Optical methods in chemistry
or
Photon tools for chemical sciences

Session 4:

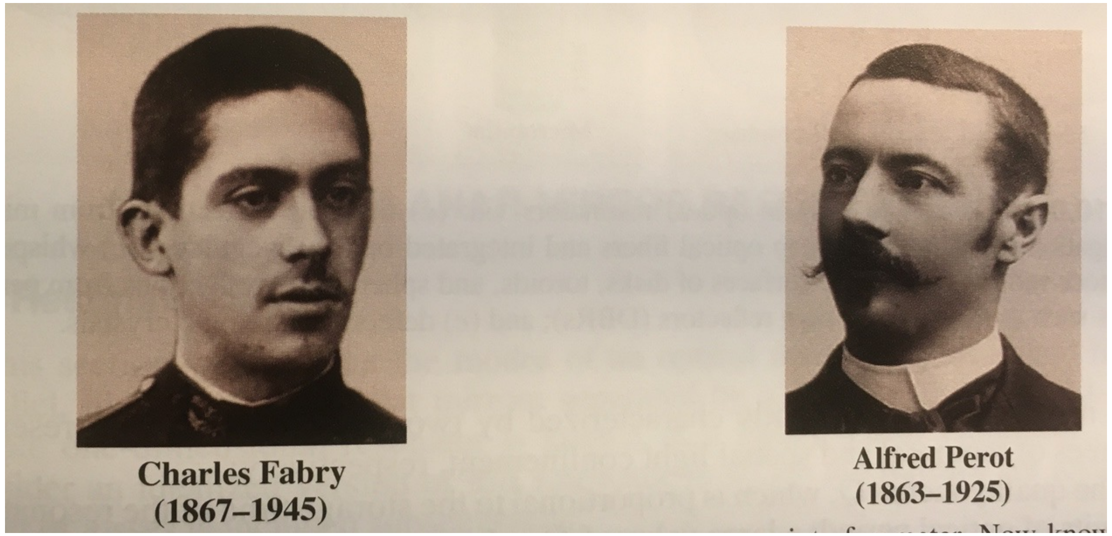
Course layout – contents overview and general structure

- 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:

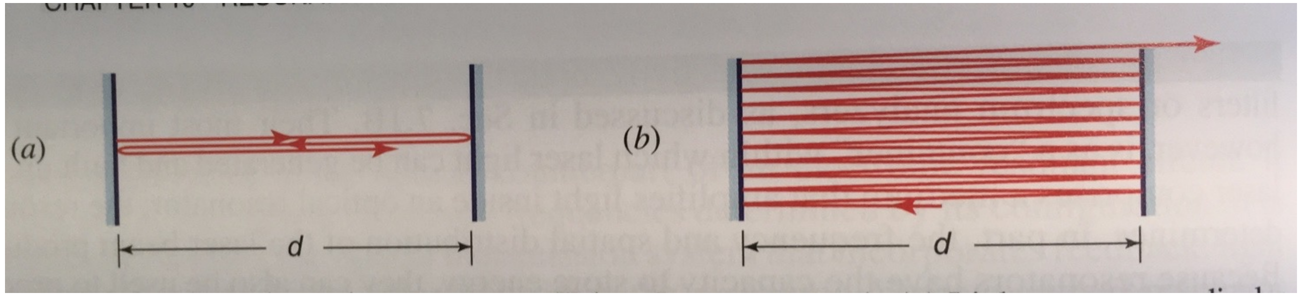
Understanding cavities and the principles of lasers

Optical resonantors (“cavities”)

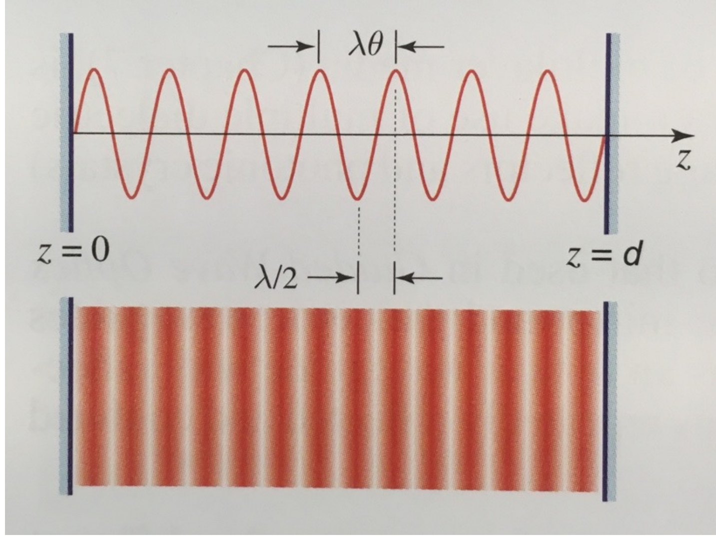


Fabry-Perot Resonator

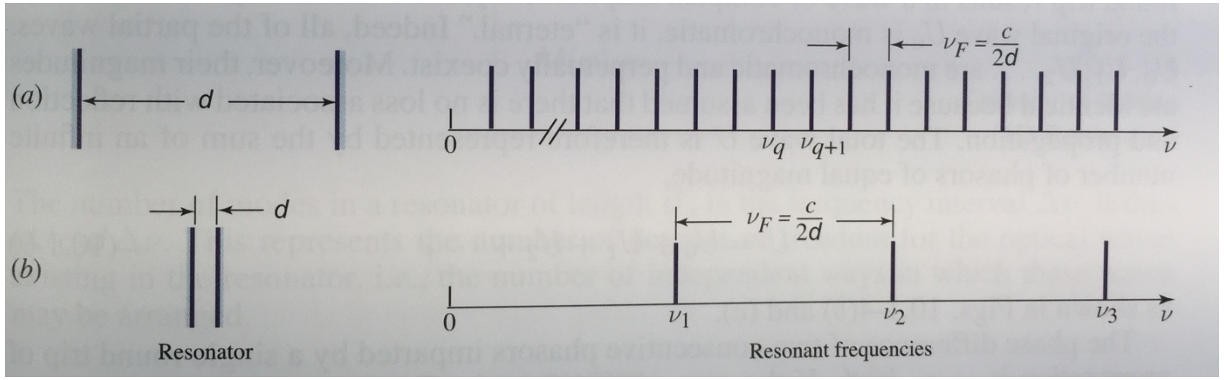
Idea: Trap light between highly reflective mirrors



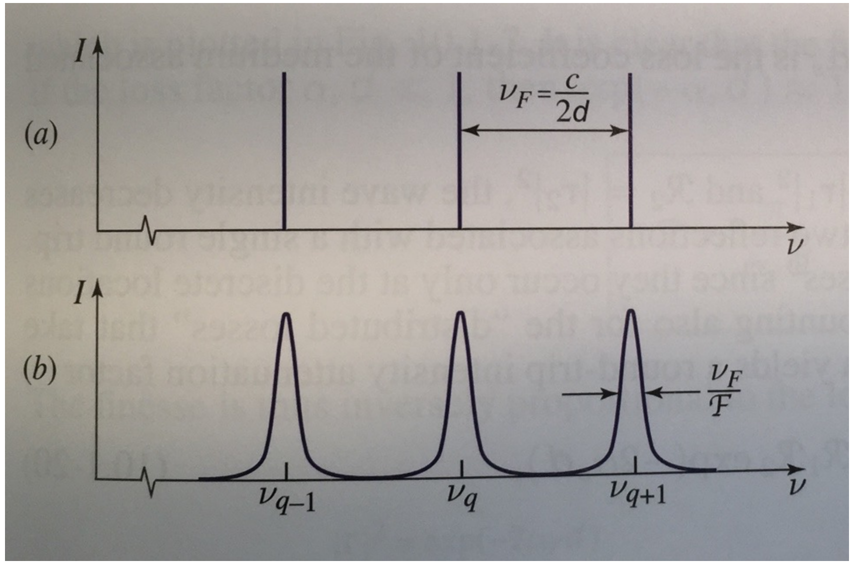
Standing waves represent resonator modes



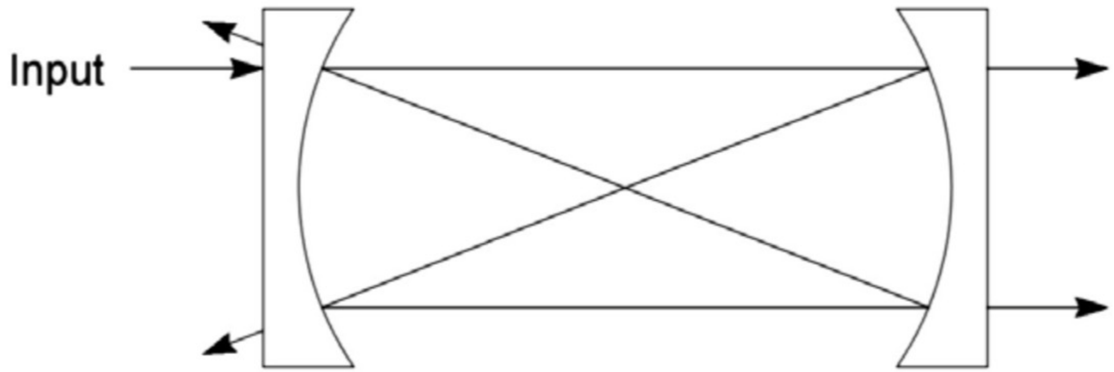
Properties of the Fabry Perot Resonator

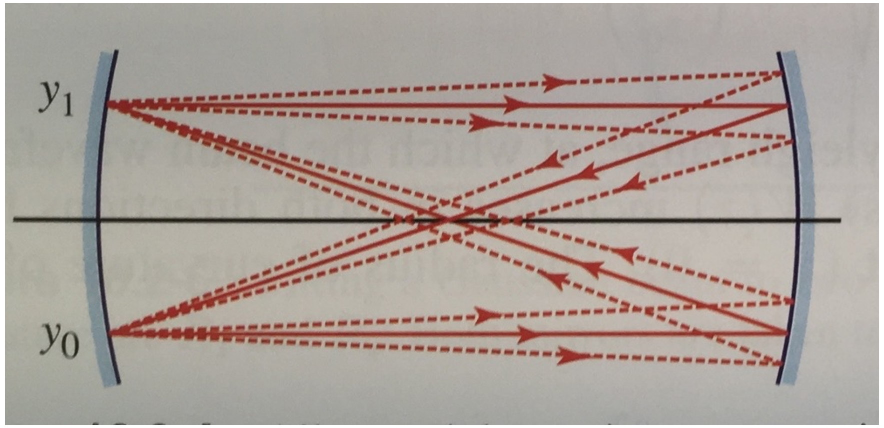


Ideal vs real resonator – real is with losses

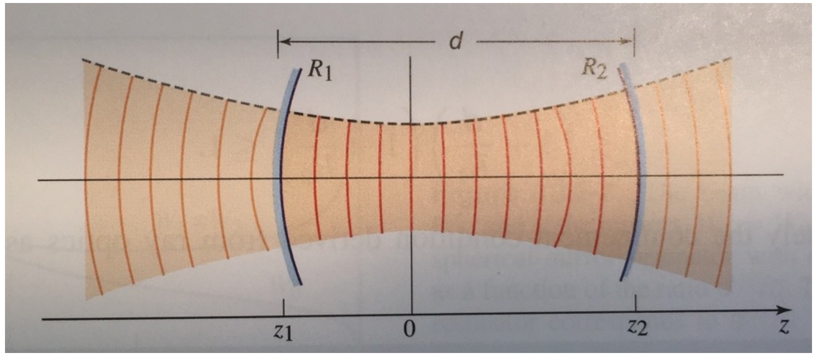


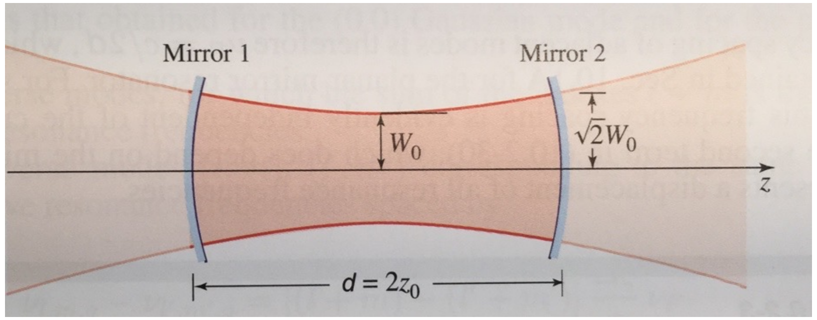
Spherical Resonator



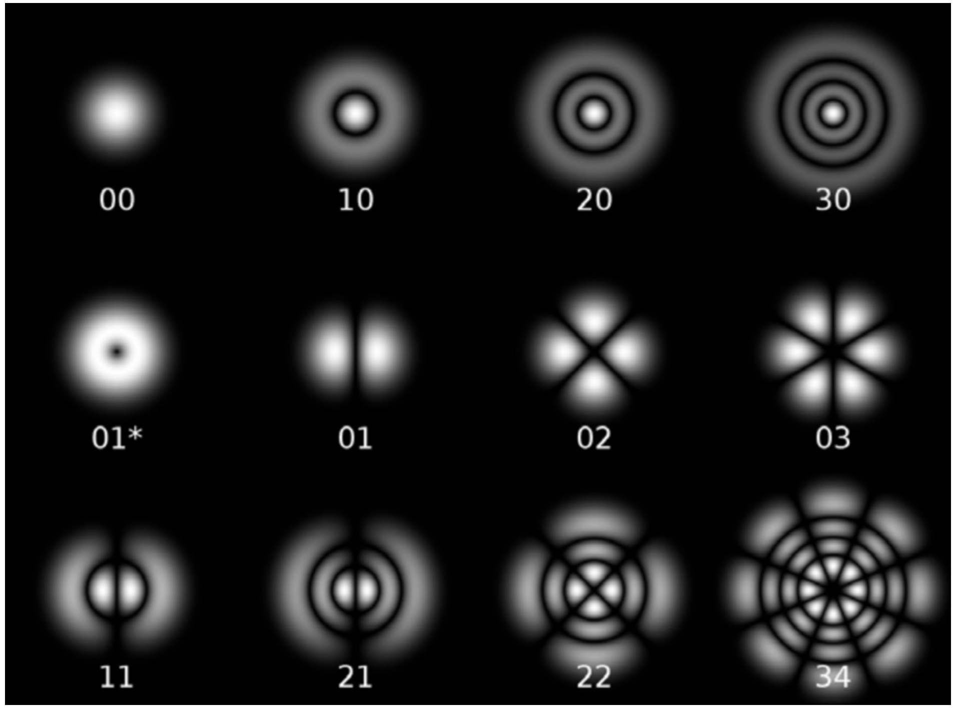


Gaussian Beam Resonator

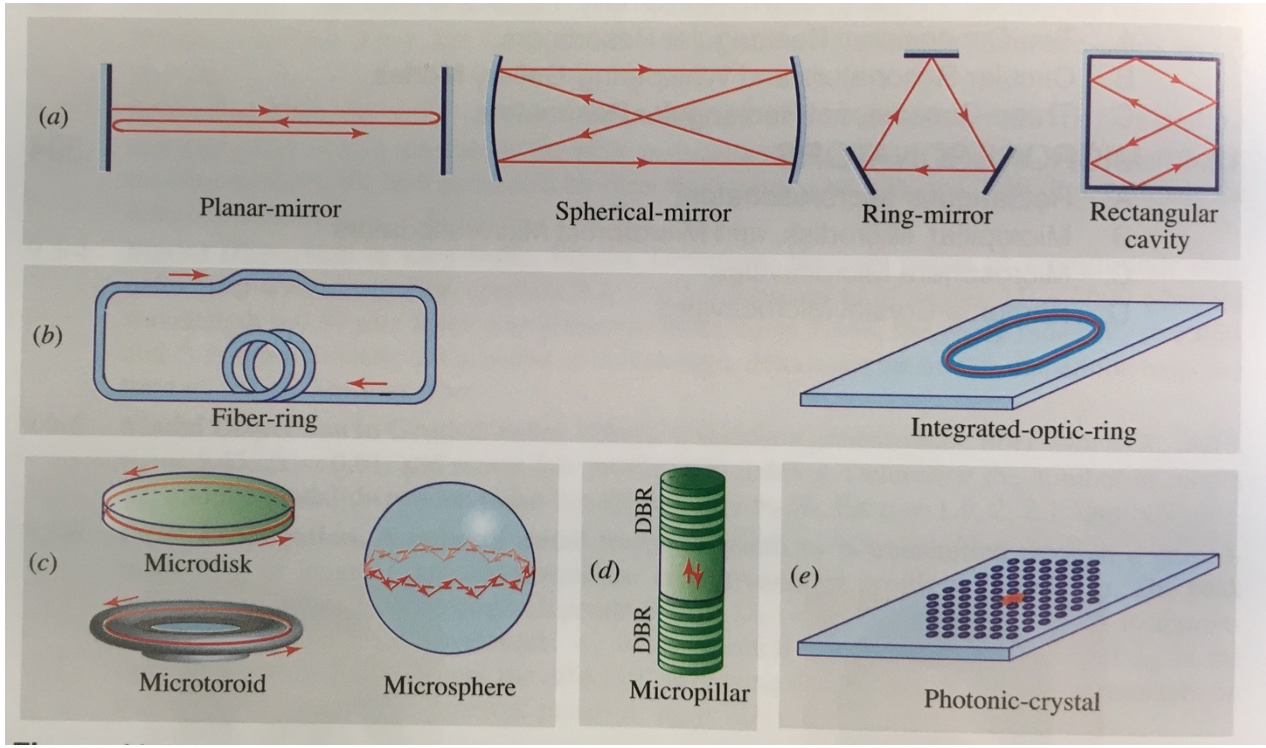




Laguerre-Gaussian modes



Note: There are many other possible cavity configurations!



Application Note: Cavity Ring Down Spectroscopy

- Absorption spectroscopy guided by Beer-Lambert-Law

- What do to for samples with weak absorption / weak transitions?

- Solution: Use a

Homework Reading: Cavity Ring Down Spectroscopy

- Idea: Instead of measuring absorption measure decay time

FARADAY RESEARCH ARTICLE

Cavity ring-down spectroscopy

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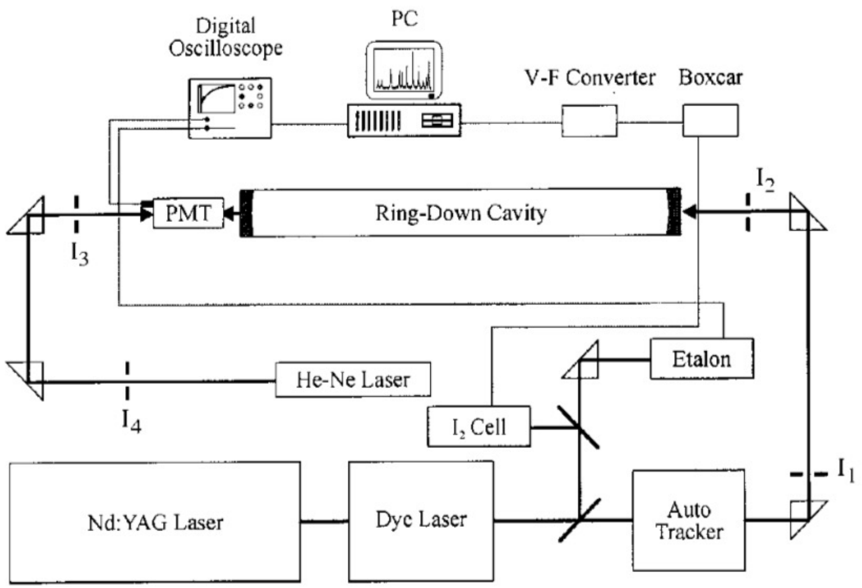


Fig. 2 Schematic diagram of the CRD apparatus at Bristol. Abbreviations in the figure are: photomultiplier tube (PMT), voltage-to-frequency converter (V–F) and irises (I) used to assist cavity alignment. The iodine cell and etalon provide accurate calibration of the laser wavelength.

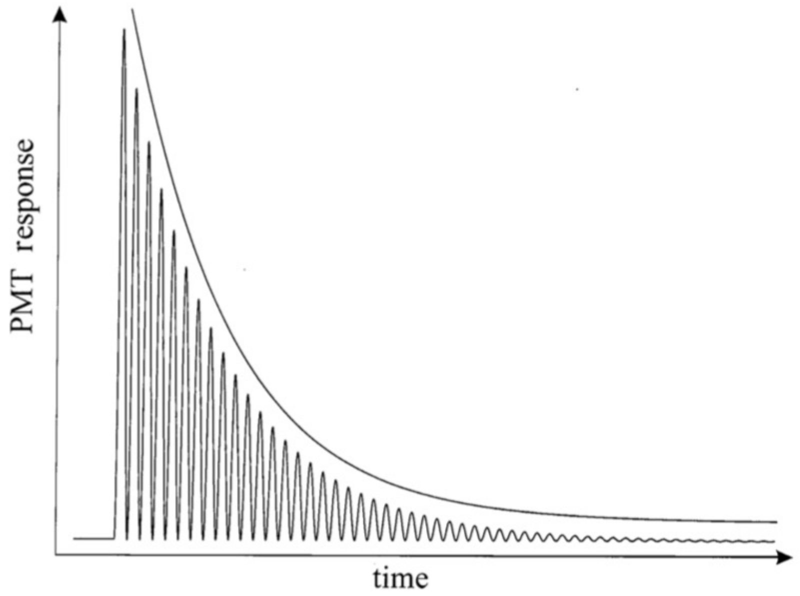


Fig. 3 Schematic diagram of the expected response of the photomultiplier tube to a train of laser pulses leaking through one cavity end mirror after successive cavity round trips. Also shown is the exponential envelope arising from smoothing of the pulse train by the time response of the experimental detection apparatus.

Example spectra

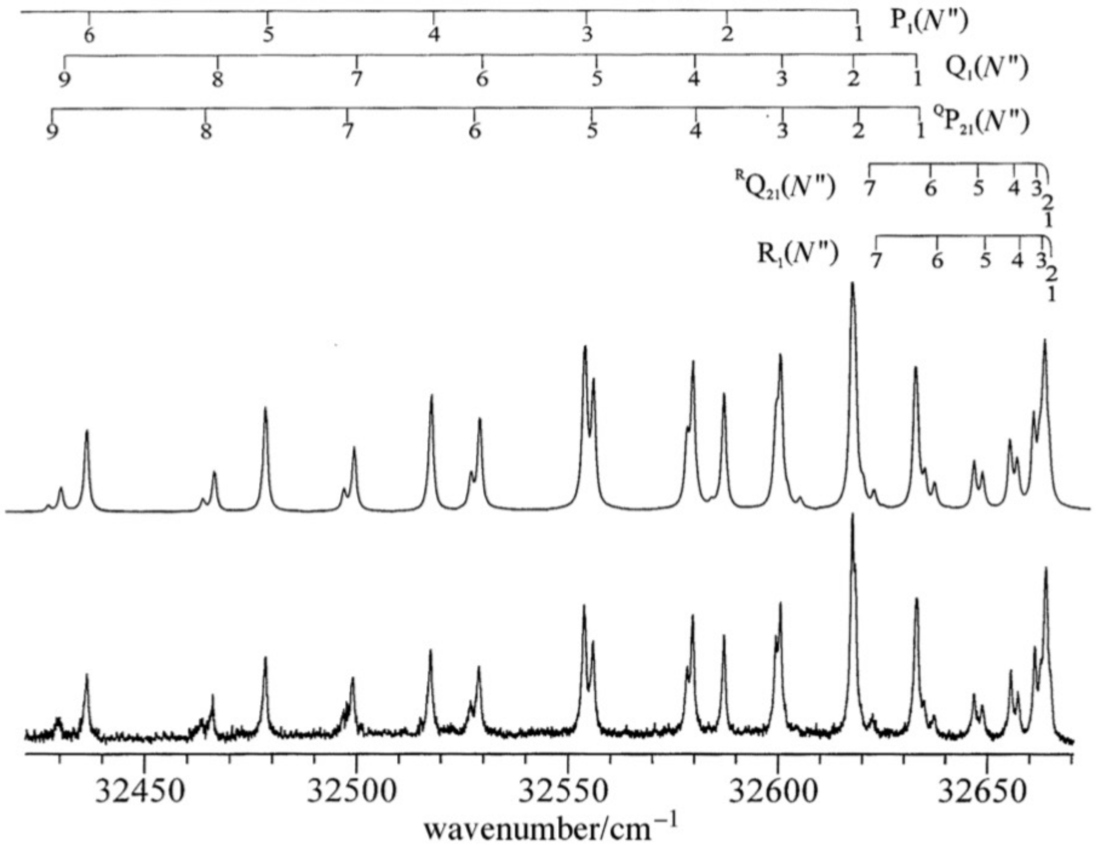
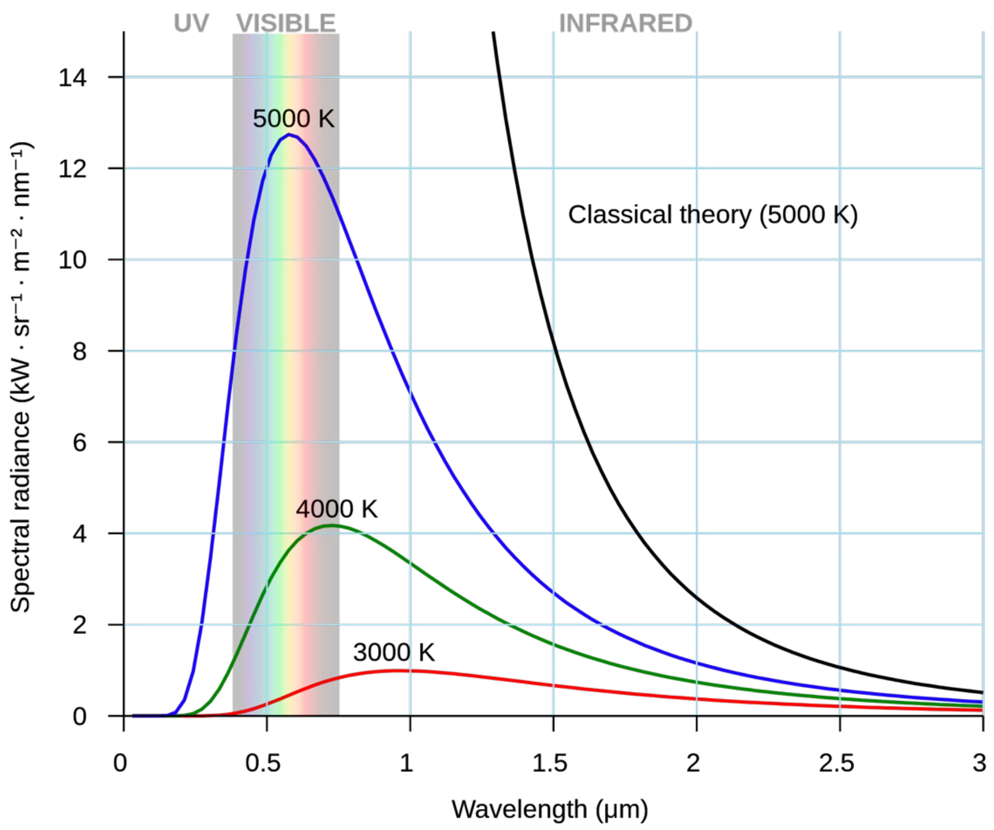


