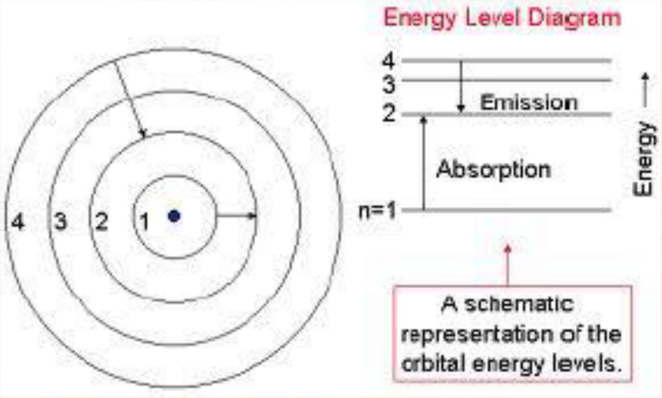
LASER: Lecture 2

Pumping Schemes

- **Atoms characterized by a large number of energy levels.**
  - Only two, three or four levels are pertinent to the pumping process.

- **Classified as**
  - Two-level,
  - Three-level and
  - Four –level schemes.



- Two-level scheme will not lead to laser action.
- Three-level and four-level schemes are important and are widely employed.

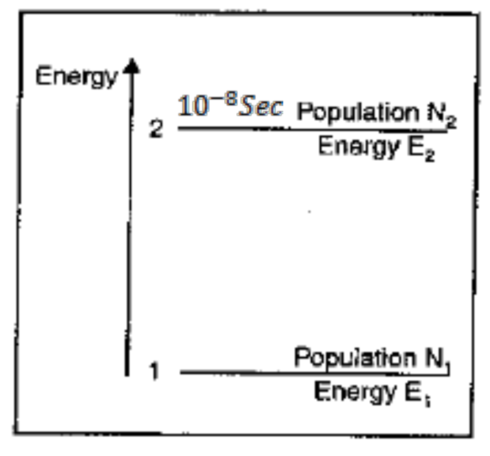
Two Level Pumping Scheme

- Appears to be most simple and straight-forward method to establish population inversion;
  - Pumping an excess of atoms into the higher energy state by applying intense radiation.
- A two-level pumping scheme is not suitable for attaining P.I.

- P.I. requires the lifetime Δt of upper level E_2 must be longer.
- **Heisenberg's Uncertainty principle,**

$$\Delta E_2 \, . \, \Delta t \geq h/2\pi$$

$\Rightarrow$ Smaller ΔE_2 ; the upper energy level must be narrow



Two Energy level system

- **For such system, to excite atoms, pump source should be highly monochromatic.**
    - In practice, monochromatic source of required frequency may not exist.
    - Even if it exists, the pumping efficiency would be very low $\Rightarrow$ enough population cannot be excited to level E_2.
- Further, pumping radiation on one hand excites the ground state atoms and on the other hand induces transitions from the upper level to the lower level.
    - **means that pumping operation simultaneously populates and depopulates the upper level.**

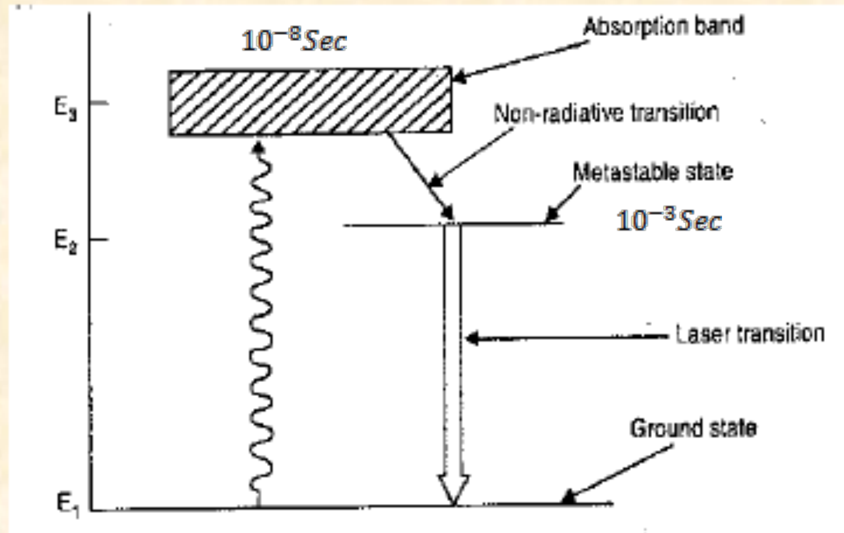
☞ **Hence, P.I. cannot be attained in a two-level scheme. All that it may achieve at best is a system of equally populated levels.**

Three Level Pumping Scheme

- **A three level scheme**; Lower level is either the ground state or a level whose separation from the ground state is small compared to kT.

E_2 – A metastable level

- Atoms accumulate at level E_2
- Build-up of atoms at E_2 continues because of pumping process.
- Population N_2 at E_2 exceeds the population N_1 at E_1 and
  - **P.I. is attained.**



Three level Energy diagram

❖ **A photon of $h\nu(=E_2-E_1)$ can induce stimulated emission and laser action.**

- **Major disadvantage of a three level scheme ⇒ it requires very high pump powers.**
  - Terminal level of the laser transition is the ground state.
  - As the ground state is heavily populated, large pumping power is to be used to depopulate the ground level to the required extent ($N_2 > N_1$)

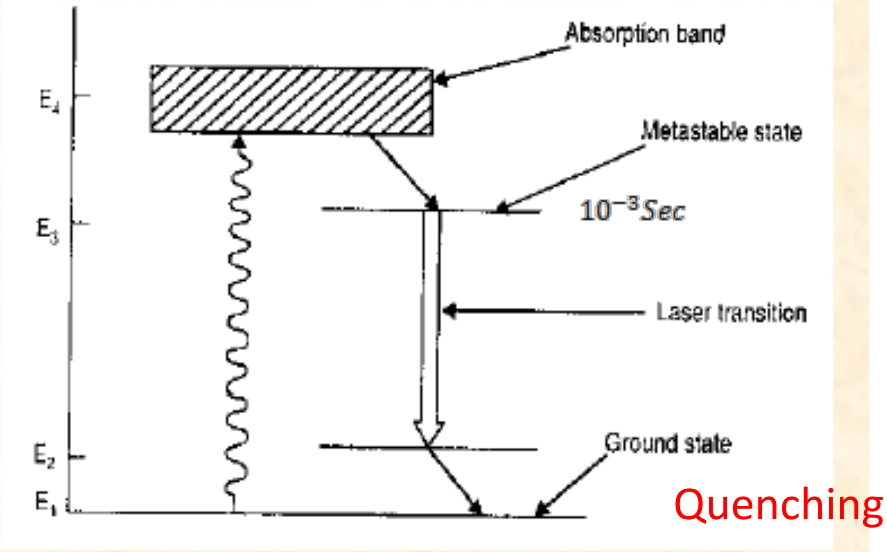
- **Three level scheme can produce light only in Pulses.**
  - Once stimulated emission commences, the metastable state E_2 gets depopulated very rapidly and the population of the ground state increases quickly. As a result the population inversion ends. One has to wait till the population inversion is again established.
  - **Three level lasers operate in Pulsed Mode.**

Four Level Pumping Scheme

- **In Four level scheme, the terminal laser level E_2 is well above the ground level such that $(E_2-E_1) >> kT$.**
  - It guarantees that the thermal equilibrium population of E_2 level is negligible.

E_3 - a metastable level

- Laser transition takes the atoms to the level E_2
- Atoms lose the rest of their excess energy & finally reach the ground state E_1.
- Atoms are once again available for excitation.



Four level Energy diagram

- ***In contrast to three level scheme, the lower laser transition level in four level scheme is not the ground state and is virtually vacant.***
  - It requires less pumping energy than does a three level laser. This is the major advantage of this scheme.

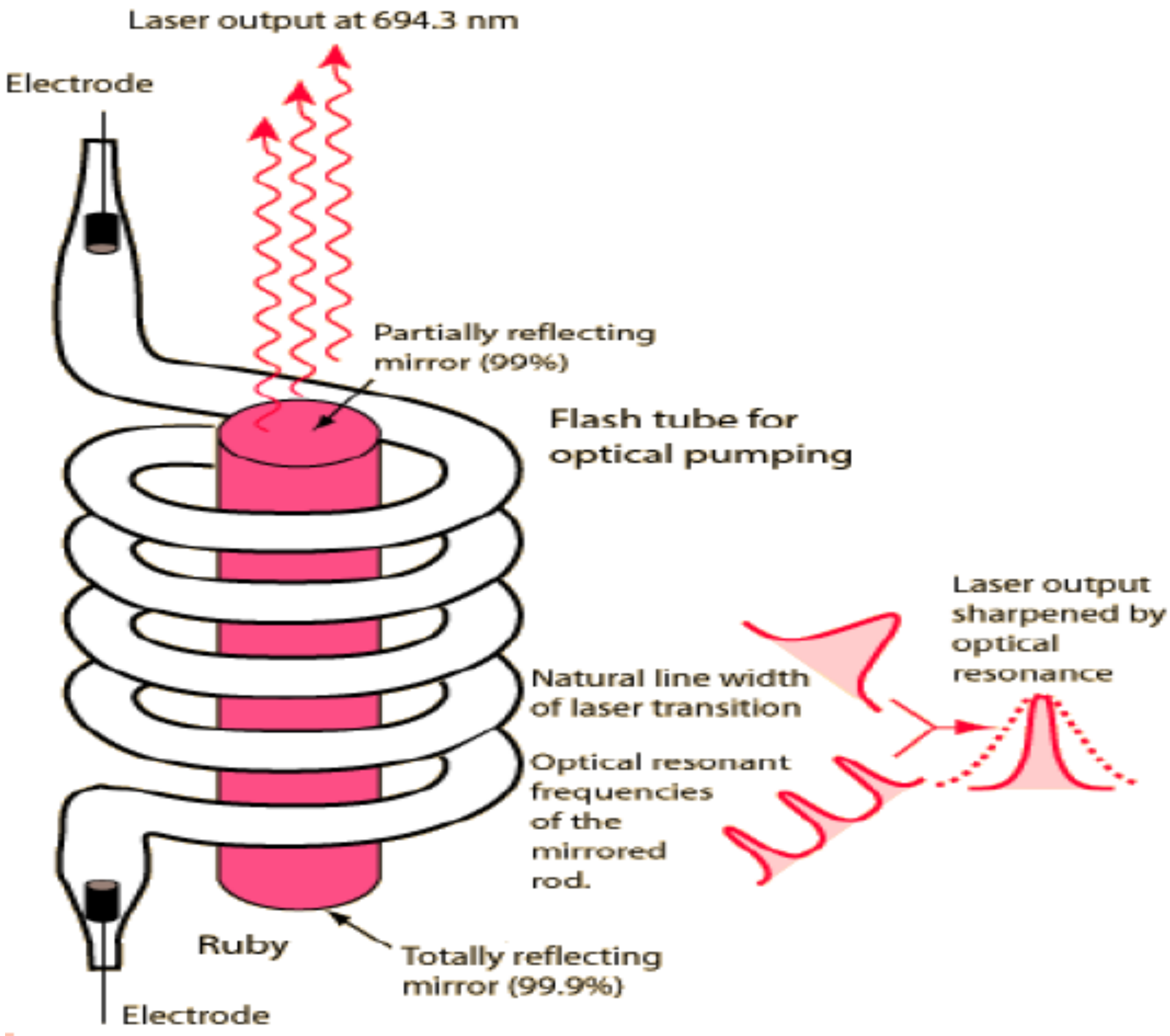
- ***Further, the lifetime of the lower laser transition level E_2 is much shorter, hence atoms in level E_2 quickly drop to the ground state.***
  - This steady depletion of E_2 level helps sustain the population inversion by avoiding an accumulation of atoms in the lower lasing level.

