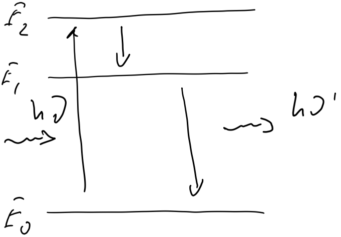
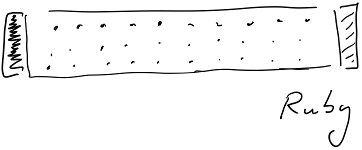
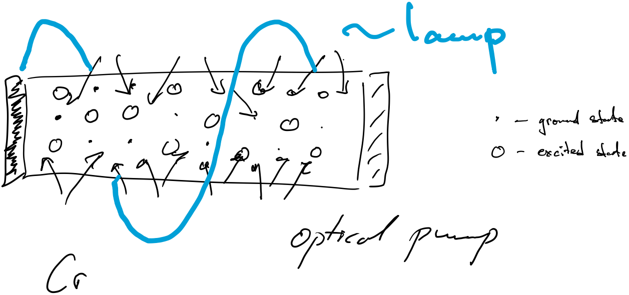
Physical principle of laser and generation of ultrashort optical pulses

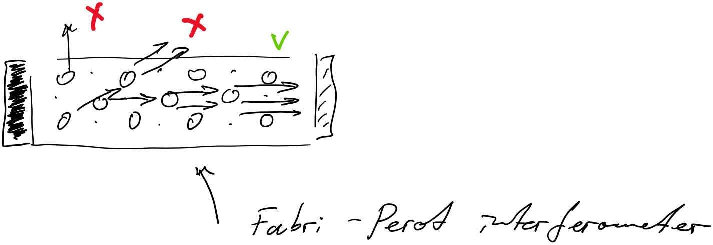

E_2
E_1
$h\nu$
$h\nu'$
E_0



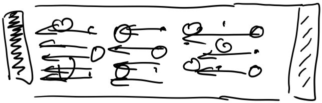
1)


~ lamp
· – ground state
○ – excited state
optical pump
Cr

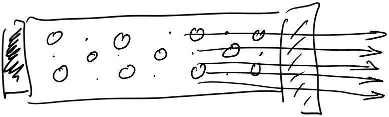
2)


Fabri - Perot interferometer

3)

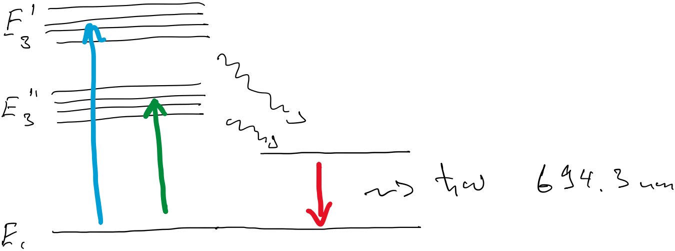


4)

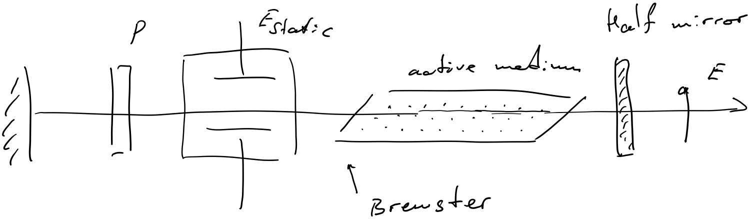


Ruby laser

$Al_2O_3 + 0.05\% \, Cr$


F'_3
E''_3
E_1
$\rightsquigarrow \hbar\omega$ 694.3 nm

To increase inverse population we can use modulation.

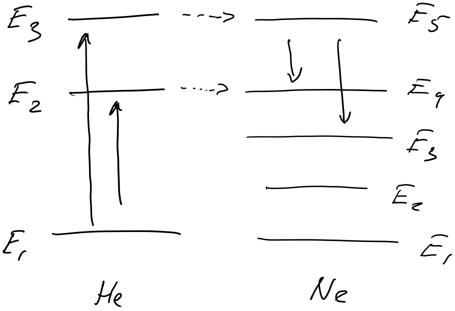

P
E_{static}
Half mirror
active medium
E
Brewster

$P \perp \vec{E}$ $E_{static} = 0$ → resonator is closed

$E_{static} \neq 0$ → resonator is open

This is Q-switching

He - Ne laser


E_3
E_2
E_1
He
E_5
E_4
E_3
E_2
E_1
Ne

He can be excited through collissions with electrons

Ne is too heavy for collission excitation but can receive energy from He.

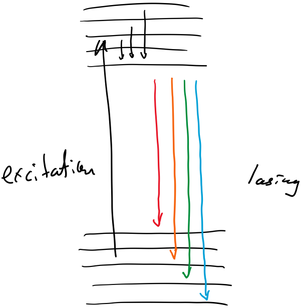
$\bigcirc \rightarrow He \rightarrow Ne$

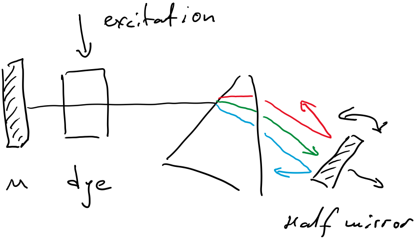
$\bar{e}$

Dye lasers

Rhodamine 6G

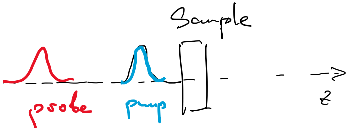
Thanks to large amount of p orbitals there is distinct and strong absorption of such organic molecules.

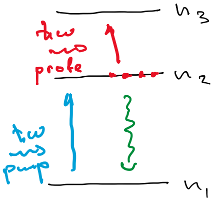

excitation
lasing

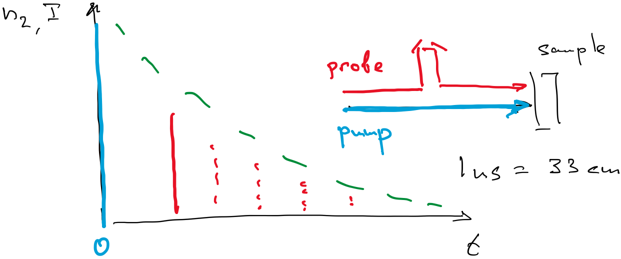

excitation
M
dye
half mirror

Mechanical analogue of fs laser

Time-resolved spectroscopy


Sample
probe
pump
z


n3
ħω
probe
n2
ħω
pump
n1



1ns = 33 cm ≈ 1 ft

Continuous wave vs fs lasers

1) Sun constant

$I = 0.15 \frac{W}{cm^2}$ → at all spectrum

2) He-Ne laser

P = 10 mW

ω = 1 mm

$I = 0.1 \frac{W}{cm^2}$ → at one particular frequency

3) FS pulse

$\tau = 100 \cdot 10^{-15}$ s

$P = 1\,mW$

$R = 1000\ Hz$ $\Rightarrow I \sim 10^{9}\ \frac{W}{cm^{2}}$

$w = 1\ mm$

Let's see now the field of proton the electron is in:

$e = 1.6 \cdot 10^{-19}\ C$

$r_0 = 5.3 \cdot 10^{-11}\ m$ → first Bohr radius

$\varepsilon_0 = 9 \cdot 10^{-12}\ \frac{S}{V \cdot m}$

$$E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{e}{r_0^2} \sim 10^{12}\ \frac{V}{m}$$

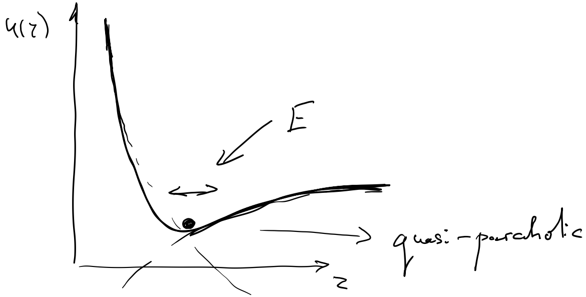
Now let's see what are the fields we can induce with He-Ne and fs:

① He-Ne

$I = 0.1\ \frac{W}{cm^2}$

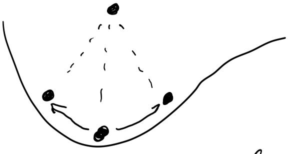
$$E = \sqrt{\frac{2I}{\varepsilon_0 c}} \sim 3\ \frac{V}{m}$$

What does it mean?


u(z)
E
quasi-parabolic
z

For He-Ne laser $E_{He-Ne} << E_{atom}$

That is small perturbation and described by simple perturbation theory.

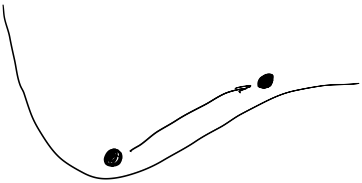


Electron behaves like ball on a spring.

Here we can define linear optics — light matter interaction, when displacement of electron from equilibrated state is minimal — pendulum.

② Let's take fs pulse.

$$E = \sqrt{\frac{2I}{\epsilon_0 c}} \sim 10^9 \frac{V}{m}$$

That becomes very comparable to the field of proton. We can kick electron away from the orbit or ionize: