Optical methods in chemistry
or
Photon tools for chemical sciences

Session 5:

Course layout – contents overview and general structure

- Introduction and ray optics
- Wave optics
- Beams
- From cavities to lasers
- More lasers and optical tweezers
- From diffraction and Fourier optics
- Microscopy
- Spectroscopy
- Electromagnetic optics
- Absorption, dispersion, and non-linear optics
- Ultrafast lasers
- Introduction to x-rays
- X-ray diffraction and spectroscopy
- Summary

Todays learning goal:

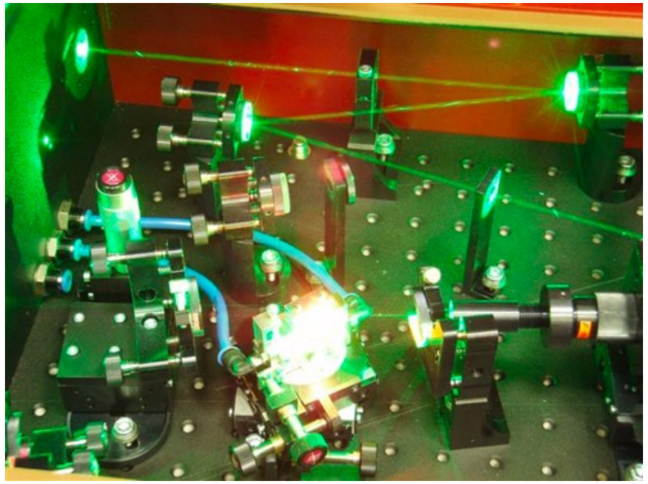
Understand wide variety of lasing transitions

Appreciate particle character of light

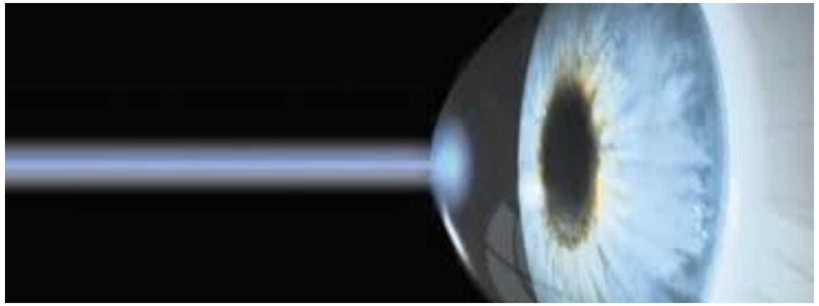
Have fun with optical tweezers

Most likely you will encounter lasers in your career

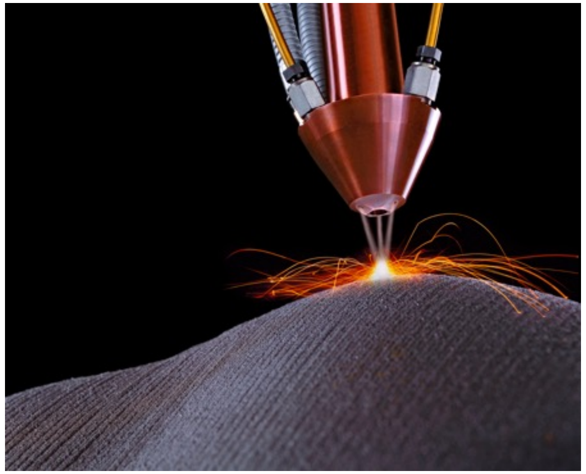
Research



Medical applications



Manufacturing

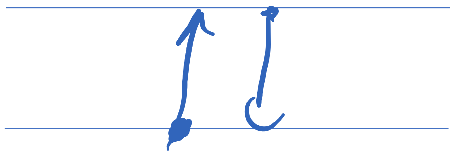


Navigation

Communications

2, 3, 4 level systems

2 level system

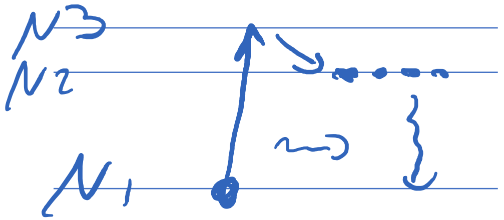


population inversion is <u>not</u> possible even with highest flux

think high flux & medium becomes transparent

↳ stimulated emission and absorption are in balance

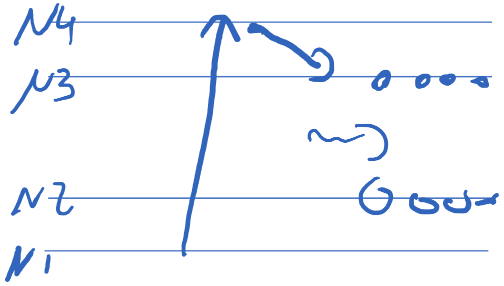
3 level system



Lasing line → N_2 populated over time

→ inversion

4 level system



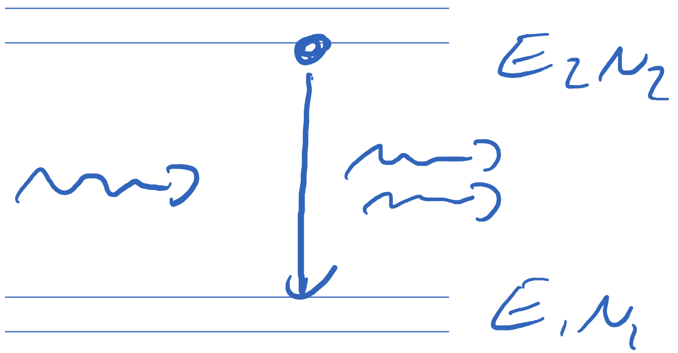
Lasing line

Fundamental concept of laser

F – flux

$$dF = \sigma_{21}\, F\, (N_2 - N_1)\, dz$$

transition probability, flux, population



need population inversion

$$\frac{dF}{dz} > 0$$

possible if $N_2 > N_1$

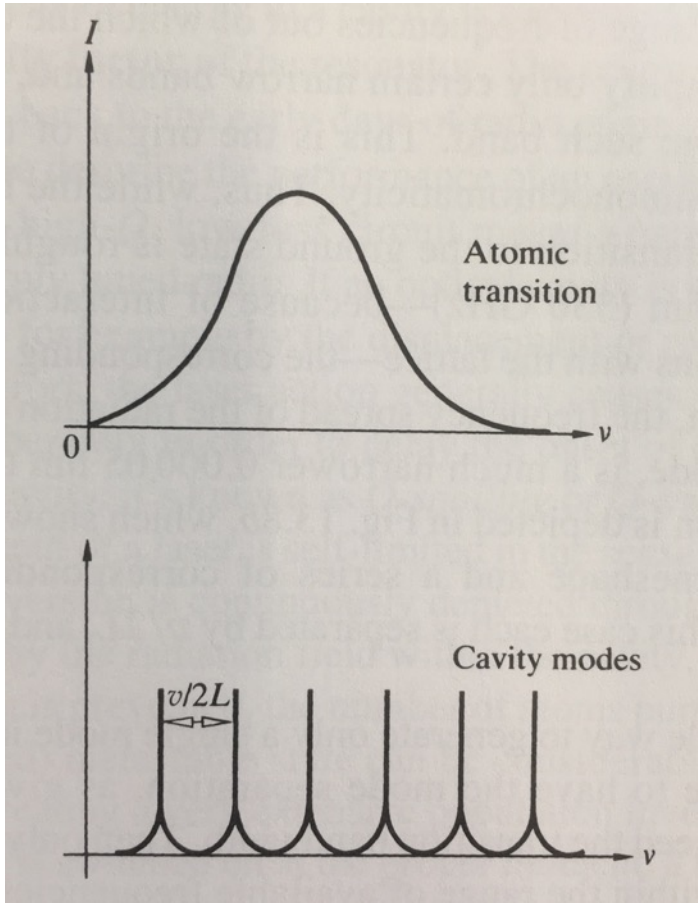
Note: The gain must always be higher than the losses!

Fundamental concept of laser oscillator:

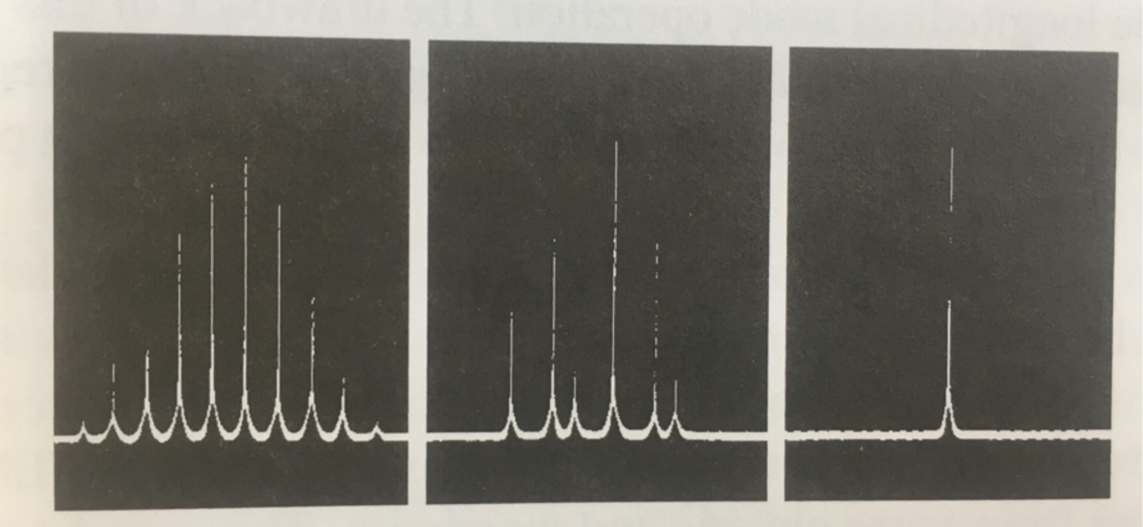
Note: The gain must always be higher than the losses!

Lasers and laser cavities

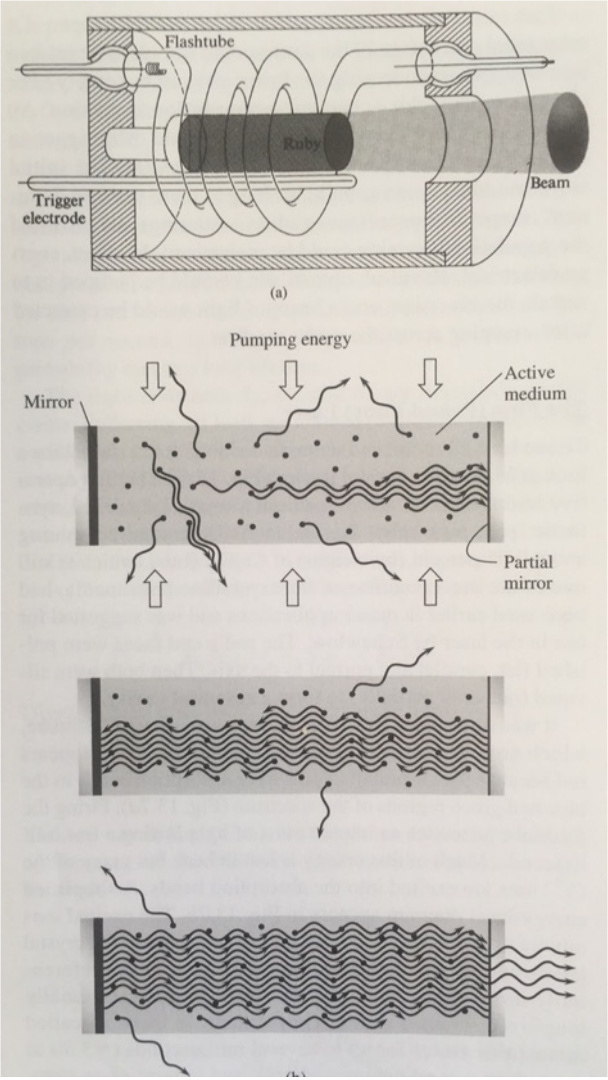
Atomic lines vs cavity modes

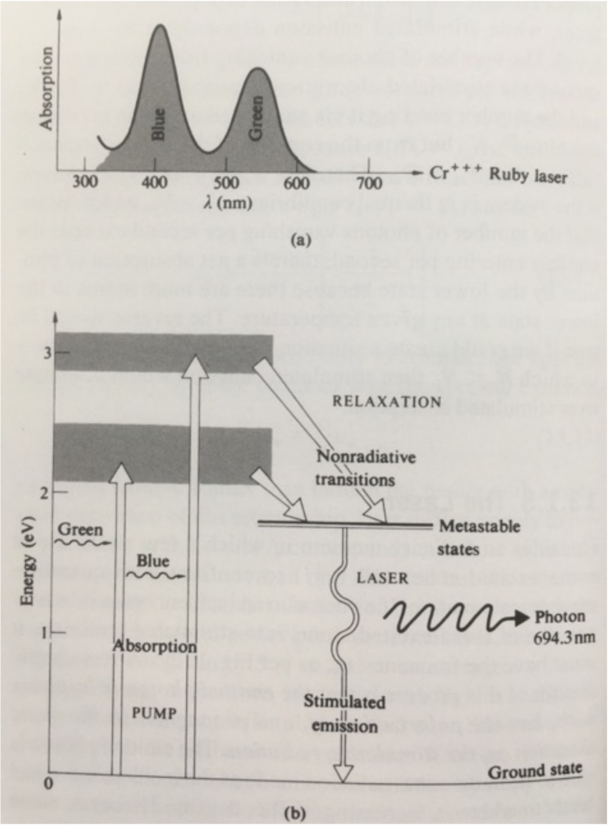


Mode selection



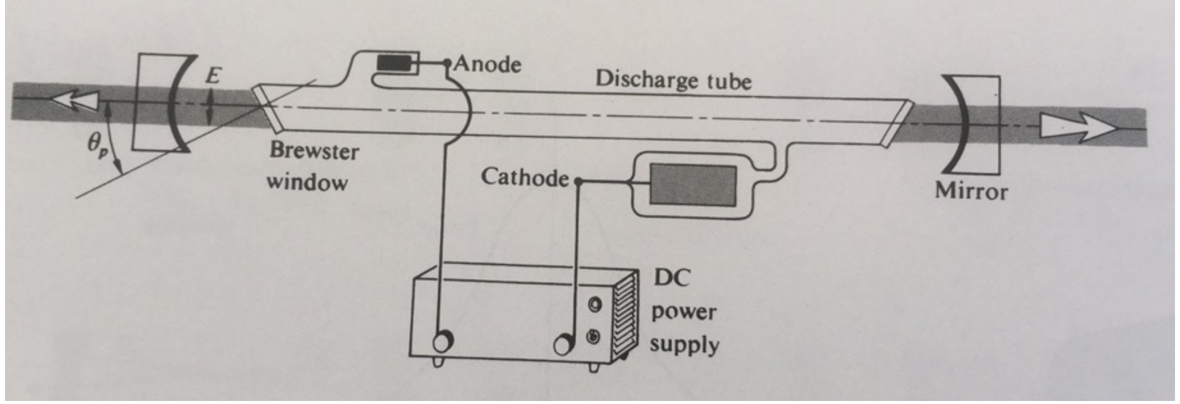
The Ruby laser

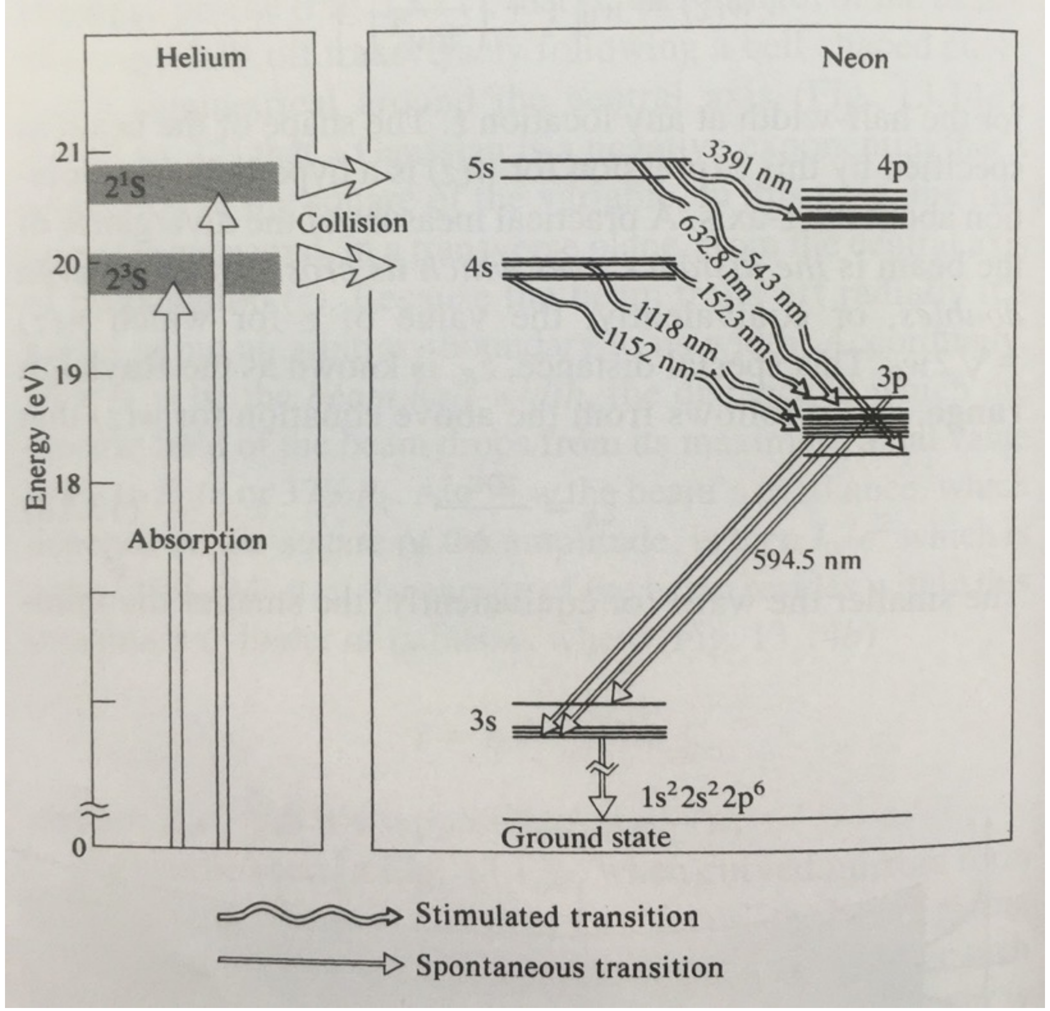




For fun https://www.youtube.com/watch?v=yV09p5LY7GA

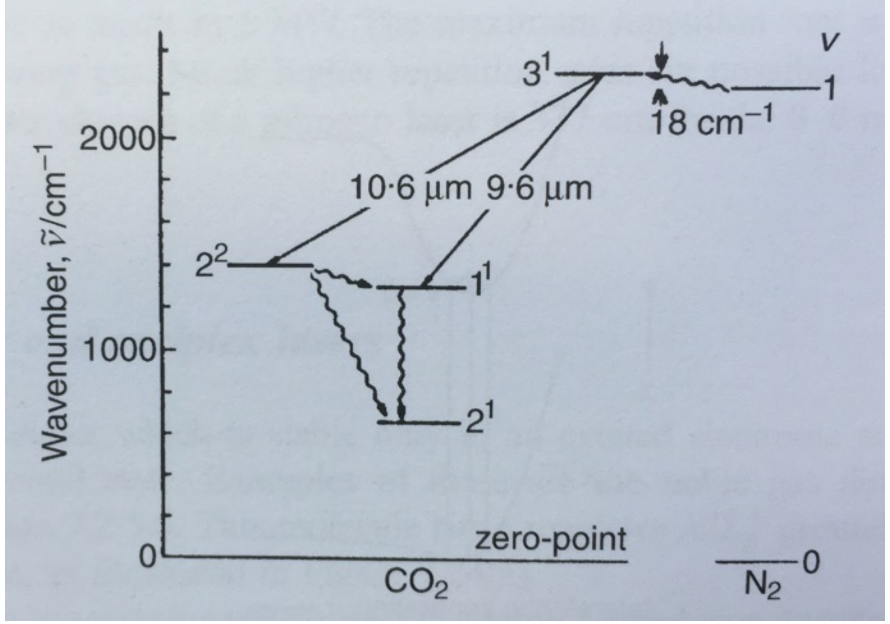
The Helium Neon Laser - HeNe





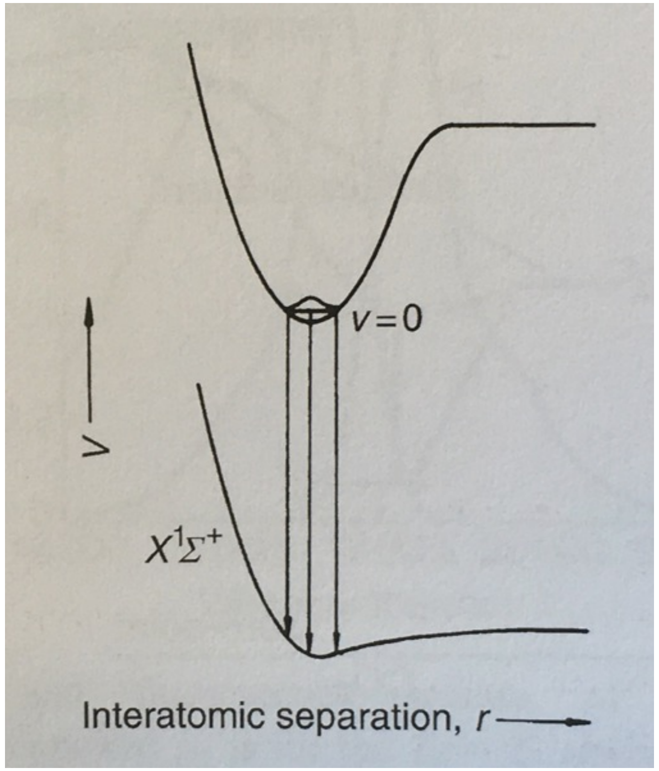
Selected laser examples: Molecular gas laser

- Example: CO_2 laser
- Output in the mid-IR region
- High-power cw laser
- Machining and medical applications



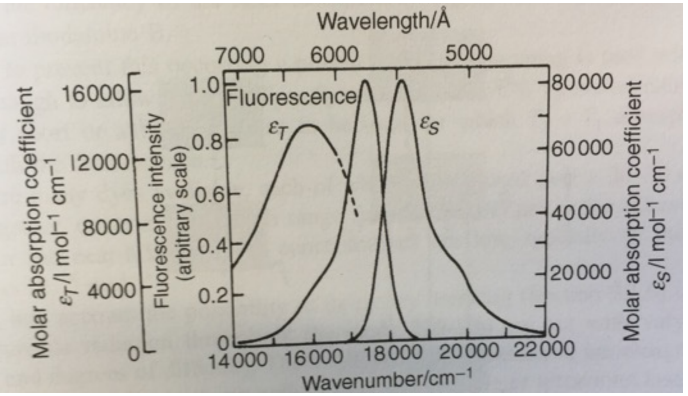
Selected laser examples: Excimer laser

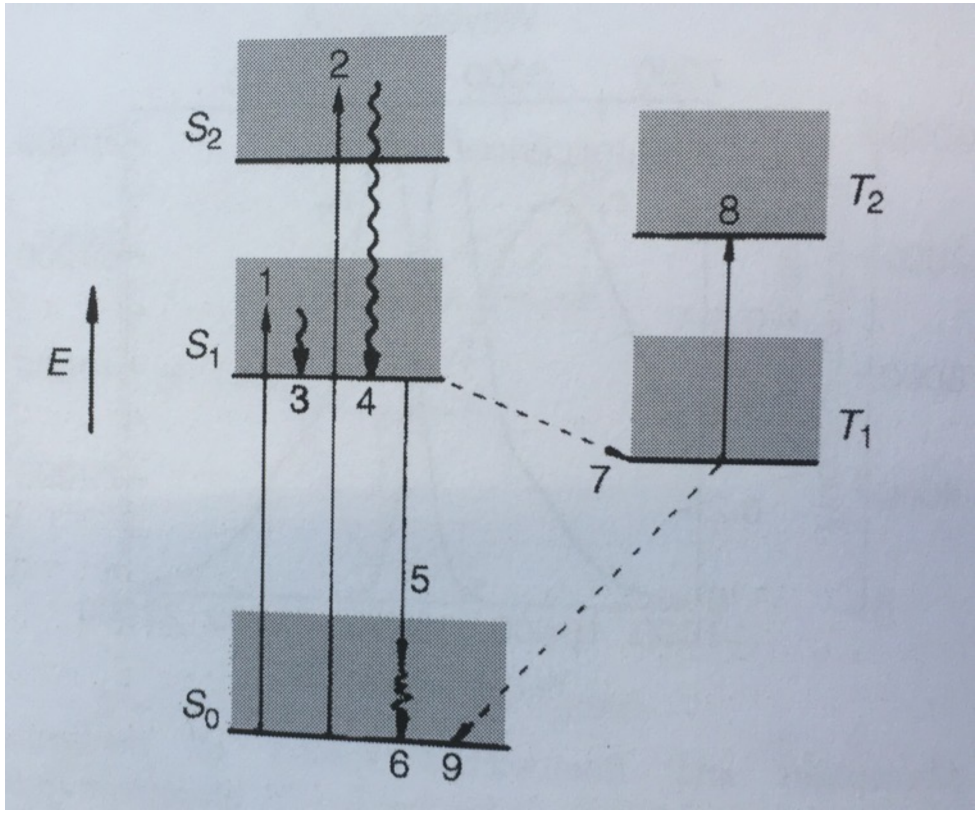
- Excimer – ”excited dimer”
- Important for output in UV spectral region
- UV processing, medical applications
- Pulsed, high output



Selected laser examples: Dye laser

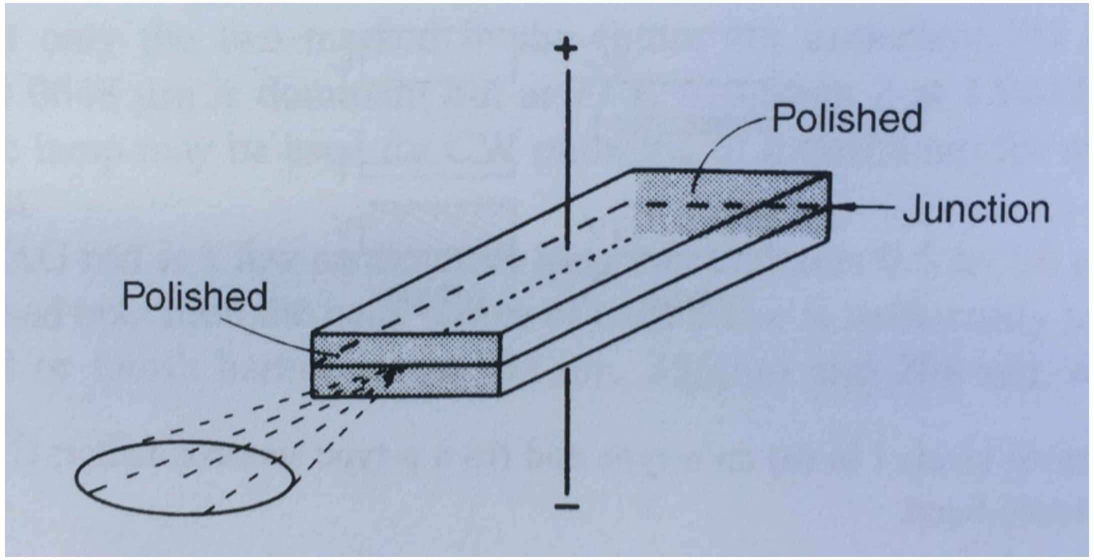
- Tunable over large wavelength regime
- Organic dyes in solution
- High maintenance, mostly replaced by solid state lasers





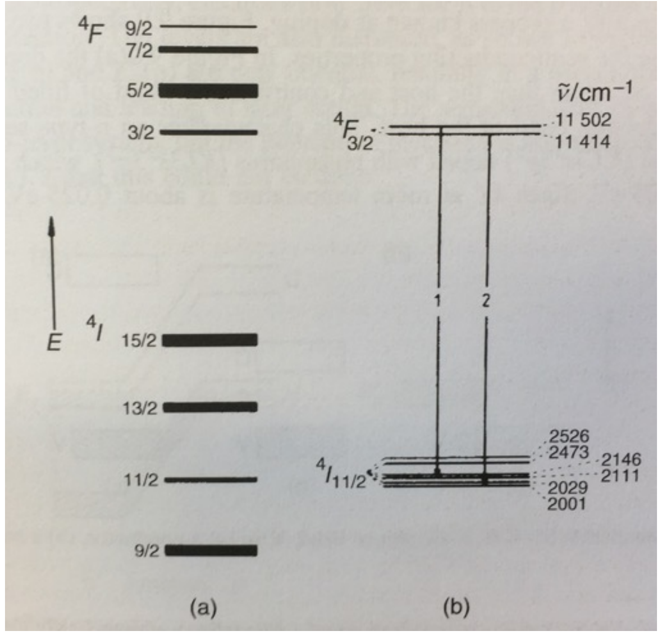
Selected laser examples: Semiconductor laser

- Based on solid state devices
- Light emitted at junction of two semiconductors
- Transitions between bands
- Compact, integrate able, …

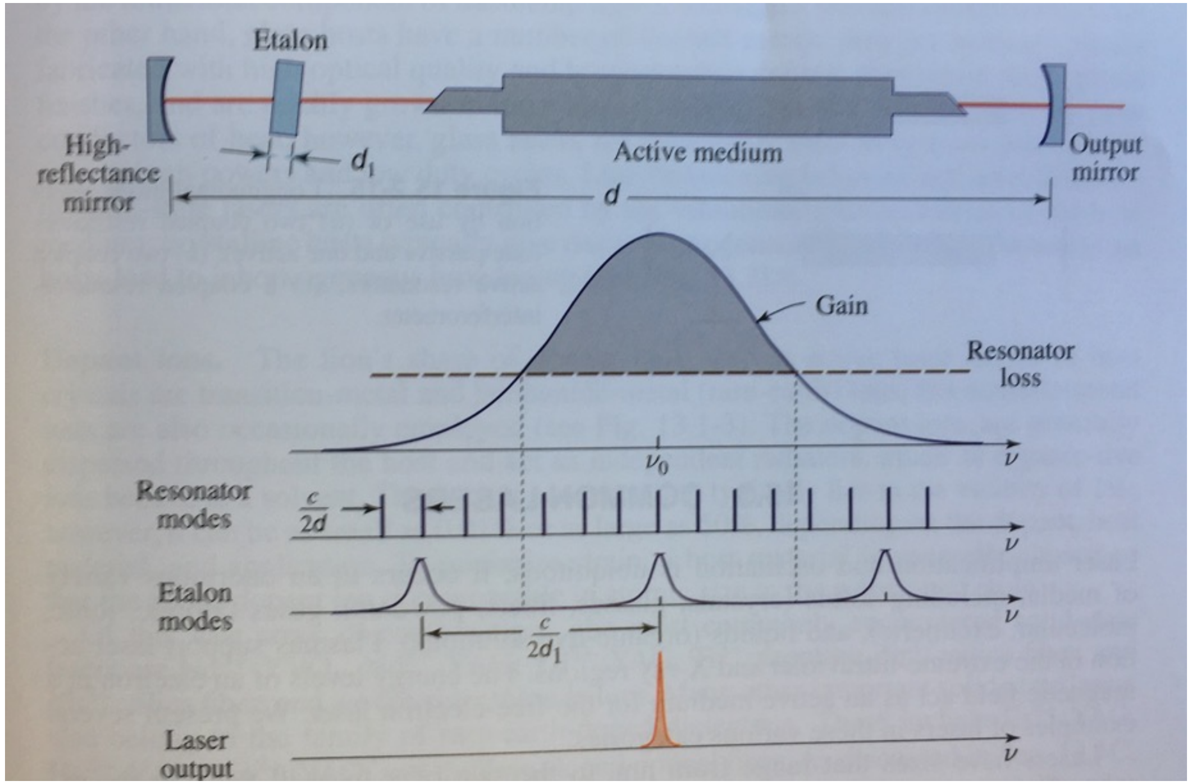


Selected laser examples: Nd:YAG

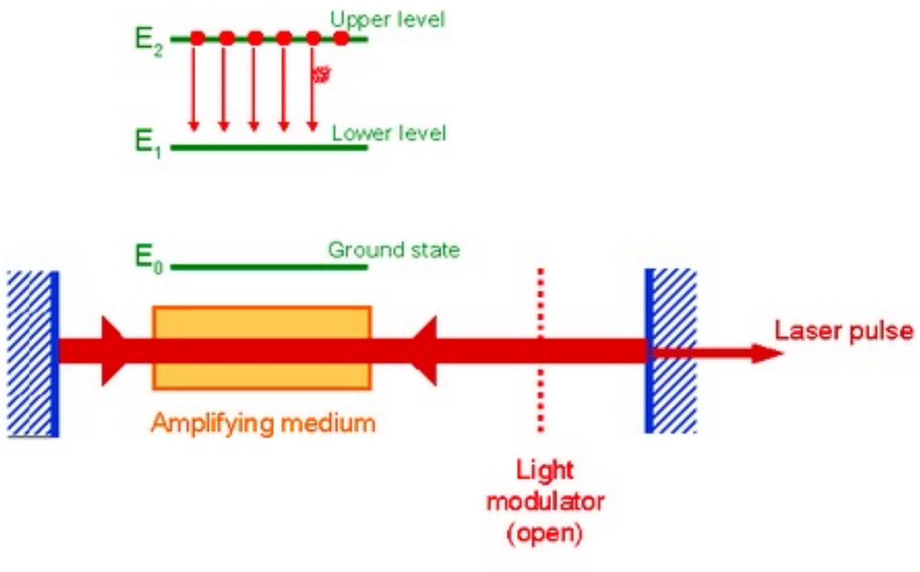
- Neodym doped Yttrium-Aluminium-Granate
- Nd3+ ions in glass matrix
- Solid state laser
- Main line 1064 nm
- Work horse laser in many laboratories

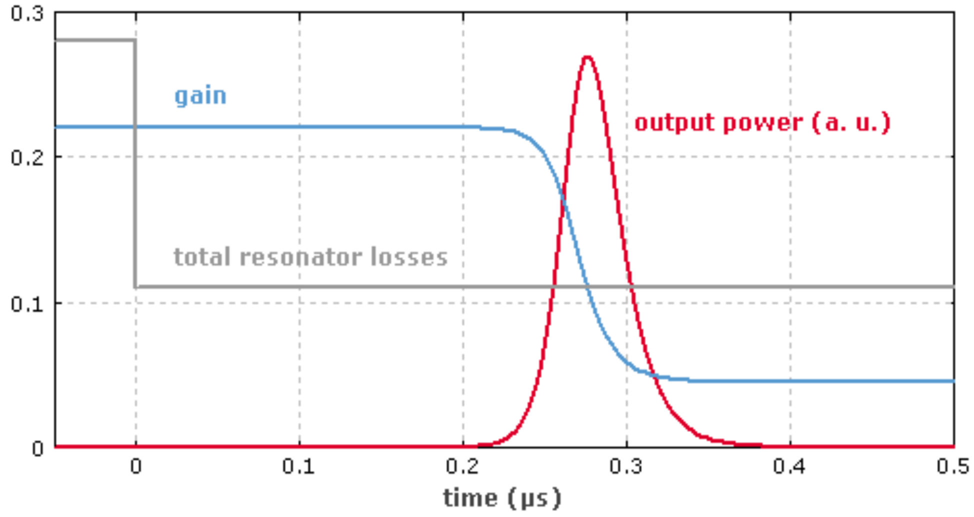


Better approach: Mode selection with intracavity etalon



Q Switching

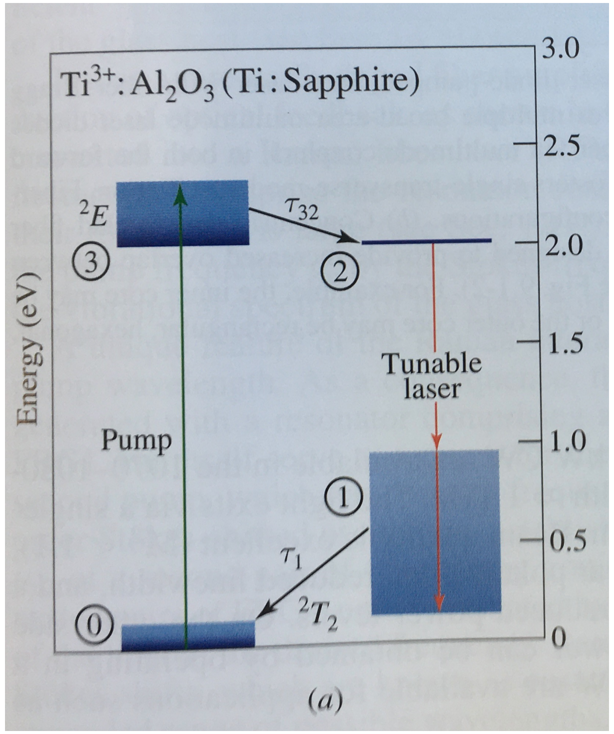


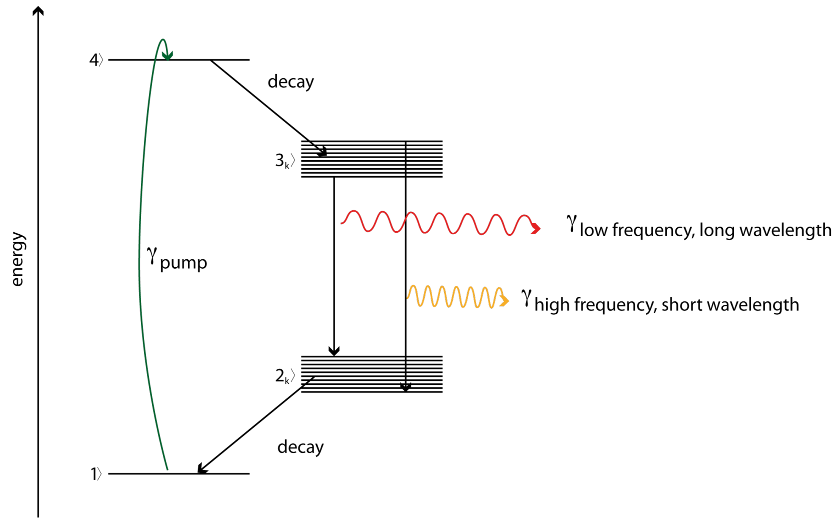


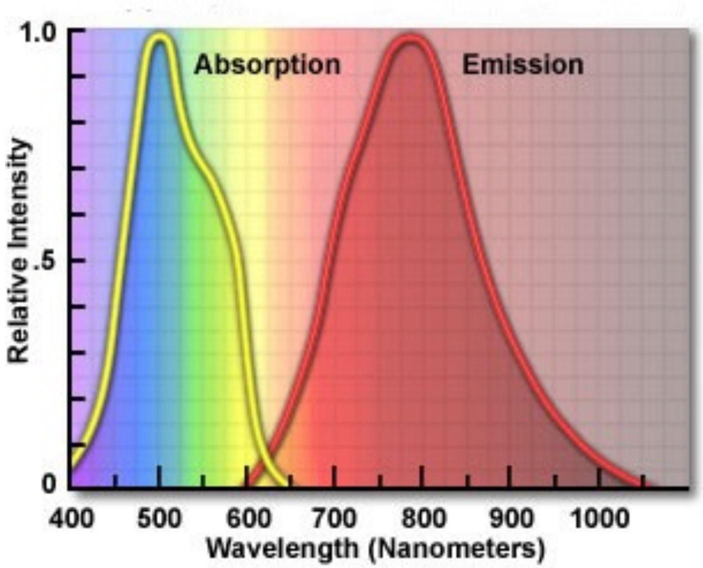
See video at: https://www.rp-photonics.com/q_switching.html

Important laser: TiSa

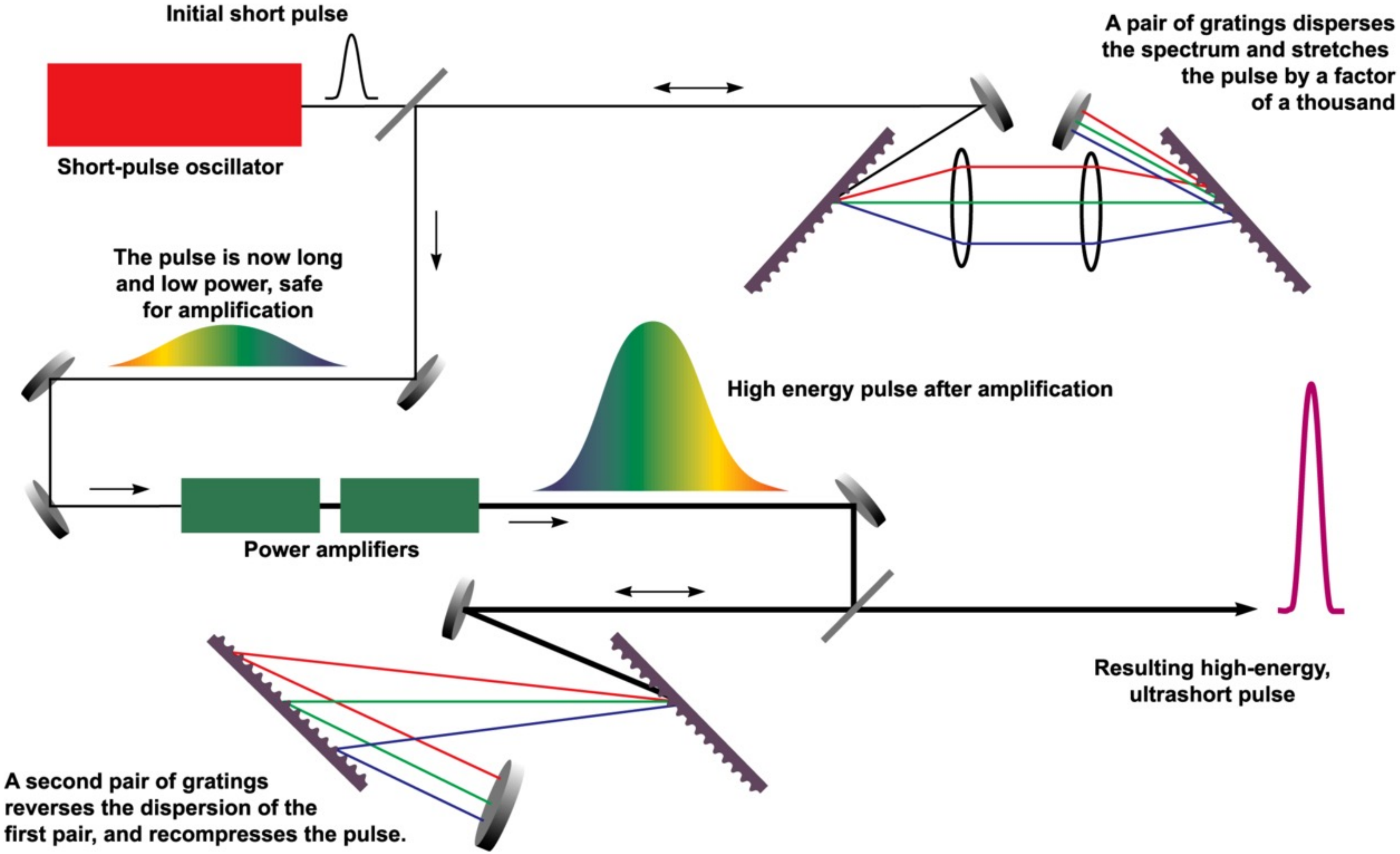
- Ti^{3+} ions in Al_2O_3 (Saphire)
- Tunable, broad bandwidth
- Can provide ultrashort pulses
- Workhorse laser for ultrafast sciences





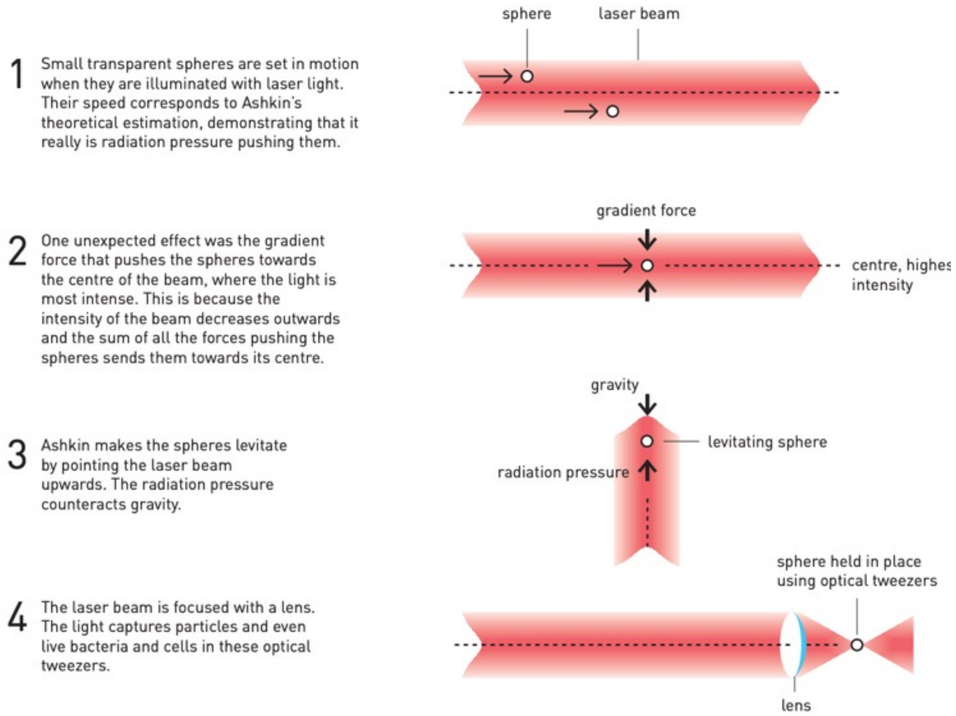


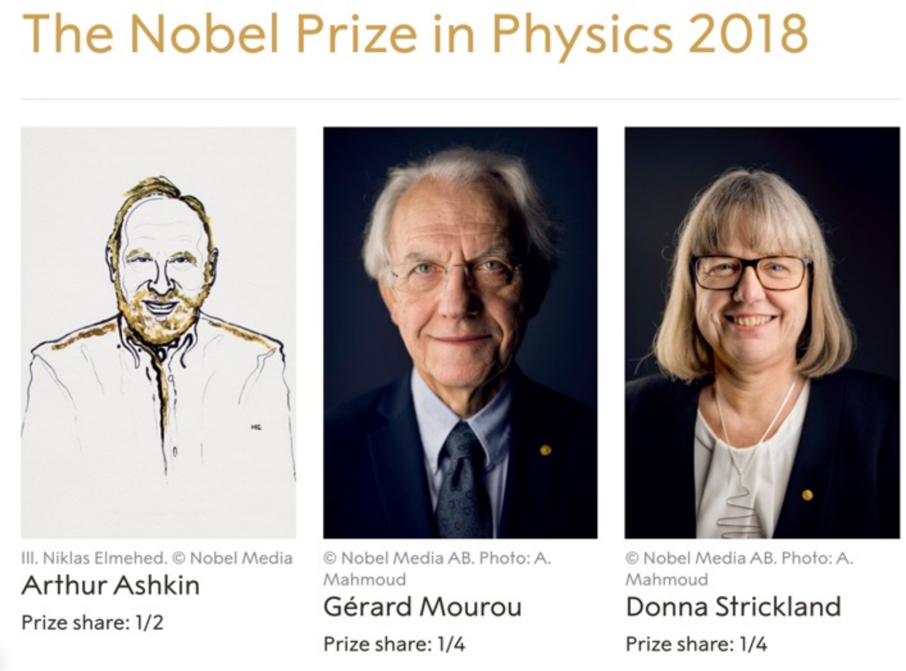
Chirped pulse amplification



Optical tweezers

Back to Session 1





Optical tweezers:
https://www.youtube.com/watch?v=ju6wENPtXu8

The inventions being honoured this year have revolutionised laser physics. Extremely small objects and incredibly fast processes now appear in a new light. Not only physics, but also chemistry, biology and medicine have gained precision instruments for use in basic research and practical applications. Arthur Ashkin invented optical tweezers that grab particles, atoms and molecules with their laser beam fingers. Viruses, bacteria and other living cells can be held too, and examined and manipulated without being damaged. Ashkin's optical tweezers have created entirely new opportunities for observing and controlling the machinery of life. Gérard Mourou and Donna Strickland paved the way towards the shortest and most intense laser pulses created by mankind. The technique they developed has opened up new areas of research and led to broad industrial and medical applications; for example, millions of eye operations are performed every year with the sharpest of laser beams.

Remember some basic properties of the photon

- Photon: Massless particle with

- Energy

- Momentum

From classical physics we know that action = reaction. That is Newtons third law.

First law: In an inertial frame of reference, an object either remains at rest or continues to move at a constant velocity, unless acted upon by a force.

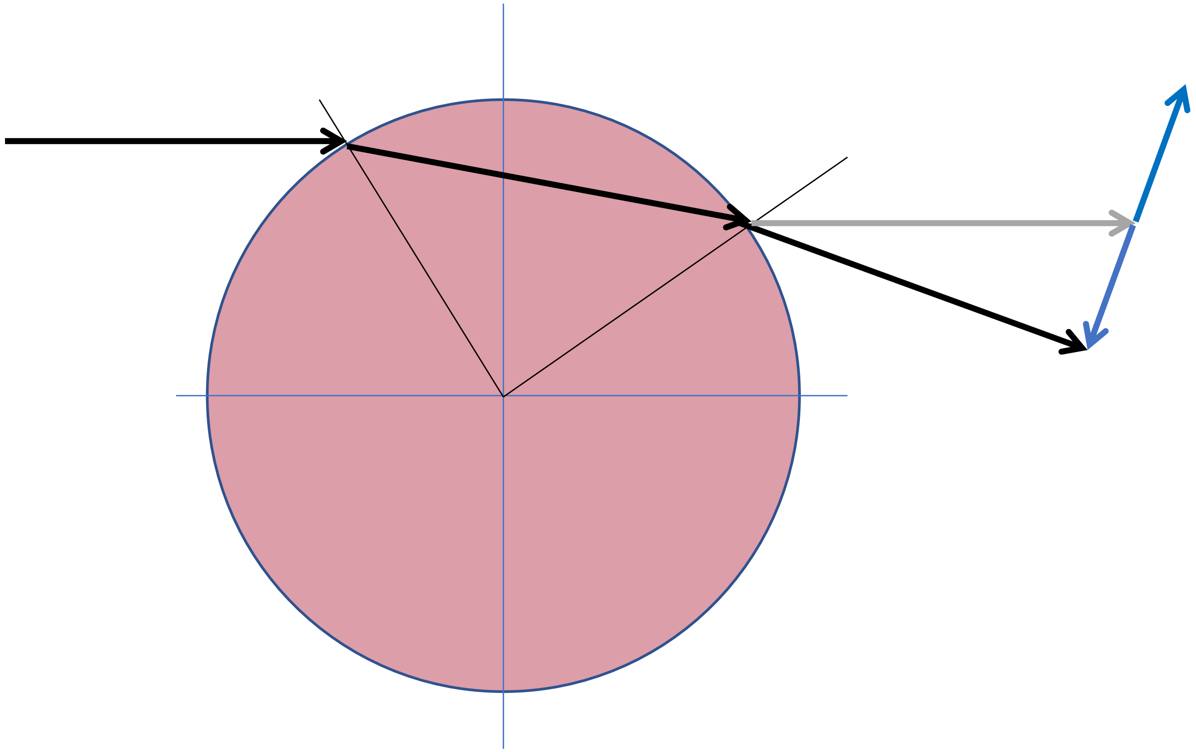
Second law: In an inertial frame of reference, the vector sum of the forces $\mathbf{F}$ on an object is equal to the mass m of that object multiplied by the acceleration $\mathbf{a}$ of the object: $\mathbf{F} = m\mathbf{a}$.,

Third law: When one body exerts a force on a second body, the second body simultaneously exerts a force equal in magnitude and opposite in direction on the first body.

