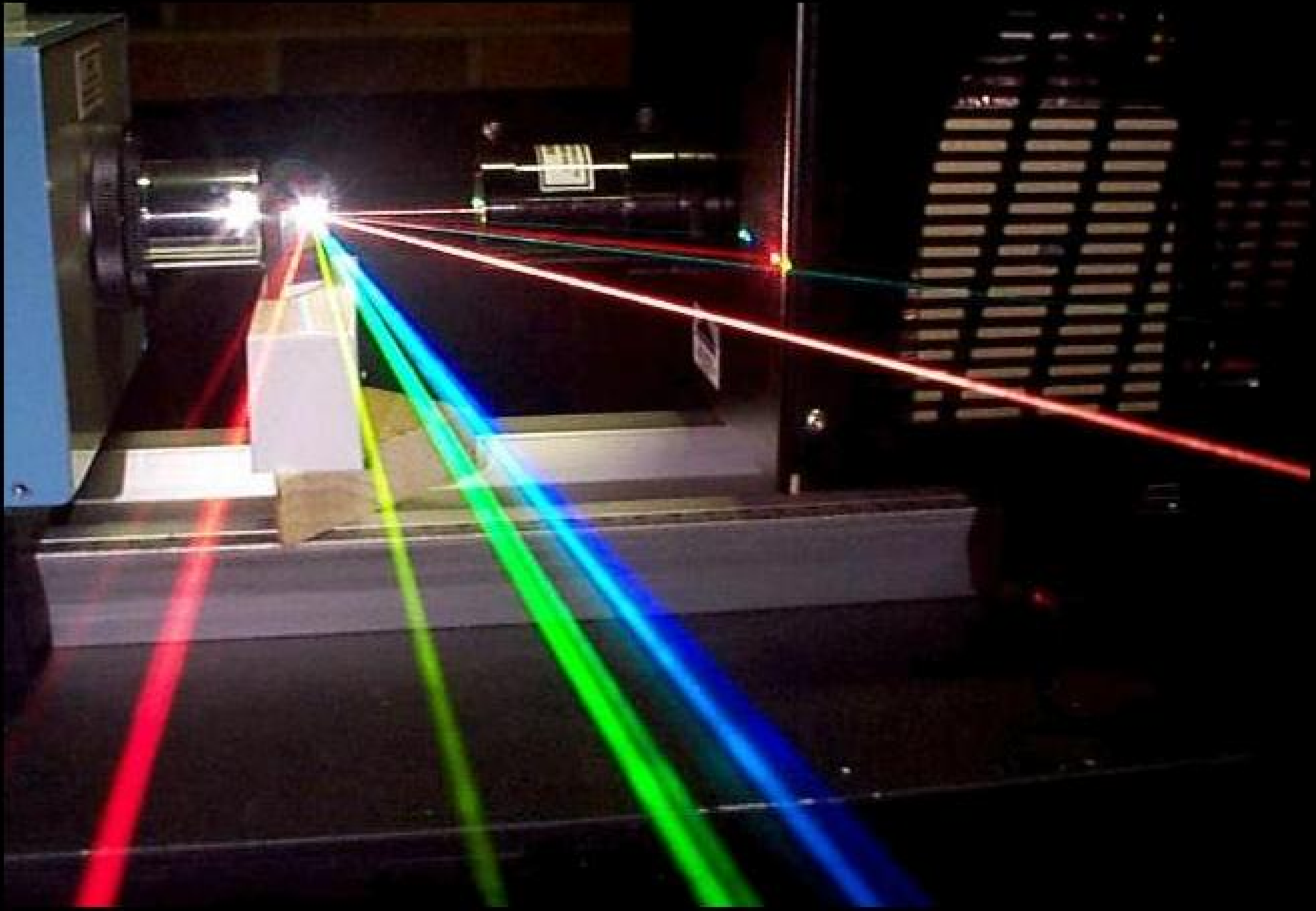
- Ar and Kr ion lasers
- Nd:YAG and Nd:YLF lasers
- CO_2 lasers
- Excimer lasers
- Dye lasers
- Transition metal lasers
- Optical parametric amplification

Ar and Kr ion lasers

- Noble gas ions are created in an electric discharge. The ions have specific electronic transitions.

- Ar^+ lines: 514, 501, 488, 476 and 457 nm.
- Kr^+ lines: 406, 413 and 752 nm.

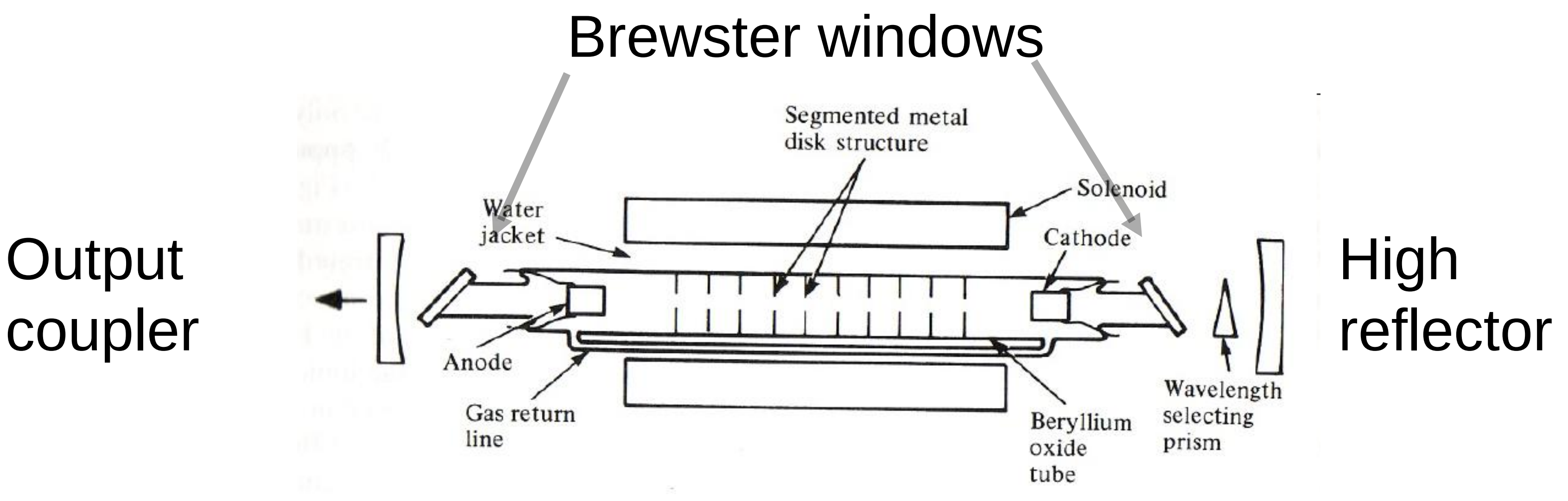
- Continuous wave (cw), non-tunable, useful narrow bandwidth source for pumping cw dye lasers.