- Four level lasers can operate in **Continuous Wave mode.**

❑ **Most of the working lasers are based on Four Level Scheme**

Ruby Laser

- A ruby laser is a solid-state laser that uses a synthetic ruby crystal as its gain medium.
- It was the first type of laser invented, and was first operated by Theodore H. "Ted" Maiman at Hughes Research Laboratories on 1960-05-16 .
- The ruby mineral (corundum) is aluminum oxide with a small amount(about 0.05%) of chromium which gives it its characteristic pink or red color by absorbing green and blue light. The ruby laser is The ruby laser is used as a pulsed laser, producing red light at 694.3 nm. After receiving a pumping flash from the flash tube, the laser light emerges for as long as the excited atoms persist in the ruby rod, which is typically about a millisecond.

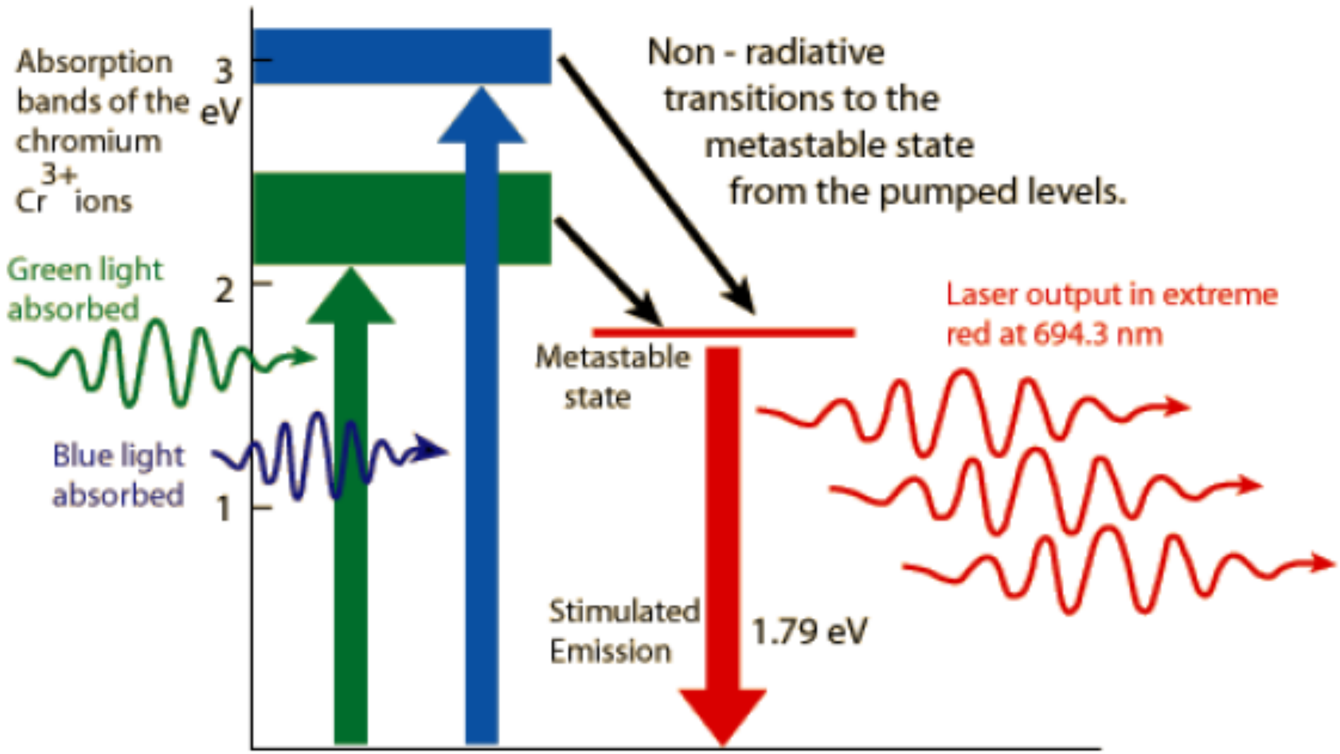

Laser output at 694.3 nm
Electrode
Partially reflecting mirror (99%)
Flash tube for optical pumping
Laser output sharpened by optical resonance
Natural line width of laser transition
Optical resonant frequencies of the mirrored rod.
Ruby
Totally reflecting mirror (99.9%)
Electrode

LASER CONSTRUCTION

- **The active laser medium (laser gain/amplification medium) is a synthetic ruby rod. Ruby is an aluminum oxide crystal in which some of the aluminum atoms have been replaced with chromium atoms(0.05% by weight). Chromium gives ruby its characteristic red color and is responsible for the lasing behavior of the crystal. Chromium atoms absorb green and blue light and emit or reflect only red light. For a ruby laser, a crystal of ruby is formed into a cylinder.**
- **The rod's ends had to be polished with great precision, such that the ends of the rod were flat to within a quarter of a wavelength of the output light, and parallel to each other within a few seconds of arc. The finely polished ends of the rod were silvered: one end completely, the other only partially. The rod with its reflective ends then acts as a Fabry-Pérot etalon (or a Gires-Tournois etalon).**
- **A xenon lamp is rolled over ruby rod and is used for pumping ions to excited state.**

WORKING OF RUBY LASER

- Ruby laser is based on three energy levels. The upper energy level E3 I short-lived, E1 is ground state, E2 is metastable state with lifetime of 0.003 sec.



- optical pumping: 510-600nm and 360-450nm (Green and Blue light).
- fast transition on ^2E.
- lasing: ^2E on $^4A_2$,

➢ Pumping source is a flash lamp, laser output is not continuous. Laser light obtained in the form of pulses.

Advantages of Ruby Lasers

- From cost point of view, the ruby lasers are economical.
- Beam diameter of the ruby laser is comparatively less than CO_2 gas lasers.
- Output power of Ruby laser is not as less as in He-Ne gas lasers.
- Since the ruby is in solid form therefore there is no chance of wasting material of active medium.
- Construction and function of ruby laser is self explanatory.

Disadvantages of Ruby Laser

- In ruby lasers no significant stimulated emission occurs, until at least half of the ground state electrons have been excited to the Meta stable state.
- Efficiency of ruby laser is comparatively low.
- Optical cavity of ruby laser is short as compared to other lasers, which may be considered a disadvantage.

Applications of ruby Laser

- Due to low output power they are class-I lasers and so may used as toys for children's.
- It can be used in schools, colleges, universities for science programs.
- It can be used as decoration piece & artistic display.

1. The wavelength of emission is 600 nm and the lifetime tsp is 1μs. Determine the coefficient for the stimulated emission.

$$A_{21} = \frac{1}{t_{sp}}; B_{21} = \frac{c^3 A_{21}}{8\pi h v^3} = 1.3 \times 10^{19} m/kg$$

2. (a) At what temperature are the rates of spontaneous and stimulated emission equal? Assume wavelength = 500 nm.
(b) At what wavelength are they equal at 300 K?

$$\boxed{R = \frac{1}{e^{hv/kT} - 1} \Rightarrow T = 41{,}600K}$$

3. Find the ratio of spontaneous emission to stimulated emission for the cavity of temperature 50 K and wavelength 10^{-5} m.

$$\frac{\text{Rate of spontaneous emission}}{\text{Rate of stimulated emission}} = e^{hv/kT} - 1 = e^{28.8}$$