Light going through a lens:

- Ray optics
- Momentum vectors

Now: Not a lens but a small particle in a (homogenous) light field



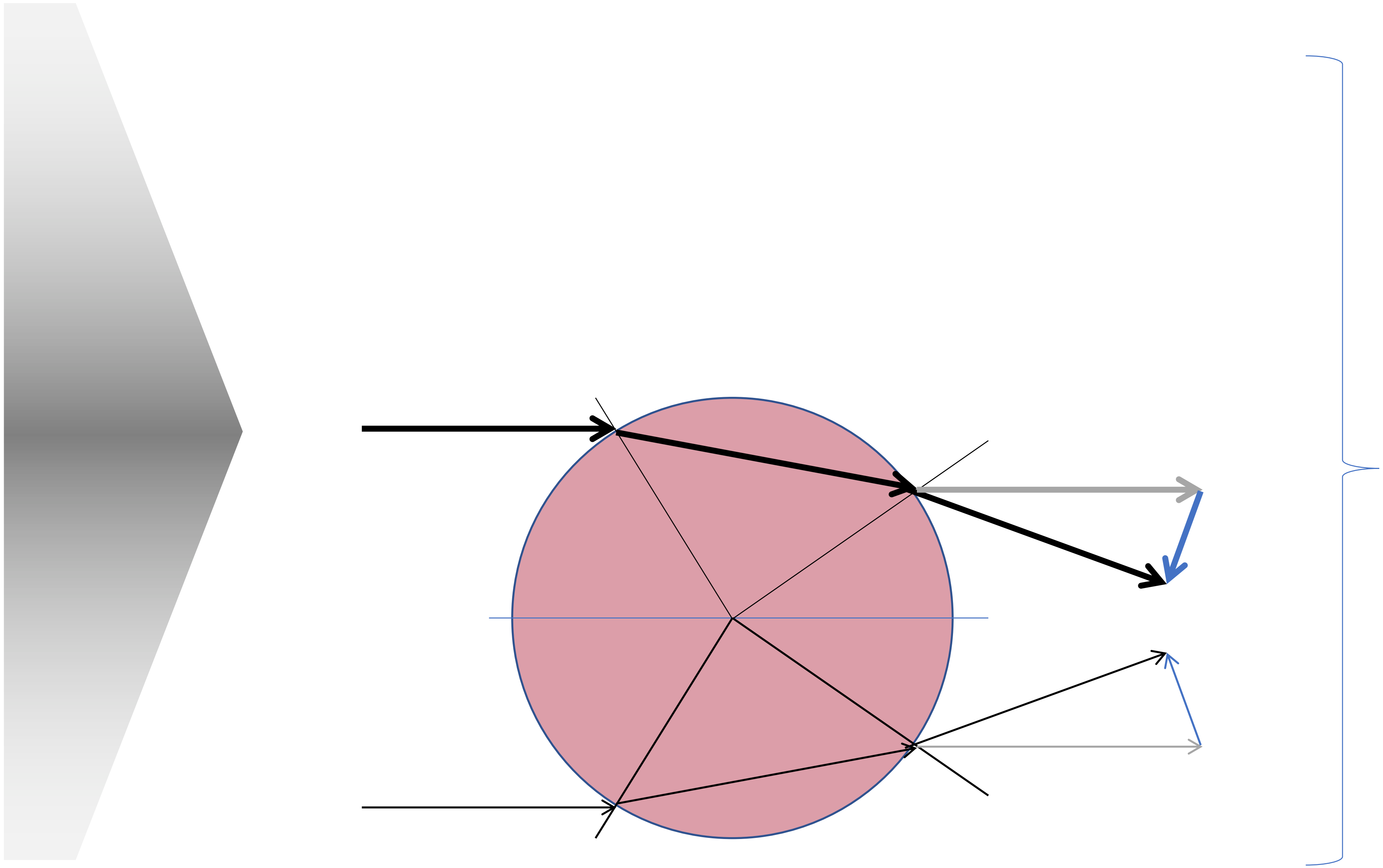
Some boundary conditions:

- Optically thicker sample in optically thinner medium
- Transparent sample, i.e., negligible scattering and reflection compared to transmission

Process:

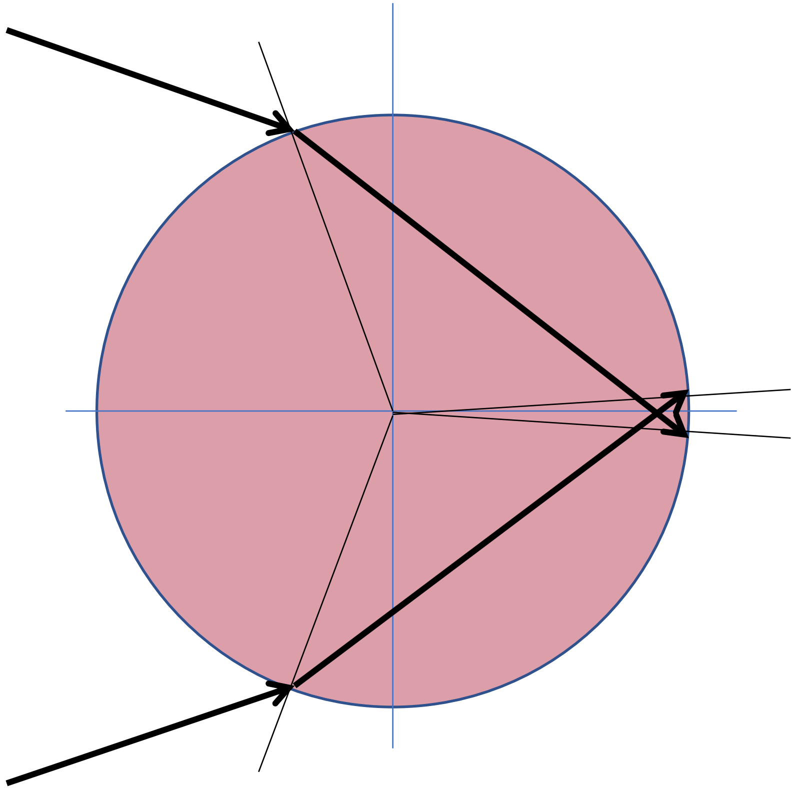
- Rays are refracted, leading to momentum change
- Action equals reaction, sphere is pushed ………..wards
- With equal illumination there is……

But we learned: Laser beam has a Gaussian beam profile. More intense in center!

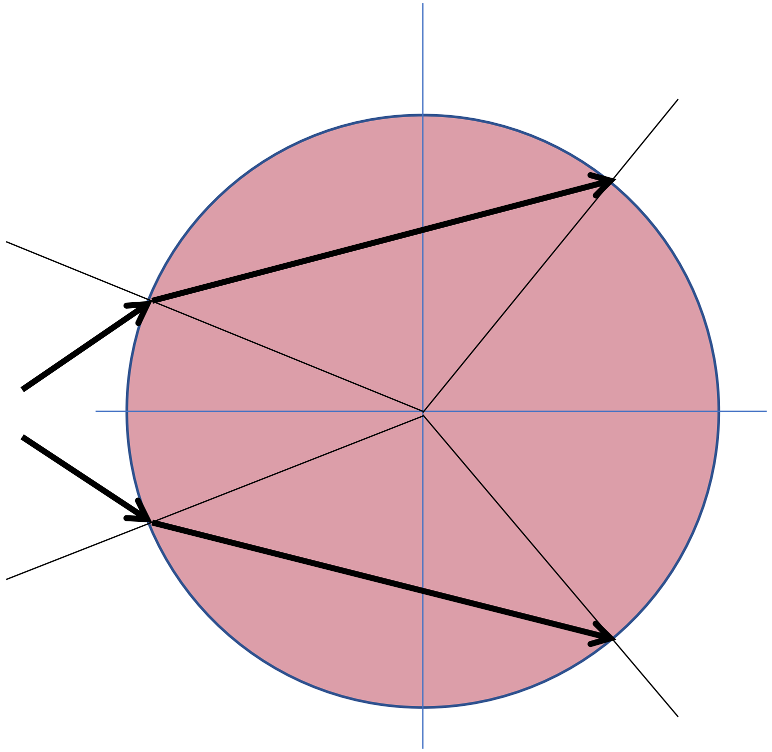


Now before and after focus

Particle before to focus



Particle behind to focus



For transparent particles much larger than wavelength we can use ray optics and momentum transfer considerations.

And it works nicely:

https://www.youtube.com/watch?v=BPN90U4yzBc

Catching and moving in liquids

https://www.youtube.com/watch?v=mnbhoTKGzPI

The end.