Fig. 8 CRD spectrum (bottom) and simulation (top) of the A $^2\Sigma^+$–X $^2\Pi$ (1, 0) band of SH. The combs above the spectra indicate rotational line assignments. The simulation includes a Lorentzian component to the rotational linewidths of 1 cm^{-1} because of lifetime broadening.

And now, towards lasers

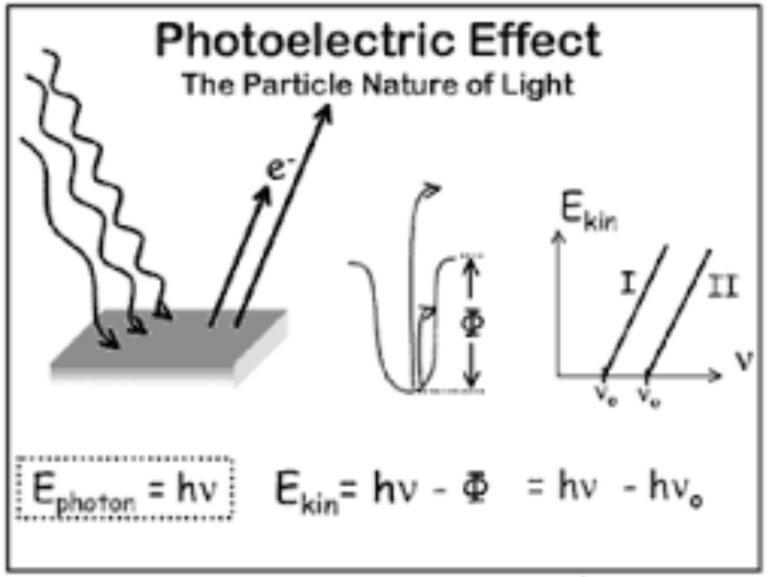
Black body radiation: Energy is quantized



- Stefan Boltzmann Law
- Wiens displacement law
- Plancks law (Nobel prize 1918)

Photoelectric effect

- Einstein Nobel prize 1921
- Light has particle nature

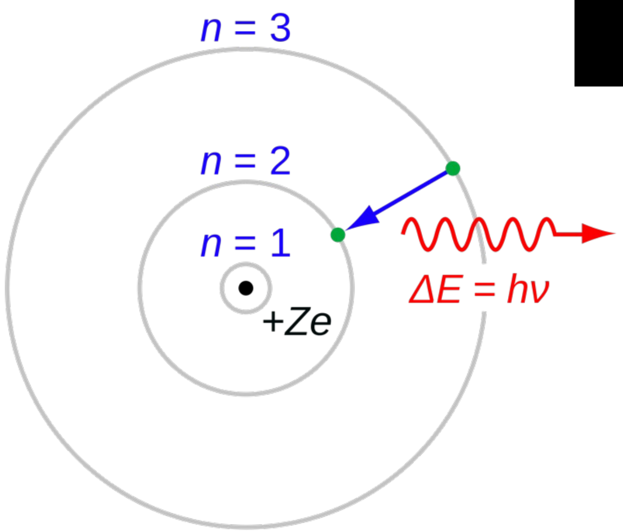


UC Berkeley's Digital Chem1A

Bohr model and Rydberg atoms

- Bohr model: semiclassical approach
- Nobel pize 1922
- Dense nucleus with surrounding electrons
- Discrete energy states
- A lot of shortcomings but works

