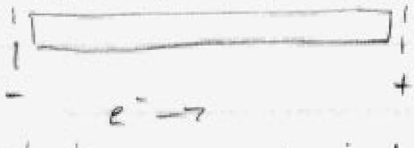
HeNe Laser

lasing: Ne 632.8 nm, also 543 nm, 1.15, 3.39 μm
He is there to assist pumping.

HeNe was first gas laser, first cw laser.

tube = glow discharge (weak ionization)



electron impact ionization/excitation

He^* nearly resonant with Ne^*

$2^3S_{He} \rightleftarrows 4s_{Ne}$

$2^1S \rightleftarrows 5s$

∴ collisions can → exchange of energy.

He^* are metastable (no $2s \rightarrow 1s$ transitions)

∴ act as reservoir for cw pumping.

$\tau_s \sim 100\,ns$ $5s \rightarrow 4p$

$4s \rightarrow 3p$

$\tau_p \sim 10\,ns$ $4p \rightarrow$

$3p \rightarrow$

- choose operating λ w/ mirrors
- line width dominated by Doppler broadening
- max pumping rate is limited by collisional de-excitation.
- design: - He:Ne partial pressures (5:1 or 9:1)
  633 nm 1.15 μm
  - optimize e^- temperature
  → total pressure, capillary size.

Solid-state lasers

composition:

- host material - crystal YAG, Al_2O_3, YVO_4 ...
- doping ion - <u>Nd^{3+}</u>, Ti^{3+}, Cr^{3+}
  - → doping densities ~ 1%

example system: Nd:YAG (Svelto 9.2.2, K 2.1, 2.3)

YAG = $Y_3Al_5O_{12}$ yttrium aluminum garnet

isotropic crystal ∴ no natural birefringence.

crystal is grown synthetically

Nd substitutes for Y in crystal

3% difference in size

→ max ~ 1% conc. of Nd w/o lattice distortion

~ 1.38×10^{20} ions/cm^3 (~10_x atm)

Level notation

All closed shells can be ignored

54: Xe $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6$

55 Cs cesium $6s^1$

56 Ba barium $6s^2$

57 La lanthanum $6s^2 5d^1$

then the rare earth elements start:

- filling 4f shell

58: Ce cerium $4f\, 5s^2 5p^6 5d\, 6s^2$

60: Nd neodymium $4f^4 5s^2 5p^6 6s^2$

Nd → crystal: Nd^{3+} trivalent $4f^3 5s^2 5p^6$

(loses $6s^2$ and a 4f)

∴ 4f shell is partly filled. → optical transitions

$5s^2 5p^6$ shells are closed ∴ no transitions
- since they are spatially outside the 4f shell, 4f is screened from local crystal fields
∴ transitions are relatively narrow.

Energy levels:

ground state $^4I_{9/2}$

Russell - Saunders scheme $^{2S+1}L_J$

L: orbital quantum number

S, P, D, F, G H I . . .

ℓ = 0 1 2 3 4 5 6

f:  $L = 3 + 2 + 1 = 6$

2S+1 total spin ↑ ↑ ↑ → $S = 3/2$, $2S+1 = 4$

$J = L - S = 6 - 3/2 = 4\frac{1}{2} = 9/2$

(L − S: lowest energy)

- J can range from L−S to L+S

9/2 11/2 13/2 15/2

(11/2, 13/2, 15/2: excited states)

For each term e.g. $^4I_{9/2}$ there are sublevels

J + 1/2 levels (J_z components, doubly degen)

split by crystal-field Stark effect. ($|J_z|$)

higher-lying states:

$^4F_{3/2}$ $S = 3/2$ $L = 3$ (e.g. 3+1−1)

$J = 3 - 3/2 = 3/2$ → 2 sublevels

this is upper level (storage)

thermally (Boltzmann) upper R_2 level is 40% pop.

energy diff: $11507\ cm^{-1} - 11423\ cm^{-1}$

$= 84\ cm^{-1}$

$\frac{\Delta\sigma}{\sigma} = \frac{\Delta E}{E}$ $E = 1.86 \times 10^{-19}\ J = 1.165\ eV$

$\sigma = 9.40 \times 10^{7}\ cm^{-1}$

$\Delta E = 0.1\ meV$

230 μs lifetime $kT \approx 25\ meV$

lower levels of lasing transition are not thermally pop.

∴ good 4-level laser.

1.064 nm → $^4I_{11/2}$ → ground state ~ 100's ps best line.

line broadening: 120 GHz see Fig. 2.10 Svelto

— thermally-activated lattice vibrations (phonon collisions)

$\sigma(R_2 \to Y_3) = 6.5 \times 10^{-19}\ cm^2$

but $N_{R_2}/N_{tot} \sim 43\% \to \sigma_{eff} = 0.43\,\sigma$

non-radiative decay of upper level:

$^4F_{3/2} \to {}^4I_{15/2}$ then down.

multi-phonon emission.