Introduction to Laser Physics

LASER: light amplification by stimulated emission of radiation
(MASER was first: microwave, 1954)
Townes, Schawlow

early 60's rapid progress:

1960 Maiman: Ruby laser, Ali Javan: HeNe
1961 Franken: NLO, SHG
1962 Robert Hall: injection semiconductor laser
1964 Kumar Patel: CO_2
Geusic: Nd:YAG

At first: solution looking for a problem.
Now: many applications microscopy + laser cooling
to cutting, welding, fusion

Wide parameter range:

λ: μwave to x-ray
ultra stable narrow band CW to broadband, short pulse
NLO to convert λ: OPO, OPA, harmonics
high average power (100's kW) to single photon
high peak power with short pulses
rapid, ongoing reduction in size, cost, improved efficiency

Laser physics:

application of QM, EM
advanced: statistical, nonlinear dynamics ...
practical/experimental: optomechanics, electronics, plasma, thermal

examples of lasers

microwave : maser NH_3 ammonia

far-IR : CO_2 (10.6 μm)

mid-IR : quantum cascade lasers 4-17 μm

near-IR : Nd:YAG , Ti:sapphire

rare-earth Er, Ho, Yb ...

laser diodes

visible dye lasers

ion lasers Ar^+ Kr^+

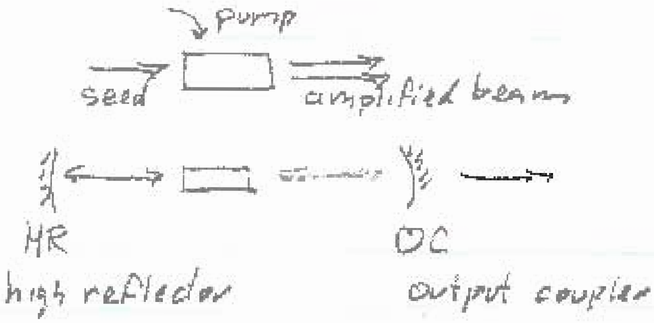
gas, metal vapor HeNe HeCd Cu vapor

UV excimer

x-ray laser plasma

How does a laser work?

need <u>optical gain</u>
<u>feedback</u>



<u>gain</u>: quantum mechanics
stimulated emission is inverse absorption

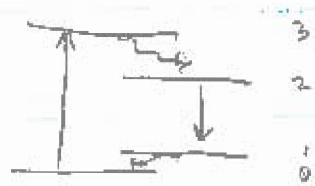
- S.E. must be resonant
- output photon = ħω of input
  = same phase → coherence.

S.E. and absorption are the same process
- different initial conditions
- for ensemble, need $N_2 > N_1$ = population inversion

How? need another level

pump fast enough → $N_2 > N_1$

optical
electrical
discharge
:
pump hard enough...



easier w/ 4 levels:
no population in level 1 → $N_2 > N_1$ with any N_2

note: spontaneous emission → decay
need metastable state in level 2 } rate equations

The role of thermal excitation

for atoms and molecules in a thermal equilibrium with the surroundings the Boltzmann distribution gives the relative populations

$$\frac{N_2^e}{N_1^e} = \frac{g_2}{g_1} e^{-\frac{(E_2-E_1)}{kT}}$$

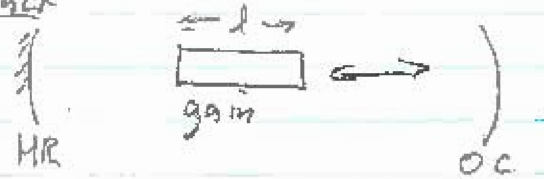
∴ no population inversion in equilibrium
amplification is intrinsically non-eqm!

example: if $\frac{N_2^e}{N_1^e} \approx e^{-1}$ at room temperature
$T = 300K \rightarrow kT \approx 1/40\ eV$
for $\Delta E_{21} = 0.025\ eV \rightarrow \lambda_{21} = 48\ \mu m$

most 4-level systems $\Delta E_{10} \gg 1/40\ eV \rightarrow N_1 \sim 0$

"quasi-3-level" $\Delta E_{10} \approx kT$
lower levels are partially populated.

feedback



resonator to confine light → many passes
- ray confinement
- EM mode

positive feedback → build up of power
loss to output

Laser threshold: gain = loss

$$G_0^2 \cdot R_1 \cdot R_2 \; (1-L) = 1 \quad \text{at threshold}$$

small signal gain; mirror reflectivities; ↳ passive loss

alternative $\quad G_0 = e^{gl}$ $\quad$ express losses in exponent

$R_1 = e^{-\gamma_1}$ etc. $\quad \gamma_1 = -\ln R_1$ log. loss

$$\rightarrow e^{2gl} \cdot e^{-\gamma_1} e^{-\gamma_2} e^{-\gamma_p} = 1$$

$$2gl - \gamma_1 - \gamma_2 - \gamma_p = 0$$

pump above threshold? gain > loss → more output
- gain is limited by available pump
→ gain saturation.

Dynamics:

turn on pump → build-up power → oscillations → stabilize.
can control for pulsed lasers (Qswitching)