

HeNe Laser

lasing: Ne 632.8 nm, also 543^m, 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

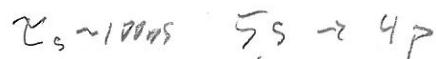
He^* nearly resonant with Ne^*



∴ collisions can → exchange of energy.

He^* are metastable (no $2S \rightarrow 1S$ transition)

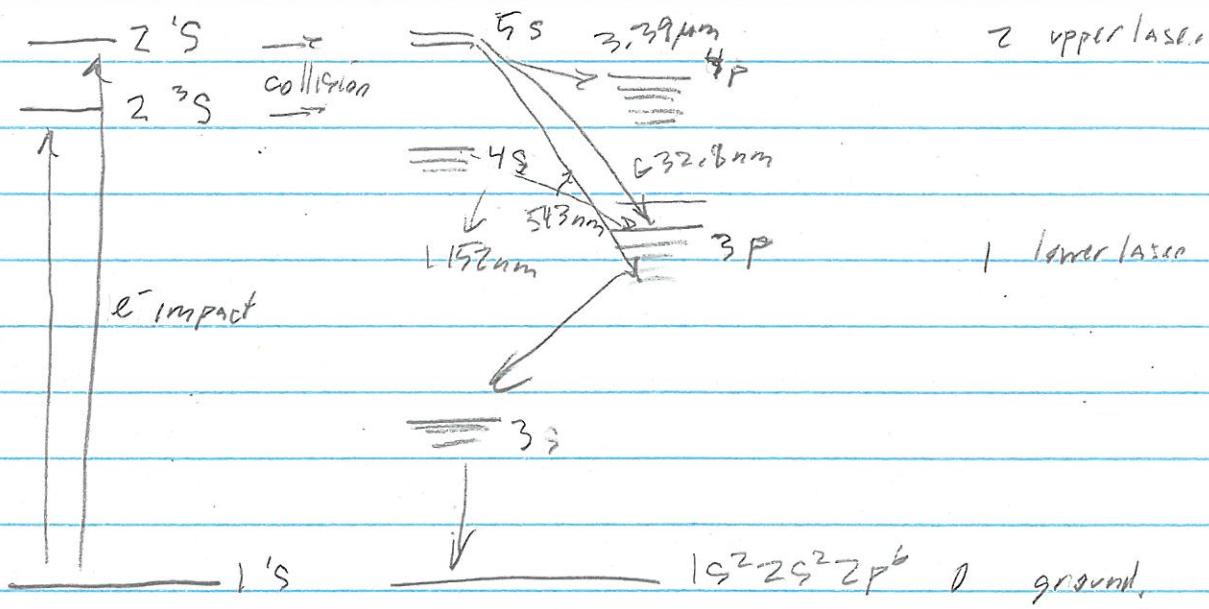
∴ act as reservoir for cw pumping.



- Choose operating λ w/ mirrors
- linewidth dominated by Doppler broadening
- max pumping rate is limited by collisional de-excitation.
- design:- He:Ne partial pressures (5:1 or 9:1)
 - optimize e⁻ temperature
 - total pressure, capillary size.

HeNe level structure

\exists (He)



2 upper laser

1 lower laser

Solid-state lasers

composition:

- host material - crystal YAG, Al_2O_3 , YVO_4 ...

- doping ion - Nd^{3+} , Ti^{3+} , Cr^{3+}

→ doping densities $\sim 1\%$

example system: Nd:YAG (Svalto 9.2.2, K2.1, 2.3)

$\text{YAG} = \text{Y}_3\text{Al}_5\text{O}_1$ yttrium aluminum garnet

isotropic crystal ∴ no natural birefringence.

crystal is grown synthetically

Nd substitutes for Y in crystal

3% difference in size

→ max $\sim 1\%$ conc. of Nd w/o lattice distortion

$\sim 1.38 \times 10^{20}$ ions/ cm^3 ($\sim 10^8$ 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 $4f^1 5s^2 5p^6 5d^6 6s^2$

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

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

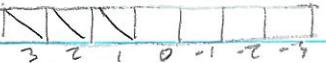
ground state ${}^4I_{9/2}$

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 $\uparrow \uparrow \uparrow \rightarrow S = 3/2$, $2S+1 = 4$

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

Tower energy

- J can range from $L-S$ to $L+S$

$9/2 \ 11/2 \ 13/2 \ 15/2$

excited states.

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

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

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

higher-lying states:

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

$J = 3 - 3/2 = 3/2 \rightarrow 2$ sublevels

this is upper level (storage)

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

$$\text{energy diff: } 11507 \text{ cm}^{-1} - 11423 \text{ cm}^{-1} \\ = 84 \text{ cm}^{-1}$$

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

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

$$\Delta E = 0.1 \text{ meV}$$

230 μs lifetime

$$kT \approx 25 \text{ meV}$$

lower levels of lasing transitions are not thermally pop.

∴ good 4-level laser.

1064 nm \rightarrow $^4I_{15/2} \rightarrow$ ground state ~ 100 's ps best line.

line broadening: 120 GHz see Fig. 2.10 Svelto

thermally-activated lattice vibrations (phonon collisions)

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

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

non-radiative decay of upper level:

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

multi-phonon emission.