Ar and Kr ion laser lines

Argon ion laser

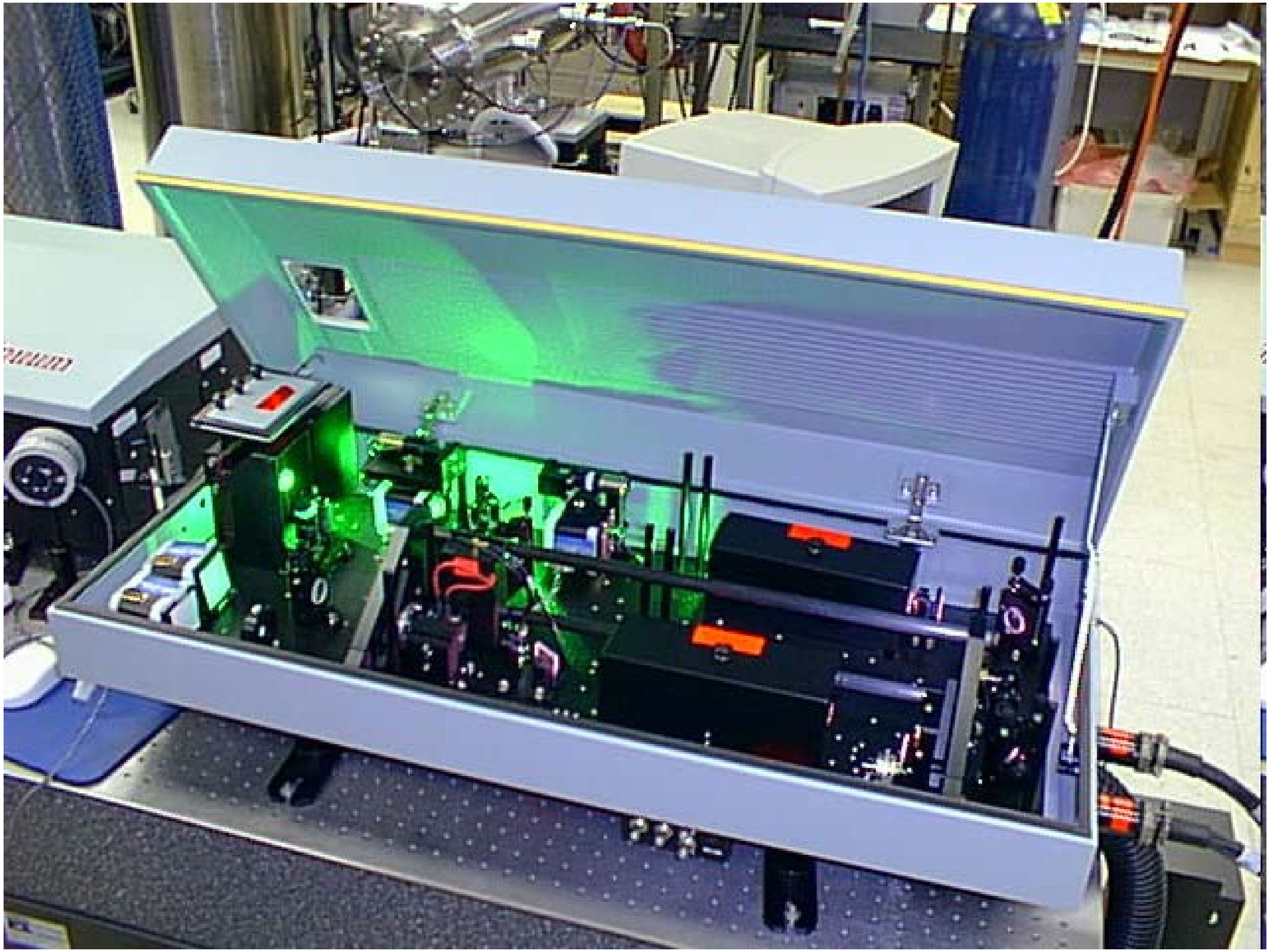
- A high discharge current is used to form ions.
- Powerful continuous wave operation can be achieved by discharge (15-50 Amps!) to maximize the pumping power.
- Up to 25 watts of CW output
- Pump to 4P states, 35eV above ground state.
- Transitions correspond to 4P-4S, 514.5nm and 488nm.
- Use Brewster windows at ends of gas tube to isolate a single polarization with minimum reflection losses.



Nd:YAG and Nd:YLF lasers

- Flash lamp pumped transitions with strong lasing at 1.064 μm. There are narrow transitions due to the fact that f-orbital transitions are buried below 5s and 5p.
- Cavity is Q-switched for 10 ns every 0.1 seconds. Q-switching is an electronic method to create a short pulse (or burst) of laser light.
- Frequency doubling using KDP to achieve 532 nm, the most frequently used wavelength in biophysical studies of biological molecules.

Frequency doubled Nd:YAG

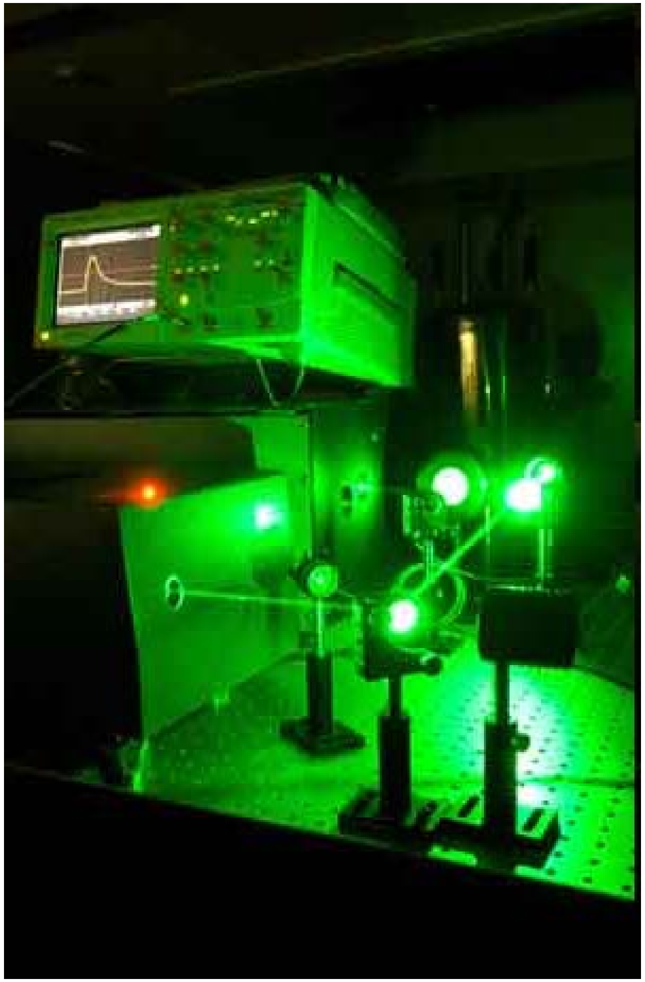


Nd:YAG

- Nd:YAG is the commonly used laser material today.
- Neodymium-doped yttrium aluminium garnet; $Nd:Y_3Al_5O_{12}$) is a crystal that is used as a lasing medium for solid-state lasers.
- It is particularly useful in nanosecond pulsed lasers.
- The Nd:YAG fundamental occurs at 1064 nm.

Nd:YLF

- Nd:YLF is used in a diode pumped configuration.
- Neodymium yttrium lithium fluoride; $LiY_{1-x}Nd_xF_4$).
- It is particularly useful in as a reliable pump source for Ti:sapphire.
- The Nd:YAG fundamental occurs at 1047 nm.



CO_2 lasers

- There are four vibrational modes of CO_2.
- The point group is $D_{infinity\_h}$.
- The vibrations are:

  totally symmetric stretch

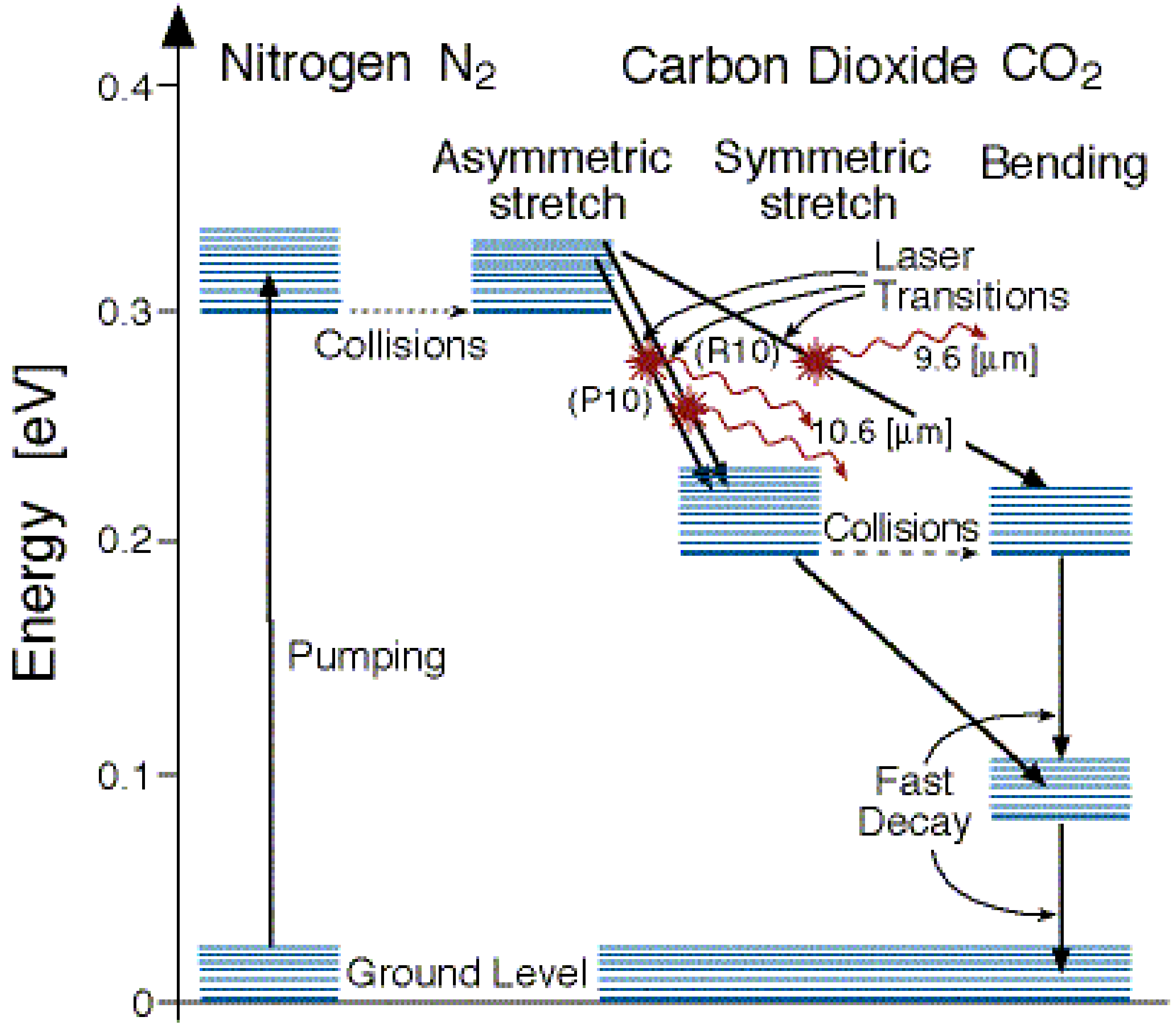
  bend (two dimensions)

  antisymmetric stretch
- The bend and anti-symmetric stretch form a Fermi resonance.

CO_2 lasers are infrared lasers

- N_2 can be pumped in an electric discharge into the first excited vibrational state.
- Efficient energy transfer results in excitation of the CO_2 symmetric stretch.
- The lasing transition occurs between different rotational states of the anti-symmetric stretch at 2400 cm^{-1} and the other vibrational modes symmetric stretch at 1400 cm^{-1} and bend at 1300 cm^{-1}.

Energy level scheme for CO_2 lasers



The gain curve of CO_2 spans the rotational states energies of the molecule

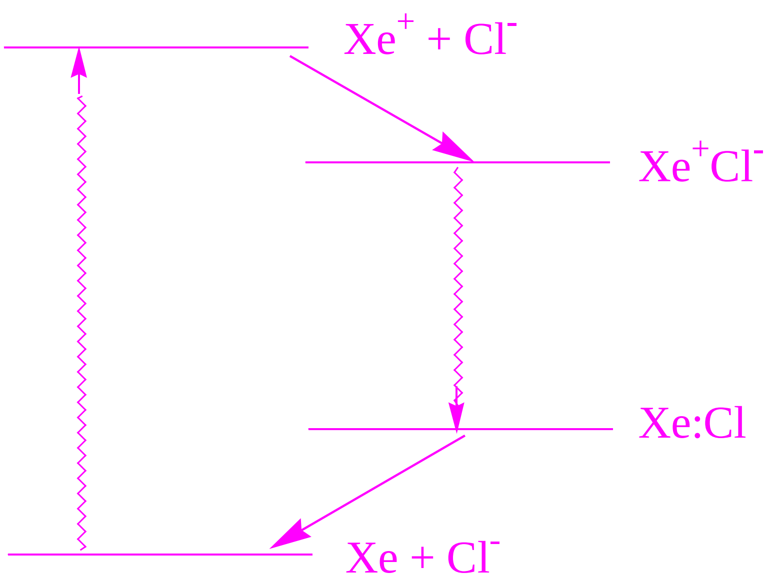
- It is logical that the tunability of a “vibrational laser” arises from the rovibrational fine structure.
- The population of an independent vibrational level J is $p_J = (2J+1)*e^{-hcB/kT[J(J+1)\backslash}/q$ where q=kT/hcB in the high temperature approximation.
- During lasing if a particular level is depleted, there is population flow into that level to maintain a Boltzmann distribution. This implies a build up into a mode where all lasing occurs from a single level.

Excimer lasers

- An excimer is an excited state charge transfer complex that is dissociative in the ground state.
- The unstable ground state serves to create a four level system.
- Typical UV lasers

    XeCl 308 nm

    ArF 247 nm



Dye lasers

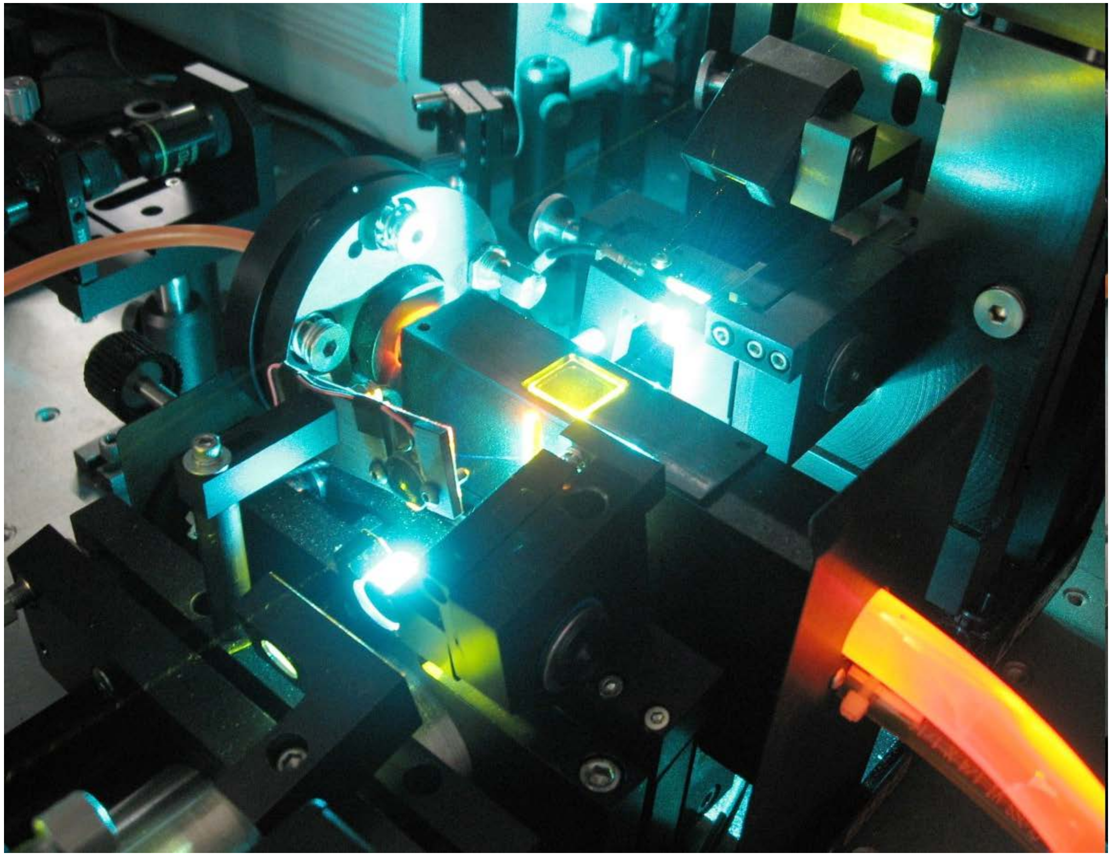
- Tunable lasers pumped both cw by Ar and Kr ion and in pulsed laser applications by Nd:YAG.
- Common dyes

  Rhodamine λ_{max}=590 nm

  Stilbene-1 λ_{max} =430 nm

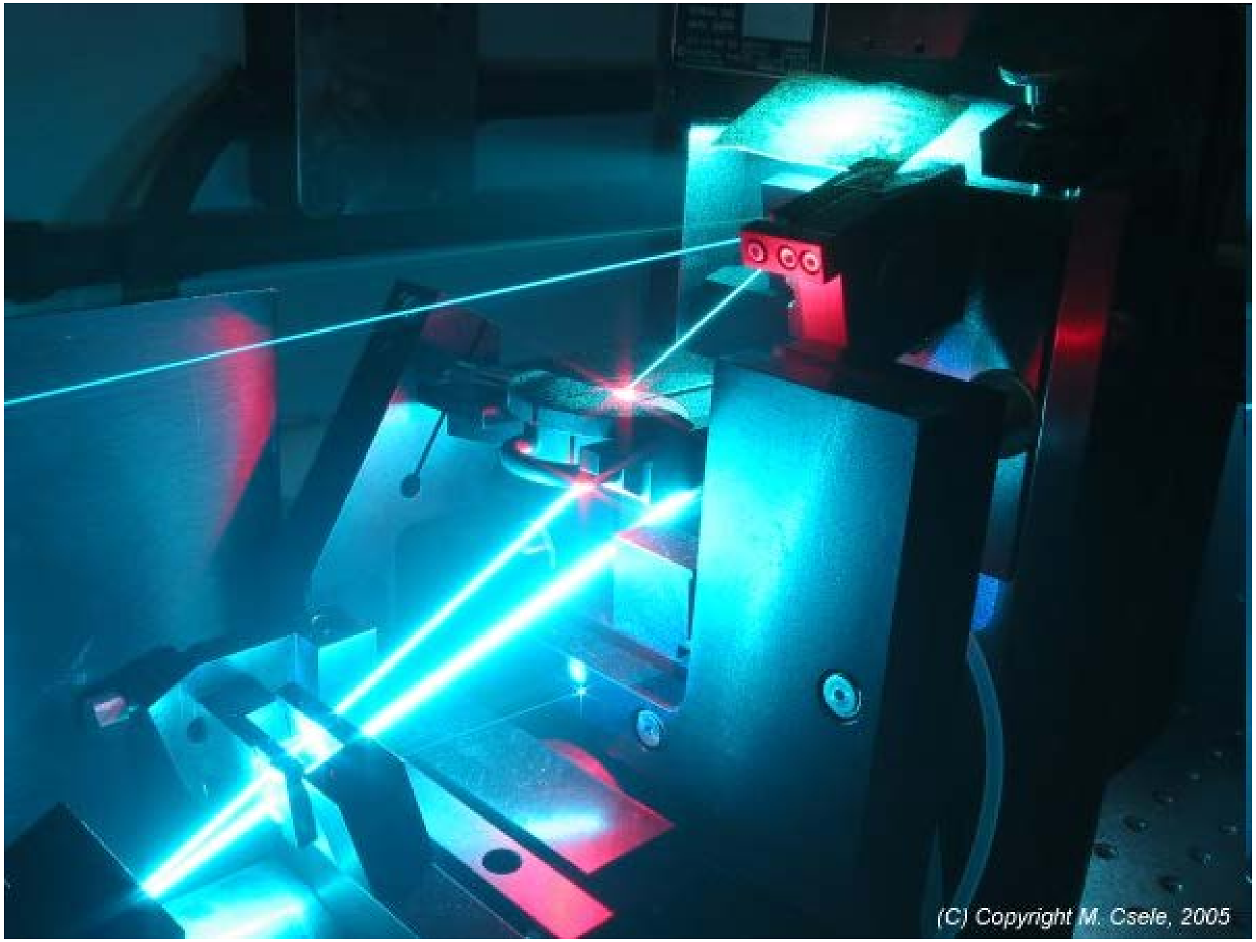
  Coumarin λ_{max} =430 nm

Dye lasers are messy



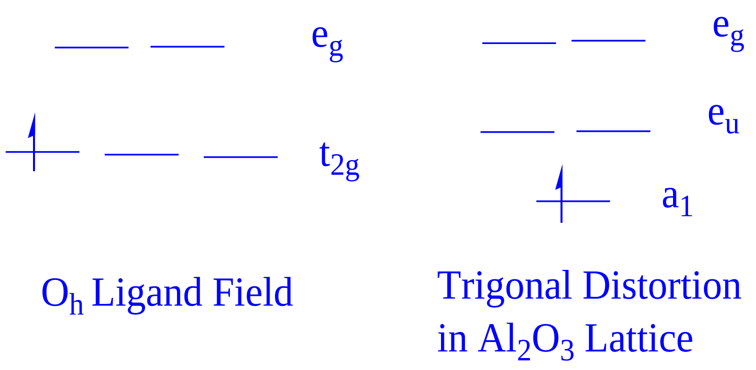
Pumped liquid contains dye. Dye degrades over time. Result is a frequent exchange of laser dyes.

Solid state alternative: Ar ion laser exciting a Ti:sapphire rod



d-d transitions can give a useful four level system for tunable lasers

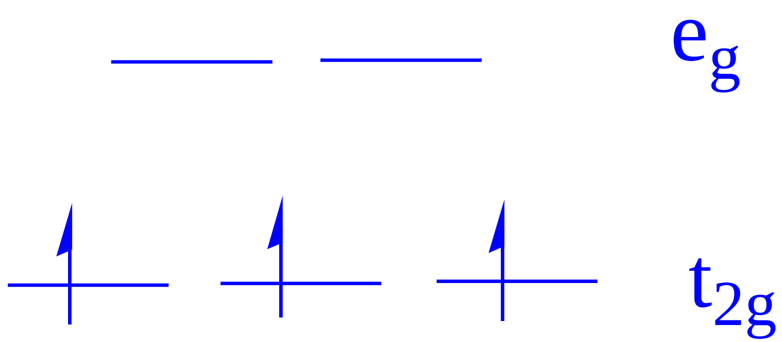
- A titanium sapphire laser Ti:Al_2O_3 is a four level system.
- This is part of a vibronic mechanism which results in a Jahn-Teller distortion of the complex. In this distorted complex e_u is the fourth state.



Ti is d^1 leading to population of a single low energy state in the d-orbitals

Comparison of three and four state systems

- Cr is d^3 and this results in a different behavior than for Ti.
- Because each of the t_{2g} levels is occupied by a single electron there is no Jahn-Teller distortion.
- Ruby has the disadvantage as well that other t_{2g} –> e_g transitions can occur absorbing the light.

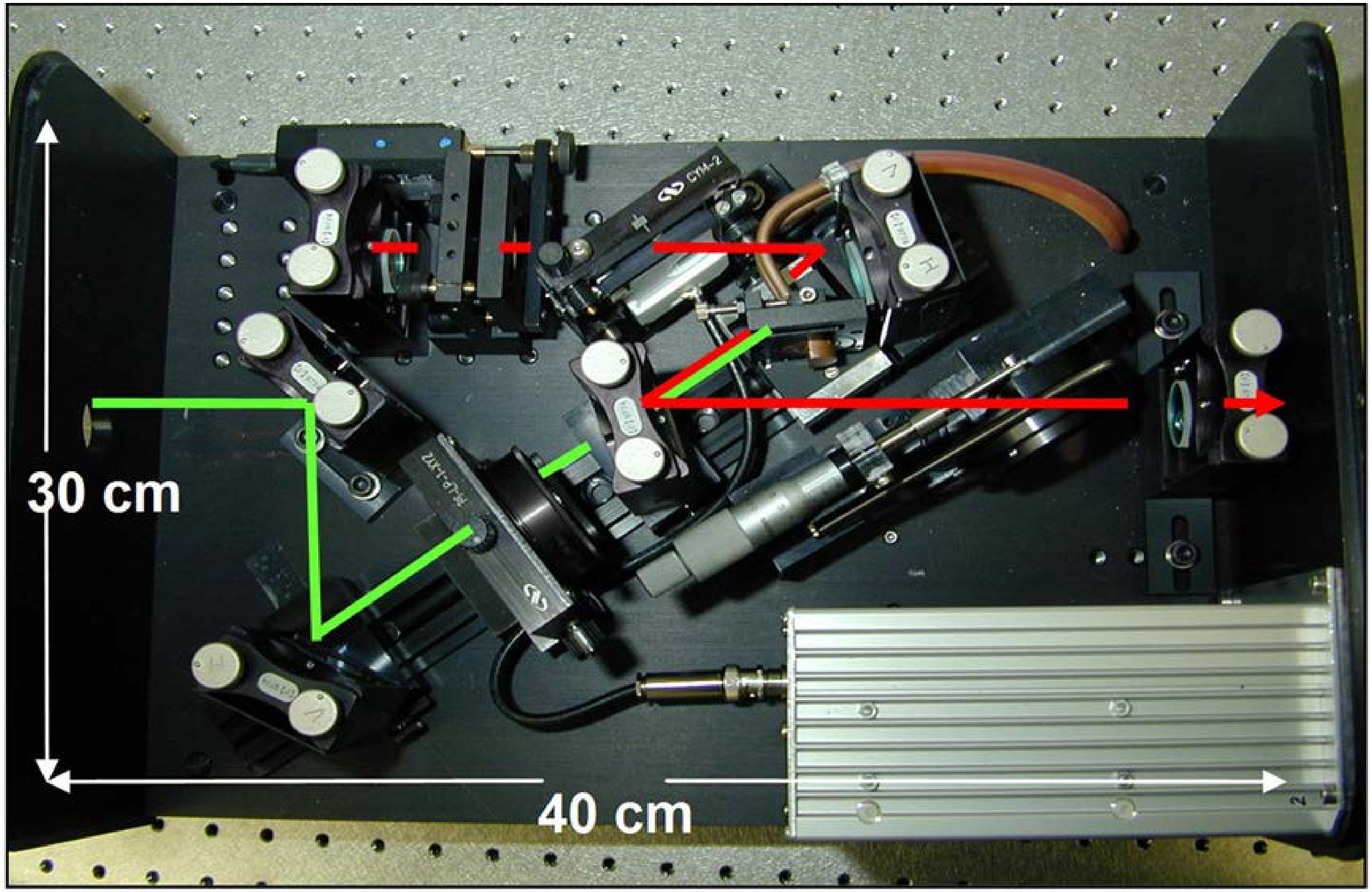


O_h Ligand Field

Cr(III) ligand field is nearly O_h so help is required from other metals

- Note that the rate equations for triply degenerate t_{2g} ground state of Cr(III) imply that the rate of absorptive transitions is 2 times higher than for the stimulated emission.
- From this view point we see that ruby is definitely not the ideal material. Alexandrite ($CrBe{:}Al_2O_4$) is a four level system and that overcomes these problems.
- Ruby and Alexandrite are transition metal lasers.

Z-shaped laser cavity standard in Ti:sapphire design



A Ti:sapphire tuning curve