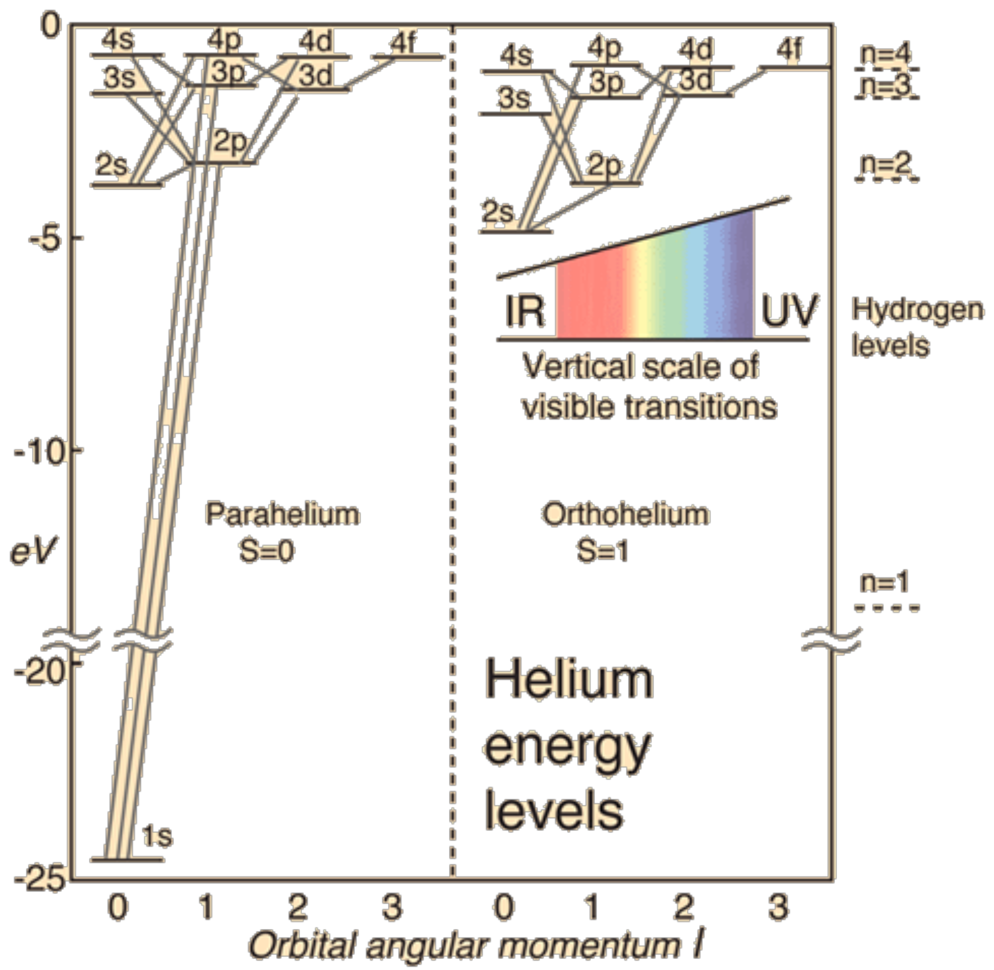
- Rydberg atom:
- excited states in Bohr model
- Principle quantum numbers n
- Transition under emission / absorption of photon
- Balmer series of hydrogen



Fermis Golden Rule

- Full quantum mechanical description of the atom (not here)
- Fermi Golden Rule describes transition probability between levels
- Including selection rules

Absorption, energy level diagram



Absorption, emission, stimulated emission - overview

Spontaneous emission

Stimulated Emission

(Stimulated) absorption

Spontaneous emission

Spontaneous emission

Energy difference is emitted as photon

Stimulated emission

Spontaneous emission

Stimulated Emission

One photon with hv simulates another transition

The second photon is identical in direction, frequency, phase and polarization

Absorption

(Stimulated)
Absorption

- The photon stimulates from lower to higher state

Atoms (systems) in thermal balance

In thermal balance the lower population is always higher than that of the upper population

Fundamental concept of laser

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

2, 3, 4 level systems

2 level system

3 level system

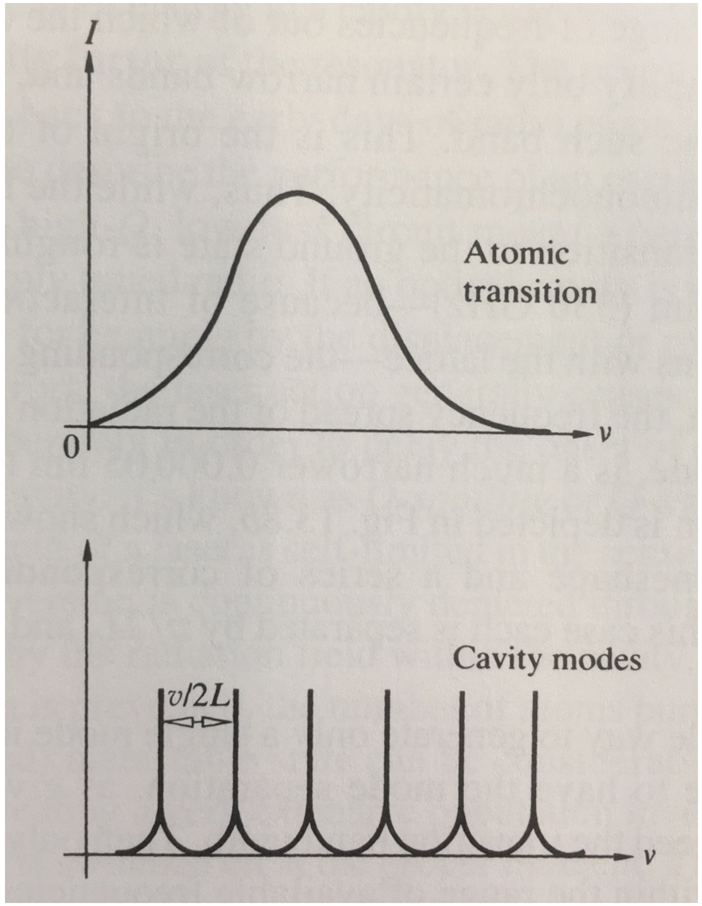
4 level system

Fundamental concept of laser oscillator:

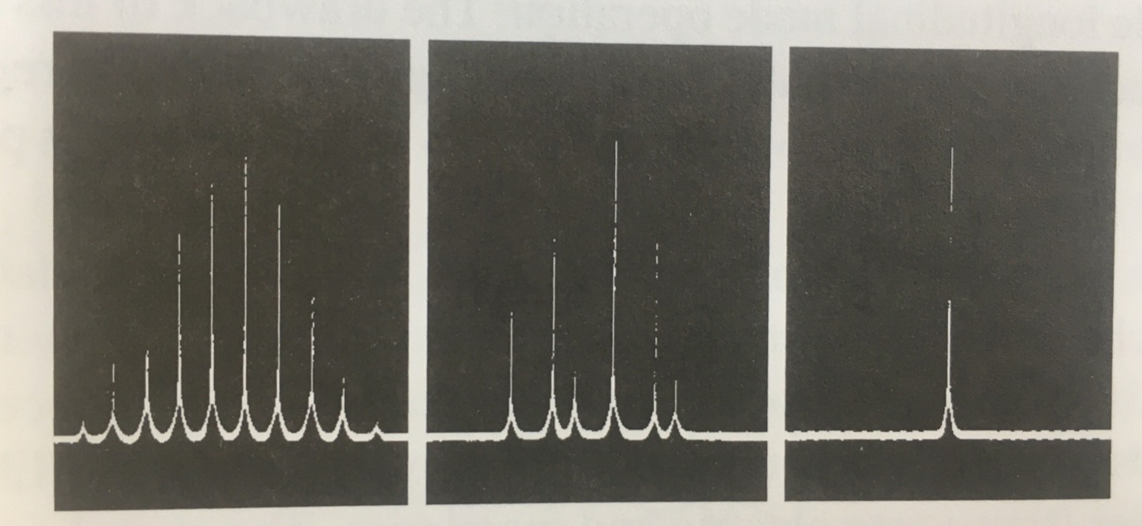
Note: The gain must always be higher than the losses!

Lasers and laser cavities

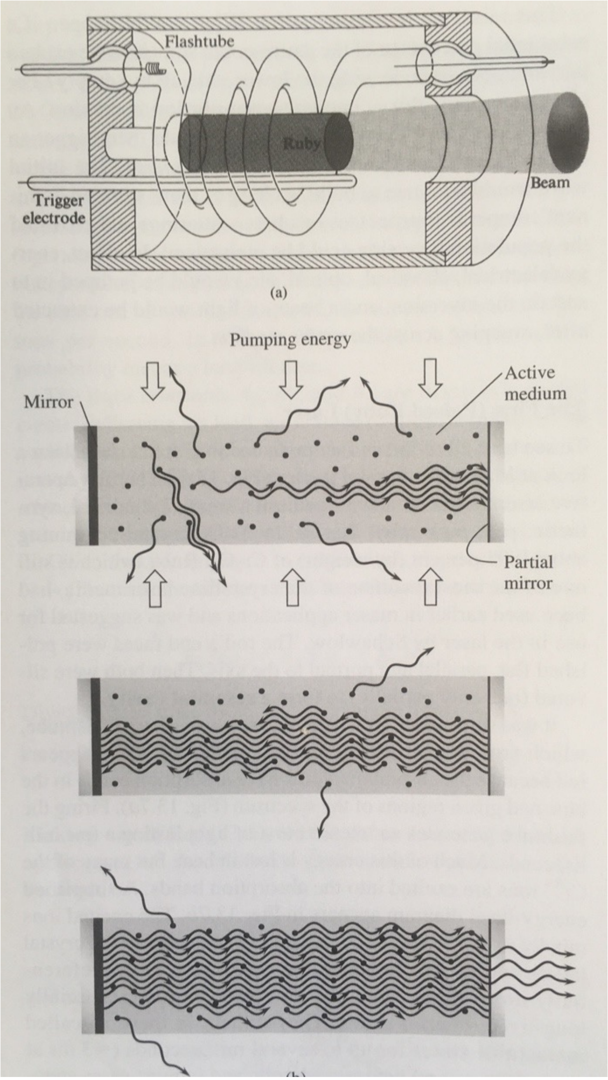
Atomic lines vs cavity modes

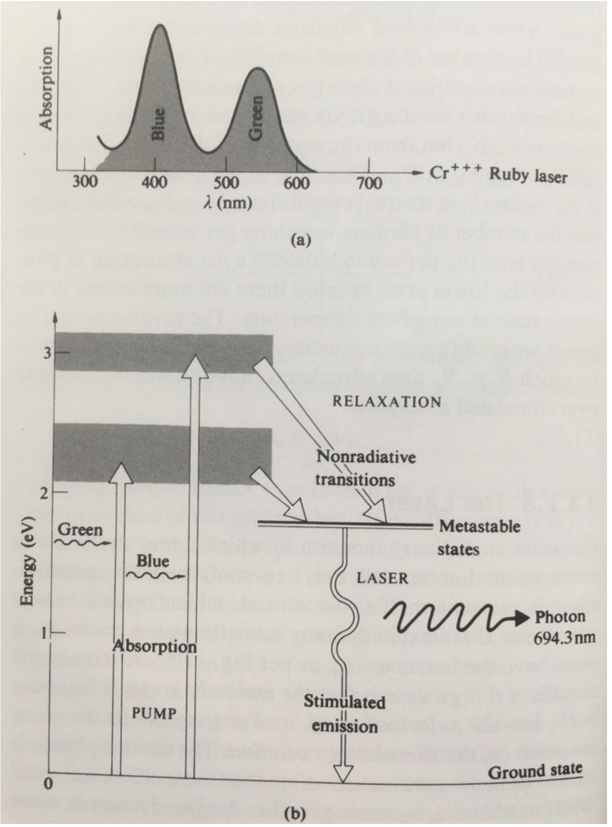


Mode selection



The Ruby laser





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

The end.

Fabry Perot Interferometer

Na D line: