Lasers for modern microscopy

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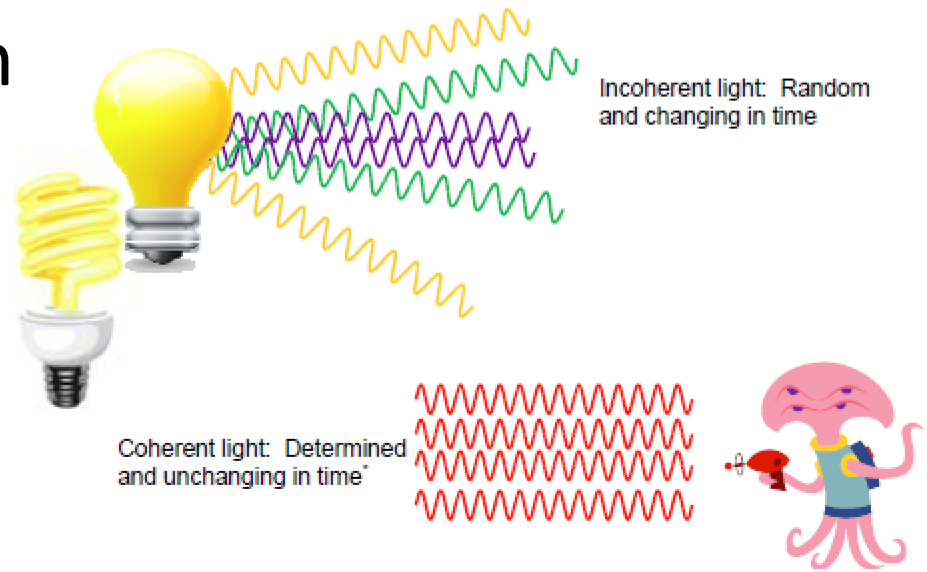
WELL-KNOWN PROPERTIES OF LASERS

- Lasers come in many colors (wavelengths/frequencies)
- A laser beam is highly directed and confined
- Lasers can carry a lot of energy

OTHER PROPERTIES OF LASERS

- Coherent emission



Stolen from Scott

- Narrow spectral width
(very narrow range of wavelengths)
  - Narrow bandwidth LEDs: 10s nm
  - Laser: 0.01 nm to 1 nm

Light

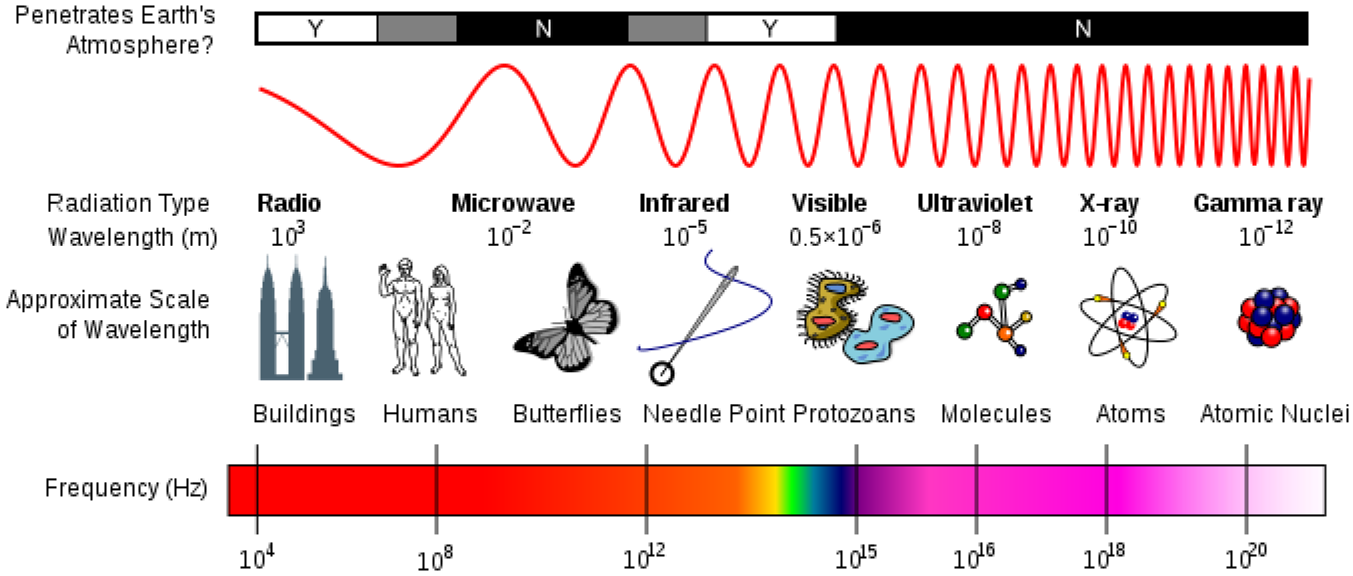
Amplification by the

Stimulated

Emission of

Radiation

- Principles of laser operation are applicable to the whole EM spectrum.
- 1st demonstration of stimulated emission was done in the microwave range (MASER)



http://en.wikipedia.org/wiki/File:EM_Spectrum_Properties_edit.svg

THE BUILDING BLOCKS OF LASER PHYSICS

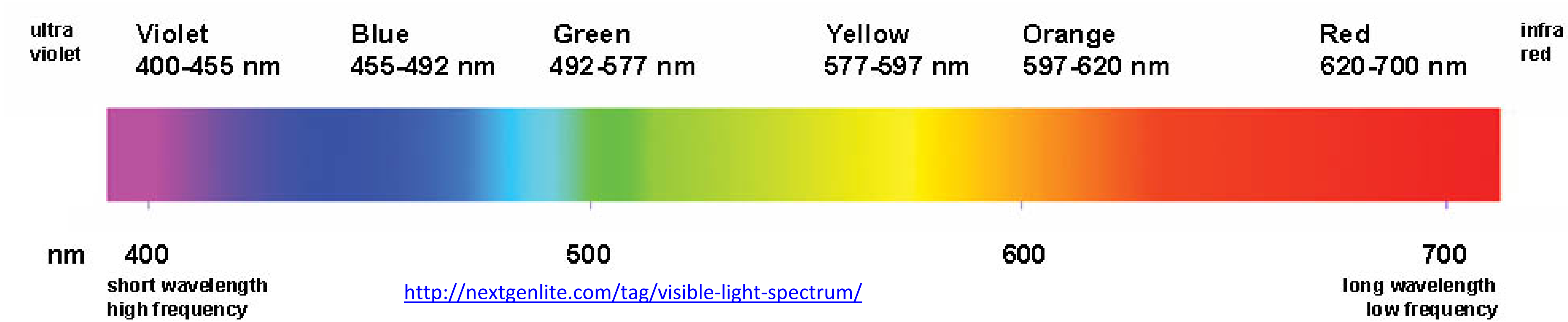
HOW A LASER WORKS &
FUNCTIONS OF THE LASER CAVITY

LASERS IN MICROSCOPY

Waves, photons, absorption, (stimulated) emission

THE BUILDING BLOCKS OF LASER PHYSICS

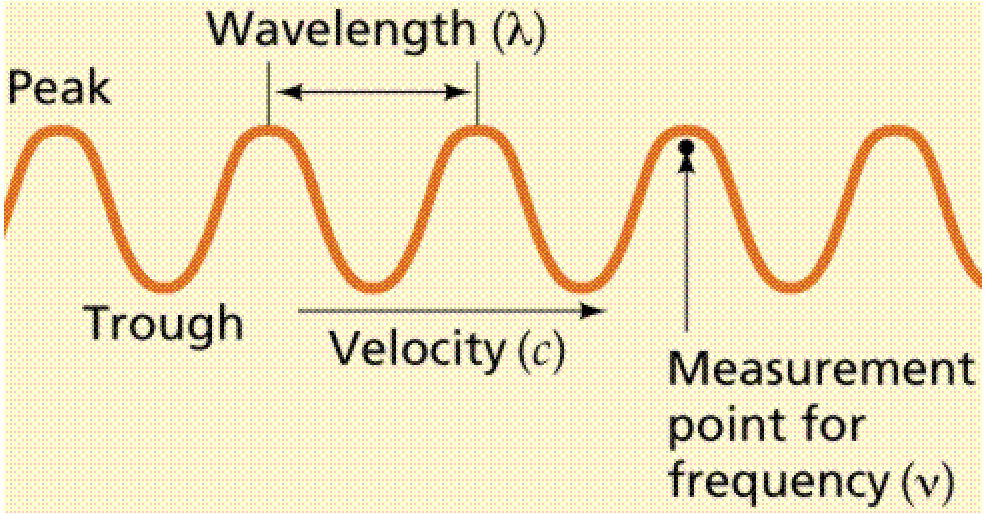
WAVE NATURE OF LIGHT



http://nextgenlite.com/tag/visible-light-spectrum/

Frequency (ν)
Wavelength (λ), ranging from
Speed of light in vacuum (c)
= 3×10^8 m/s

$$\nu = \frac{c}{\lambda}$$

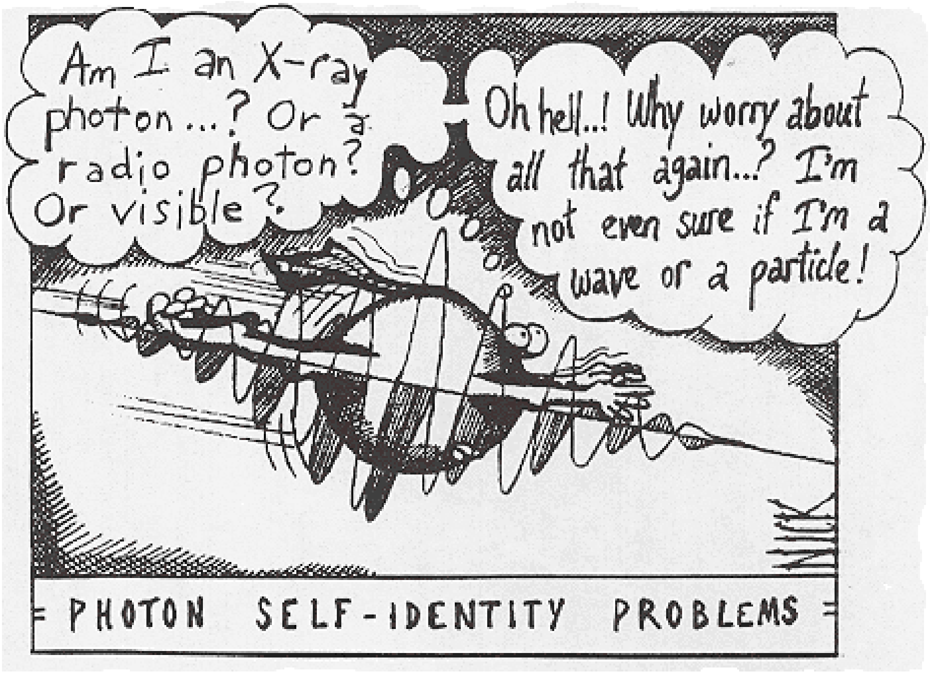


PHOTONS: LIGHT AS ENERGY PARTICLES

Energy of a light particle (photon),

$E = h\nu$

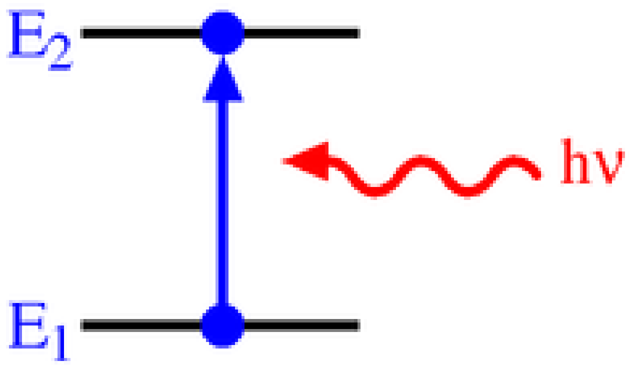
h = Planck's constant, ν = frequency of light



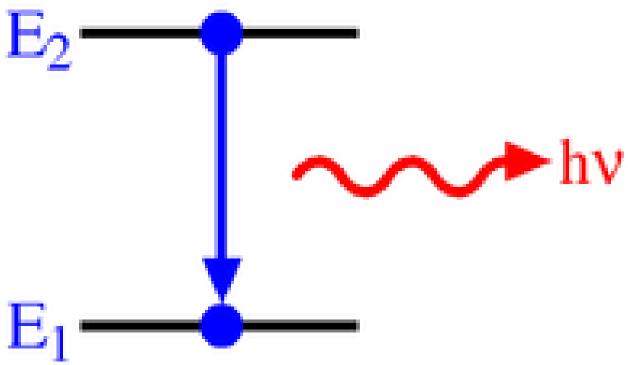
http://abyss.uoregon.edu/~js/glossary/wave_particle.html

SOME BASIC RULES OF QM

1. There are discrete energy levels associated with an atom.
2. The lowest and most stable energy state is the 'ground state'
3. Discrete pockets of energy can be absorbed bringing an atom from one energy level to the next.
4. Similarly, discrete pockets of energy ($E_2 – E_1$) can be emitted (photons)



absorption

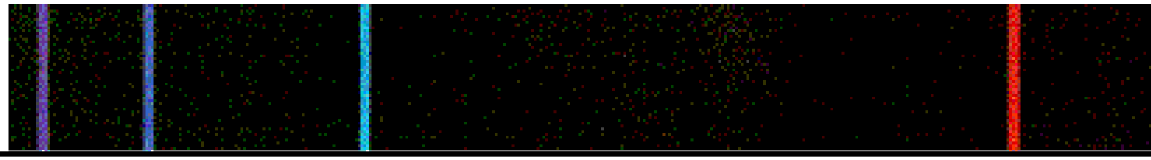


emission

http://en.wikipedia.org/wiki/Energy_level

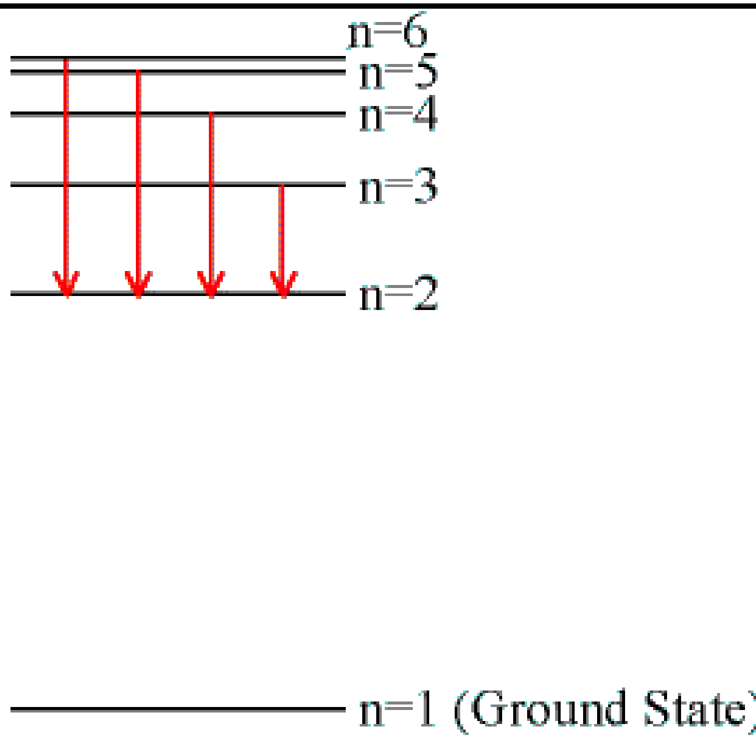
ENERGY LEVELS IN ATOM/MOLECULE DICTATE SPECTRUM OF A LASING MATERIAL

410 nm 434 nm 486 nm 656 nm



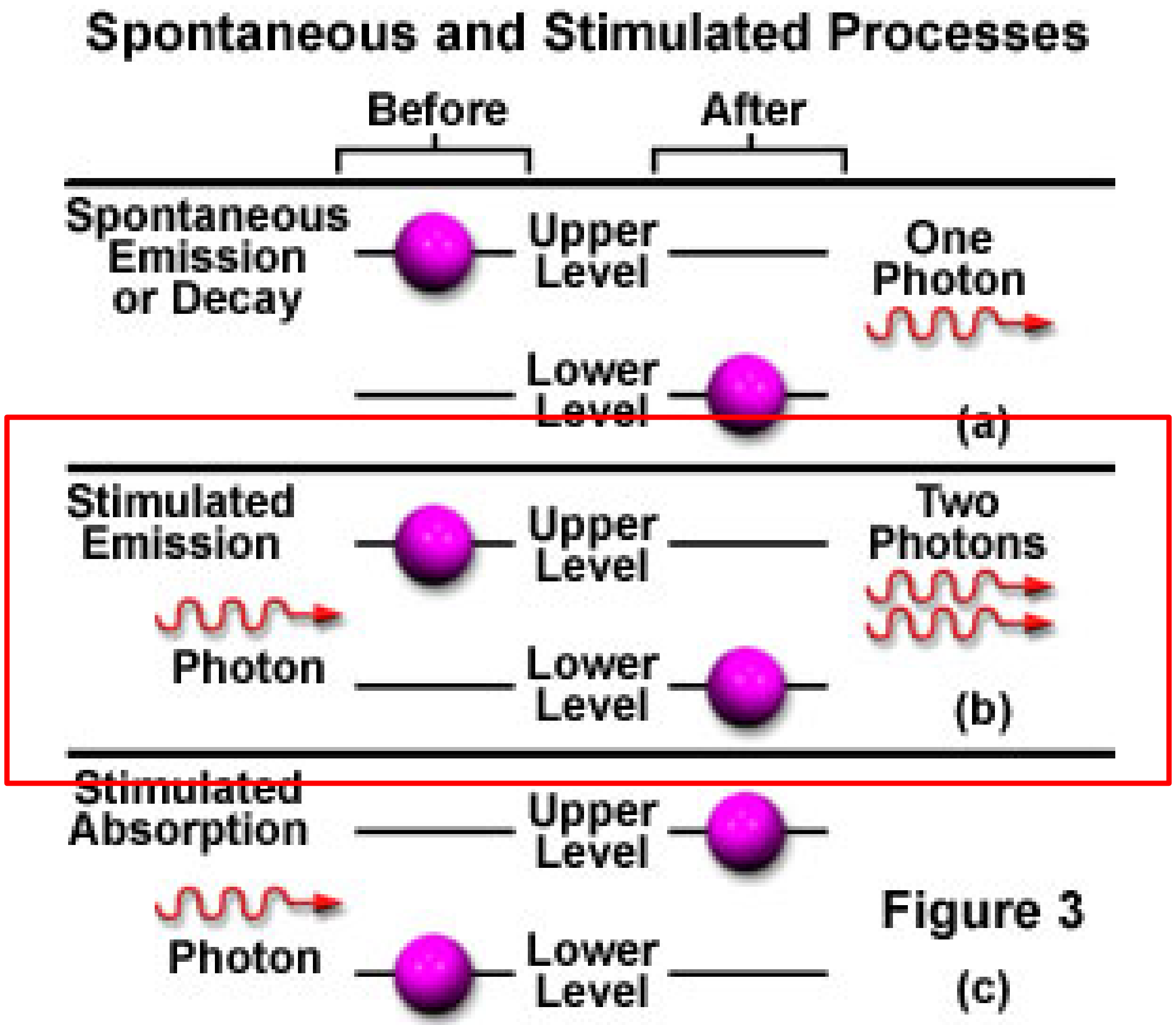
hydrogen

Which energy transition is responsible for each of these lines?



http://electron6.phys.utk.edu/phys250/modules/module%203/hydrogen_atom.htm

STIMULATED EMISSION



Emitted photon is of the same energy (frequency) and phase (coherent!) as the stimulating photon.

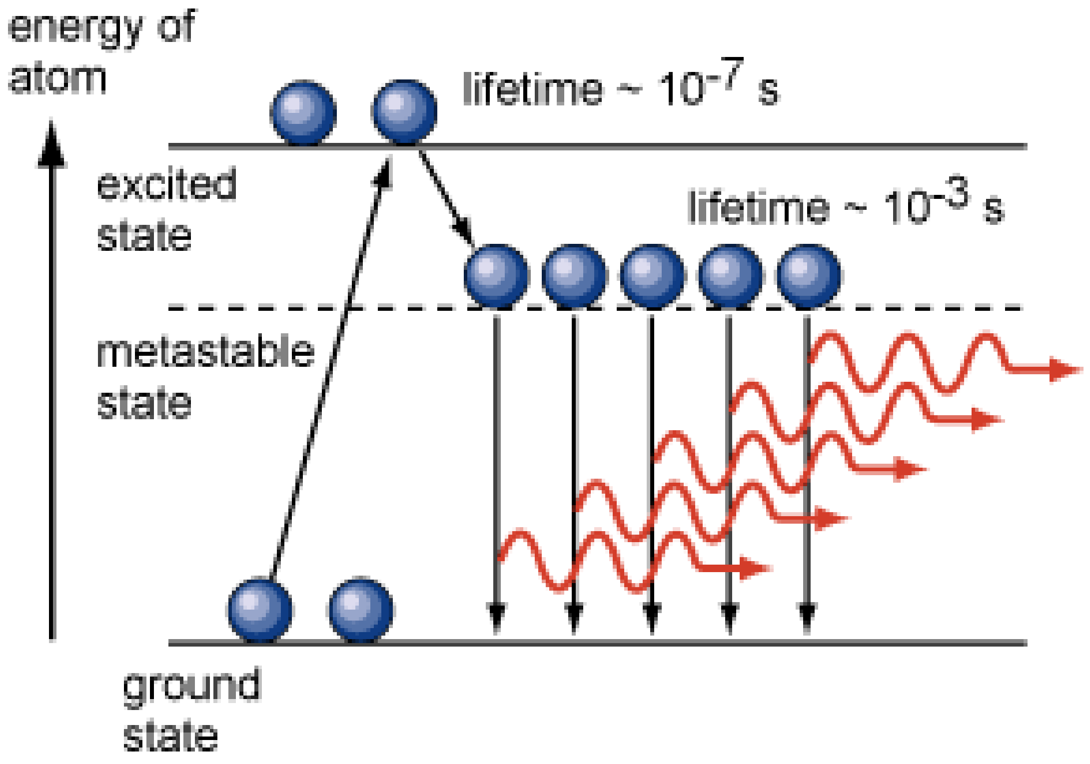
http://www.olympusmicro.com/primer/lightandcolor/lasersintro.html

Population inversion

- More atoms in the elevated energy state

$$\frac{N_2}{N_1} > 1$$

- How do we get enough of these photons to be at that high, unstable energy level?

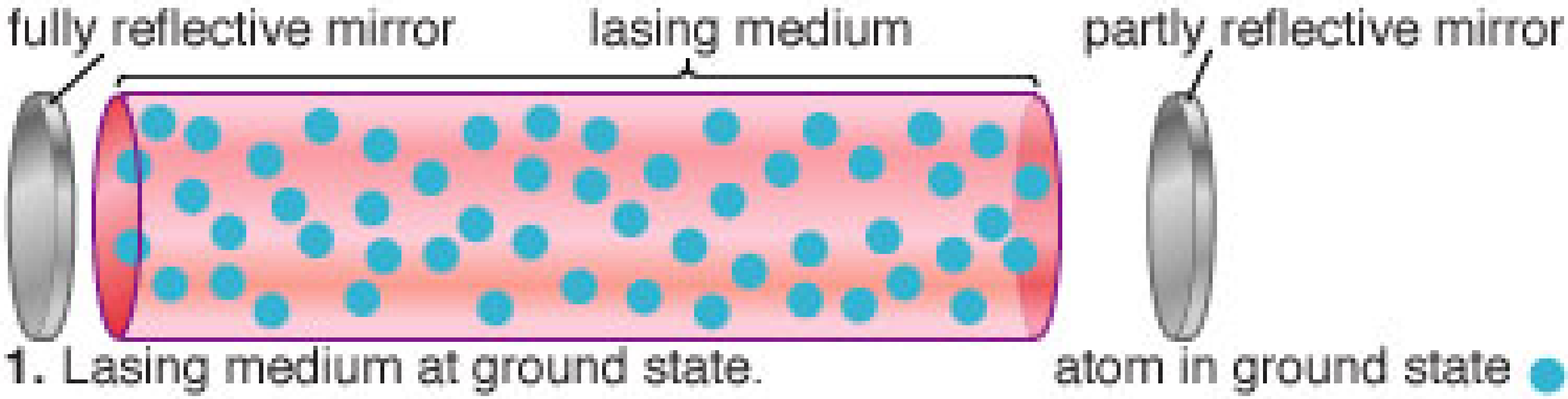


http://www.hk-phy.org/articles/laser/laser_e.html

Finally…

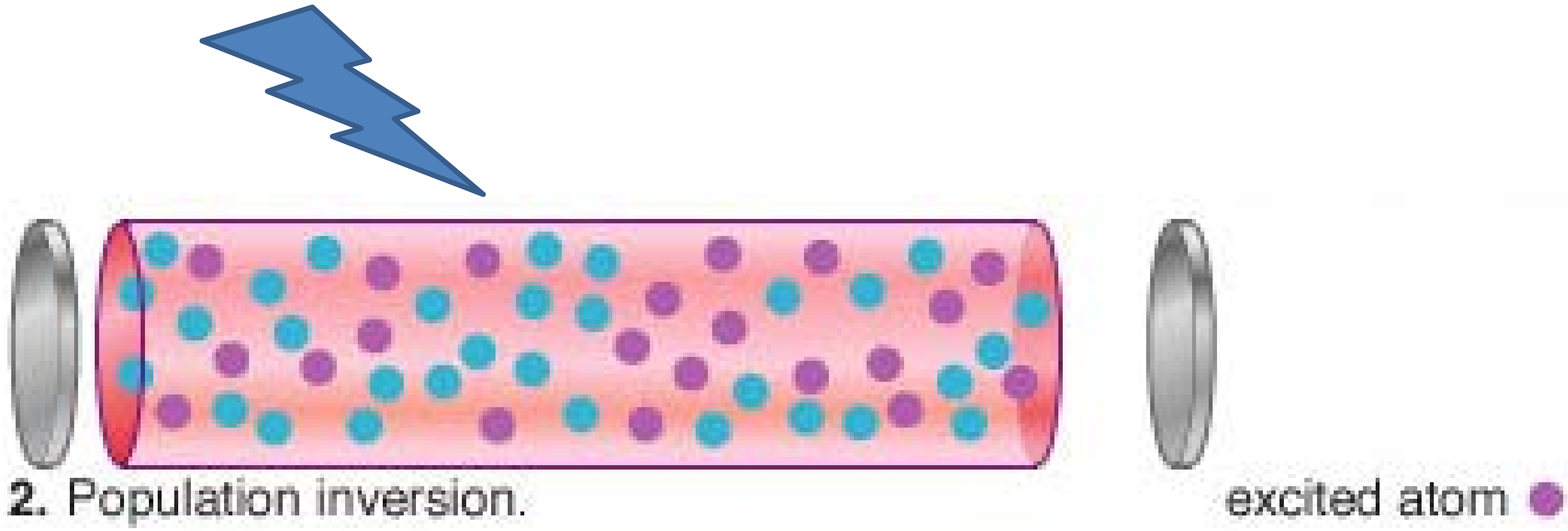
HOW A LASER WORKS

LASER AT GROUND (OFF) STATE



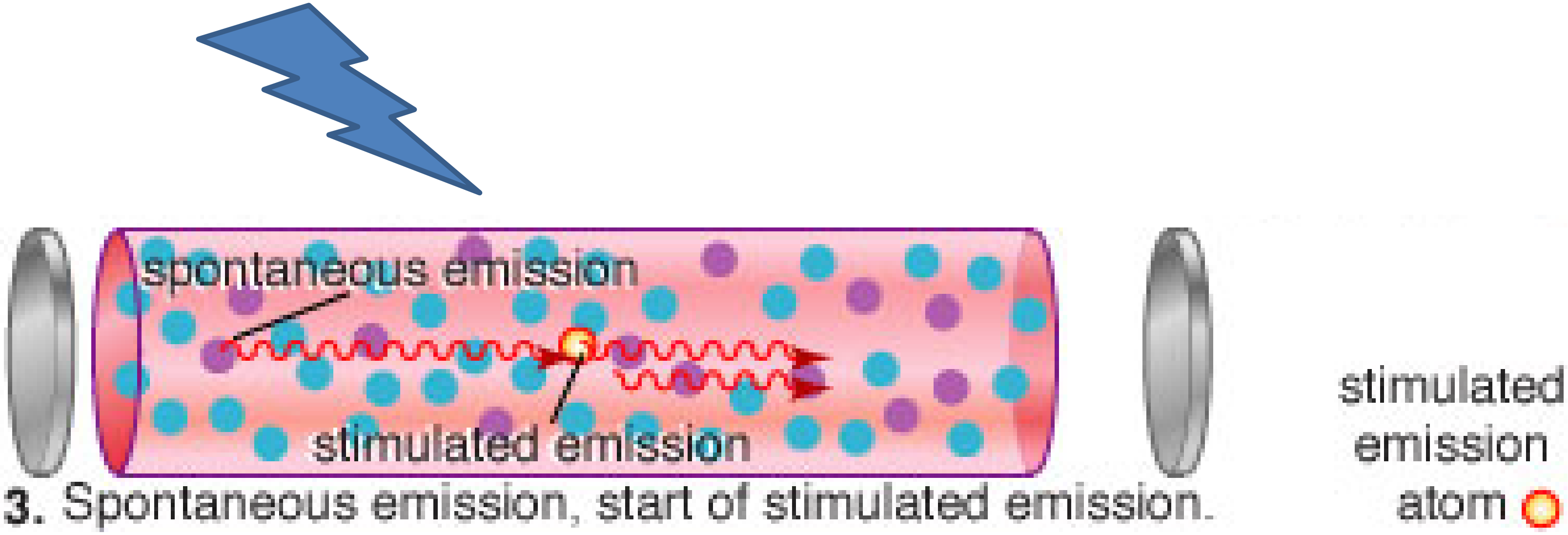
1. Lasing medium at ground state.

PUMPING



Pumping: energy input for stimulated absorption
Lasing medium can be pumped either electrically or by another light source

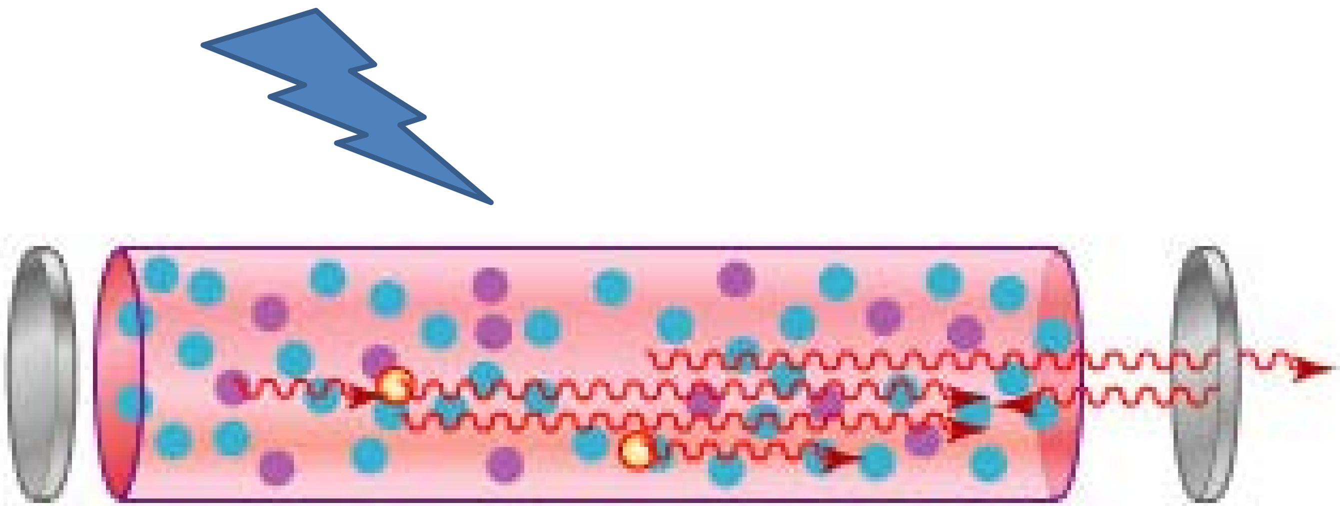
SPONTANEOUS EMISSION



Photon spontaneously emitted causes stimulated emission

Emitted photons have the same frequency and phase!

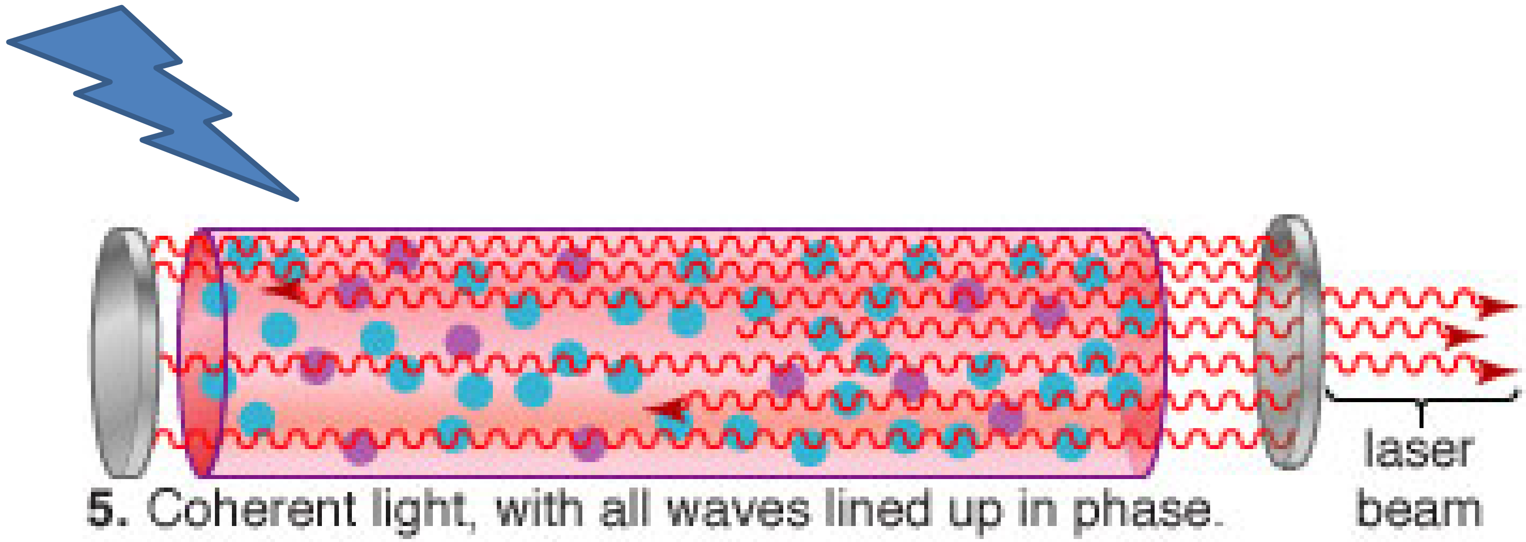
SOME PHOTONS ARE REFLECTED TO STIMULATE EMISSION OF MORE PHOTONS



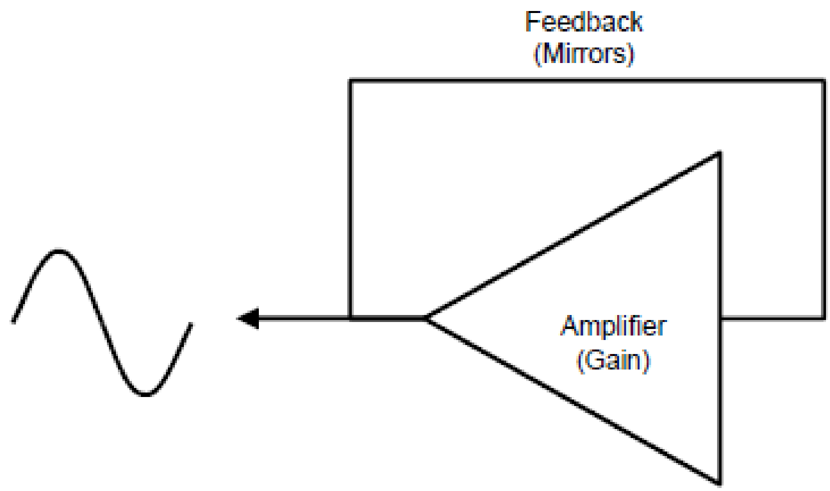
4. Stimulated emission building up.

Emitted photons have the same frequency and phase!

LASING AT EQUILIBRIUM



Laser is analogous to an oscillator



Light

~~**A**mplification by the~~

Oscillation

Stimulated

Emission of

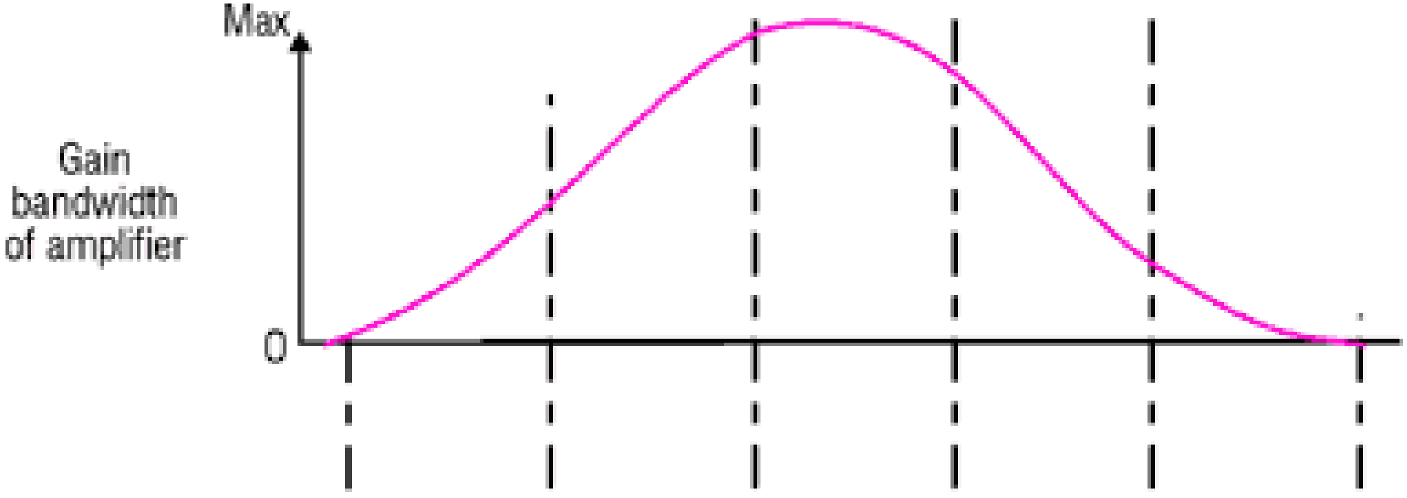
Radiation

Probably not a good acronym

CLOSER LOOK AT FUNCTIONS OF THE LASER CAVITY

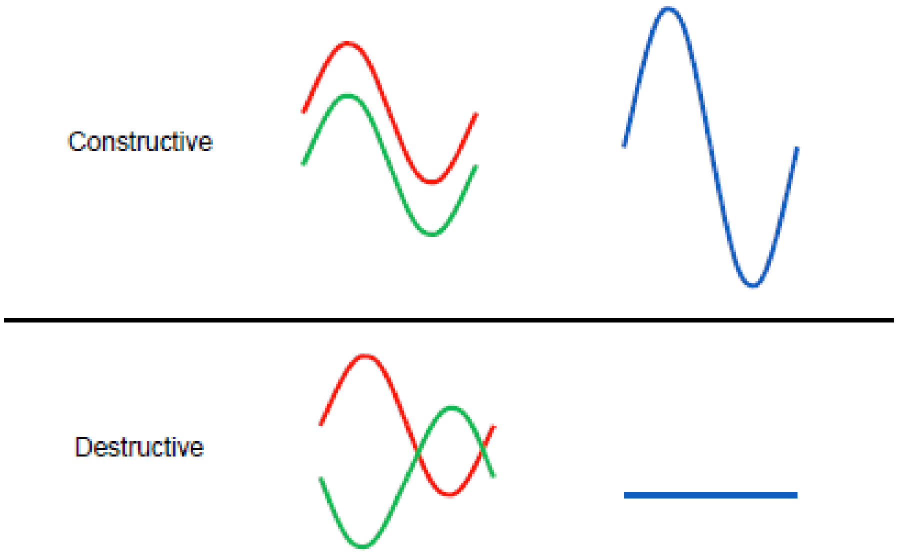
Selection of emission wavelength (longitudinal modes)

EMISSION BANDWIDTH OF LASER IS BROAD

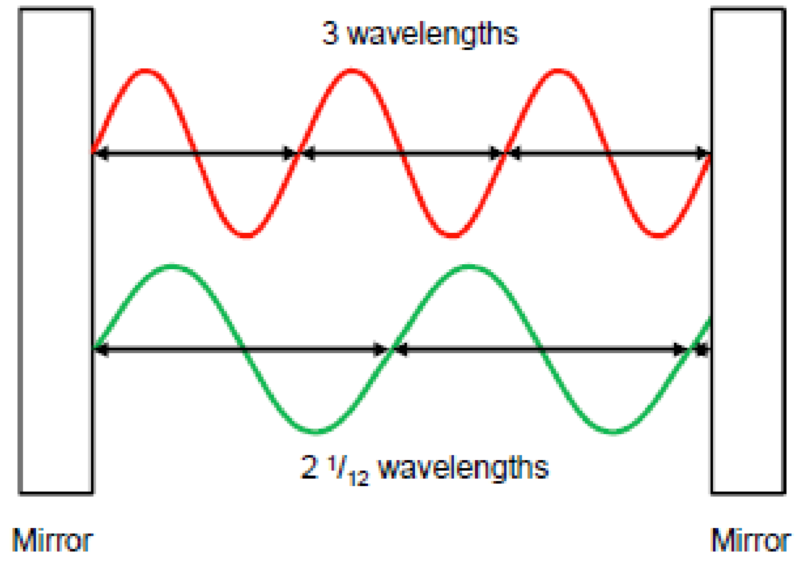


Many wavelengths are possible
How do we select for just a few?

CONSTRUCTIVE & DESTRUCTIVE INTERFERENCE



Stolen from Scott



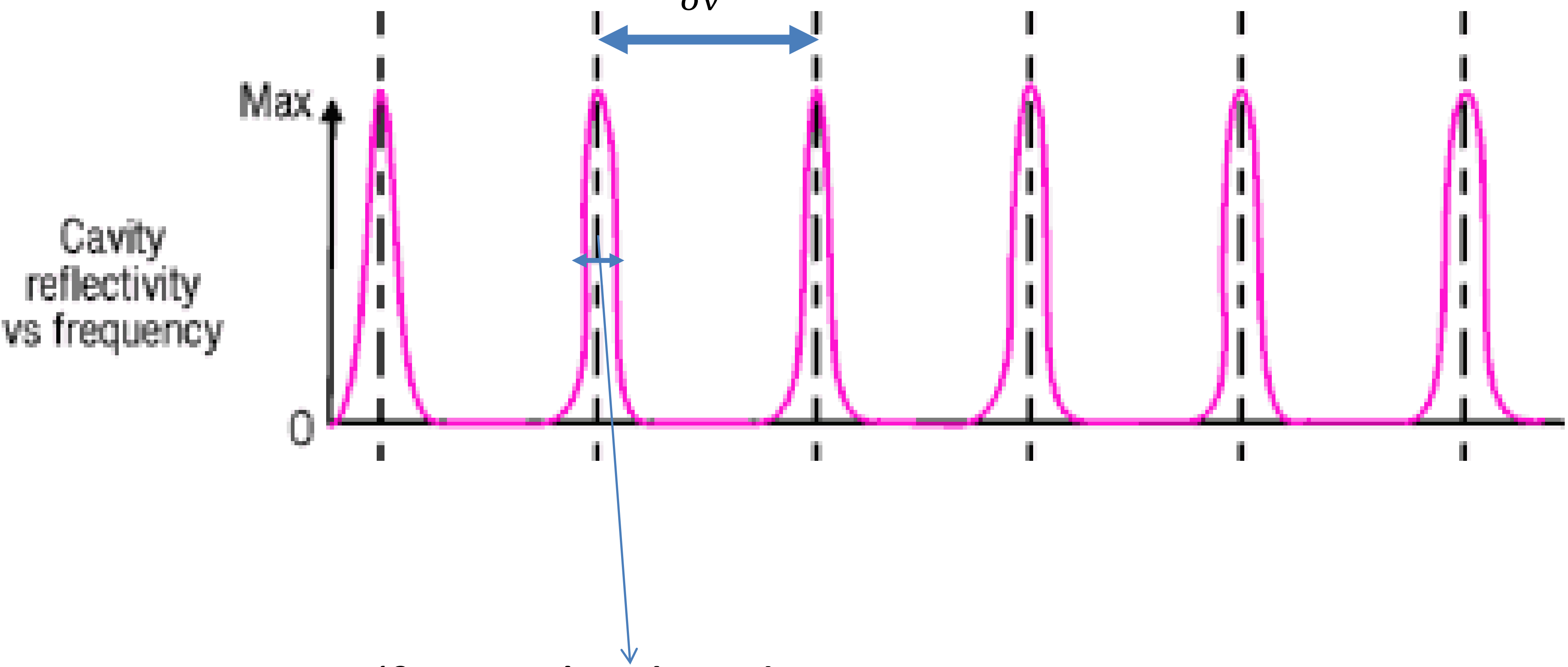
Completely constructive interference occurs when cavity length is integer multiples of wavelength

$$N \cdot \lambda = 2 \cdot L$$

N is an integer, **λ** is the wavelength, **L** is laser cavity length.

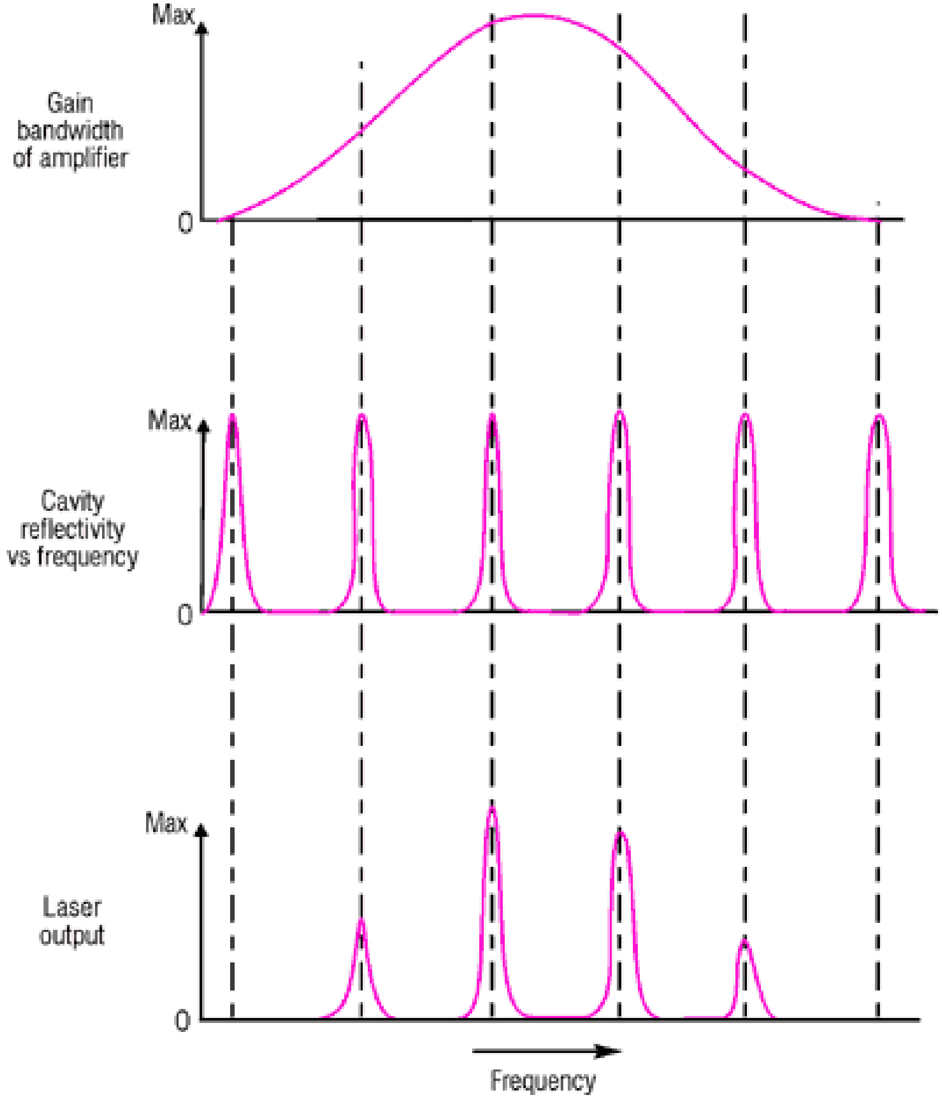
RESULTING TRANSMISSION CHARACTERISTIC OF LASER CAVITY

'free spectral range', $\delta\nu = \frac{C}{2L}$



'finesse', related to reflectivity of the mirror

RESULTING LASER SPECTRA

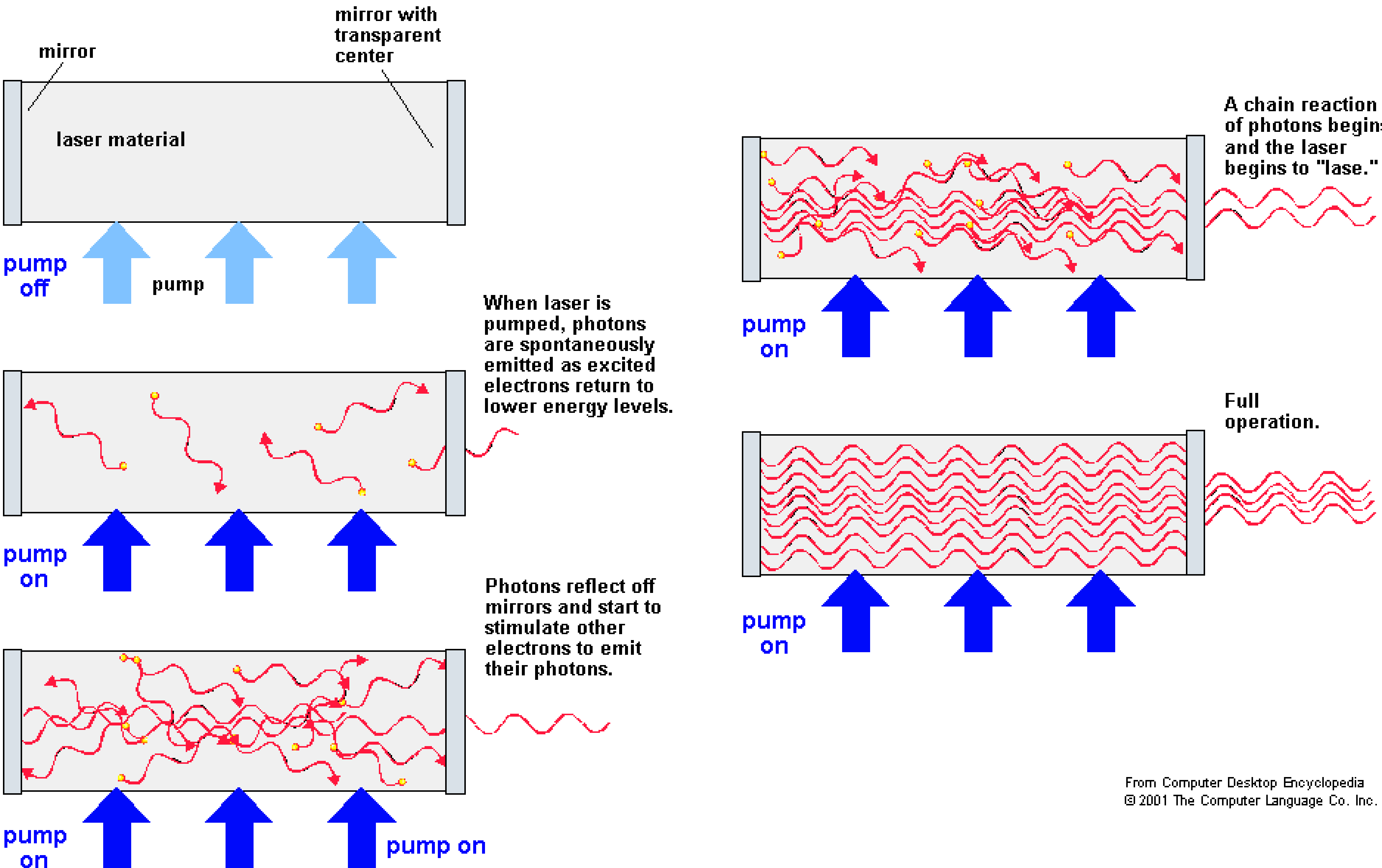


How can we make this multimode laser single longitudinal mode?

CLOSER LOOK AT FUNCTIONS OF THE LASER CAVITY

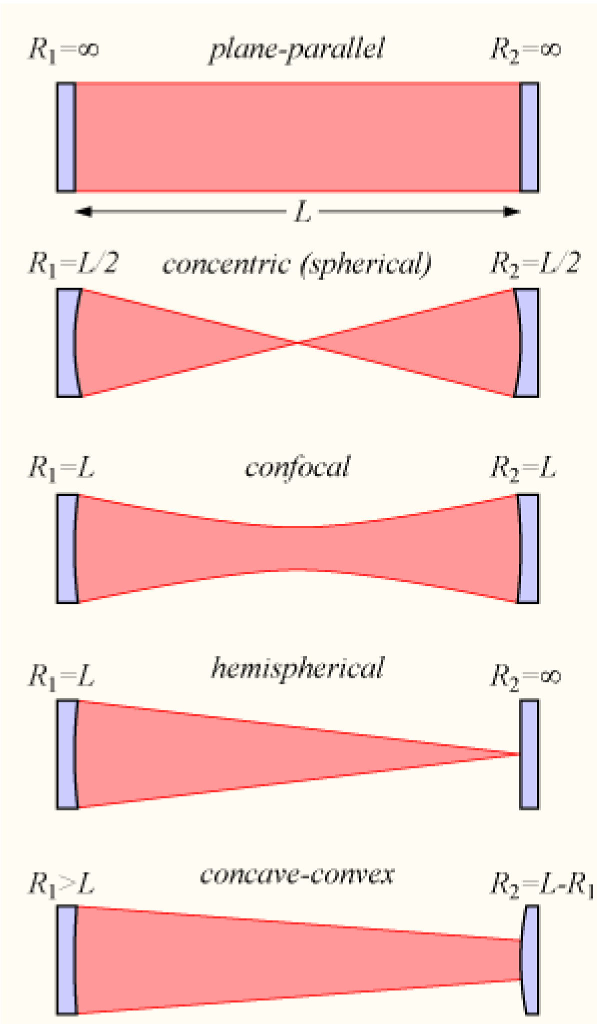
Creating a directed, confined, intense beam

LASER CAVITY IS RESPONSIBLE FOR PRODUCTION OF AN INTENSE DIRECTED BEAM

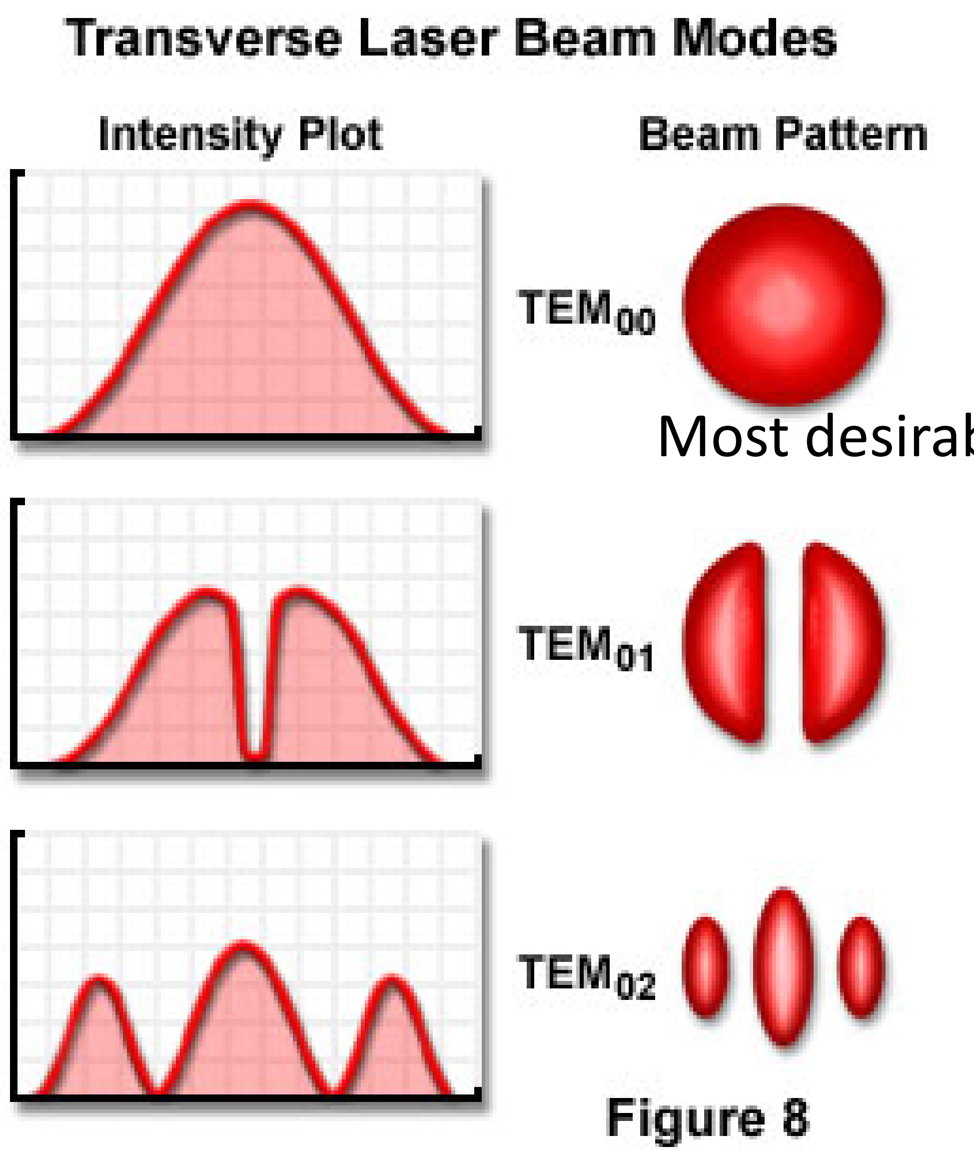


CAVITY DESIGN DETERMINES BEAM SHAPE

Cavity designs



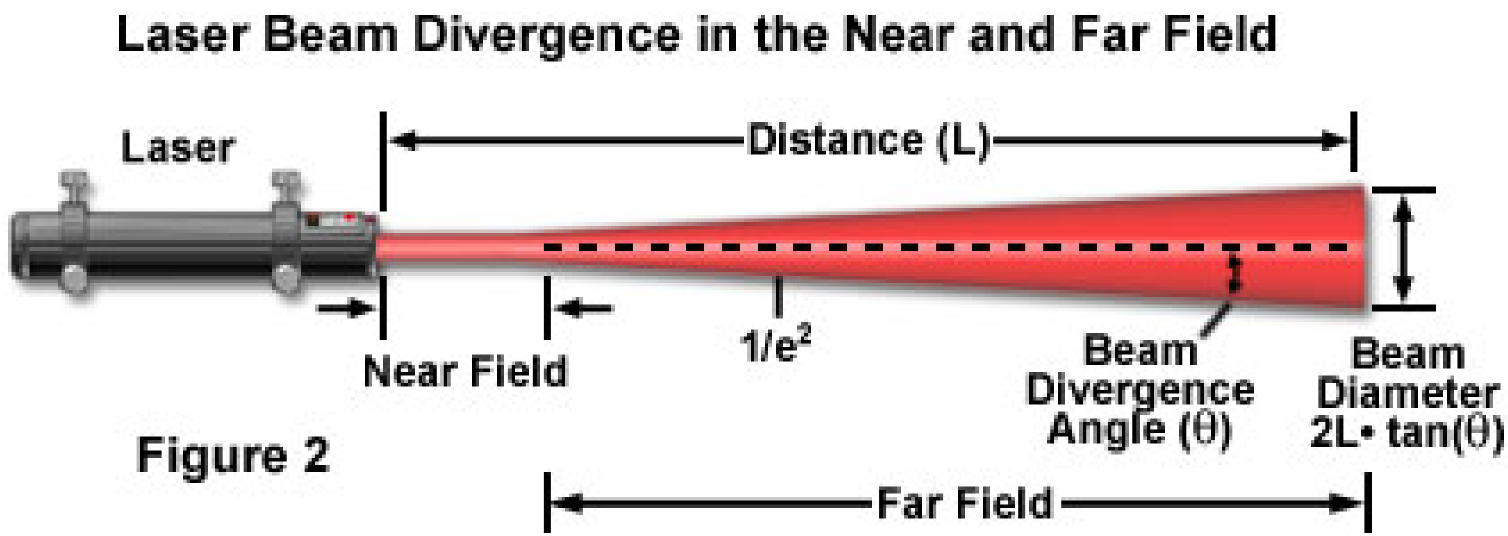
http://en.wikipedia.org/wiki/Optical_cavity



Most desirable

http://www.olympusmicro.com/primer/lightandcolor/lasersintro.html

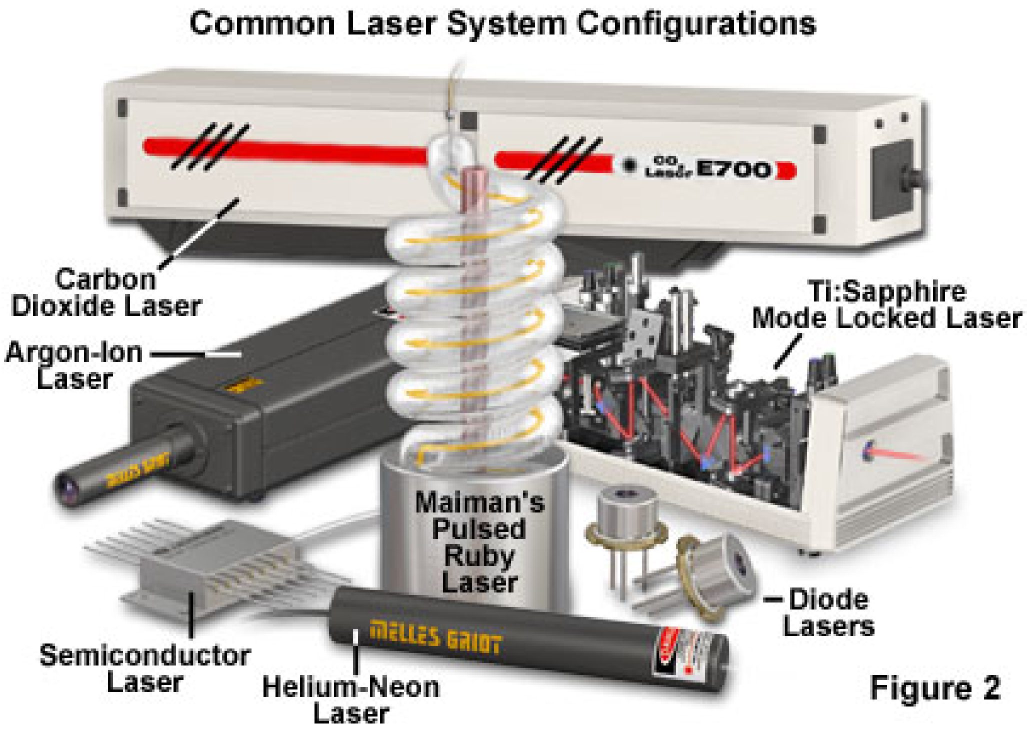
LASER PROPAGATION



Begins at A_0^2/λ,
where A_0
= beam diameter at exit of laser

The phase of the beam becomes ordered and predictable at the far field.
The divergence of a gaussian beam can be predicted by gaussian beam theory.

http://www.olympusmicro.com/primer/techniques/microscopylasers.html

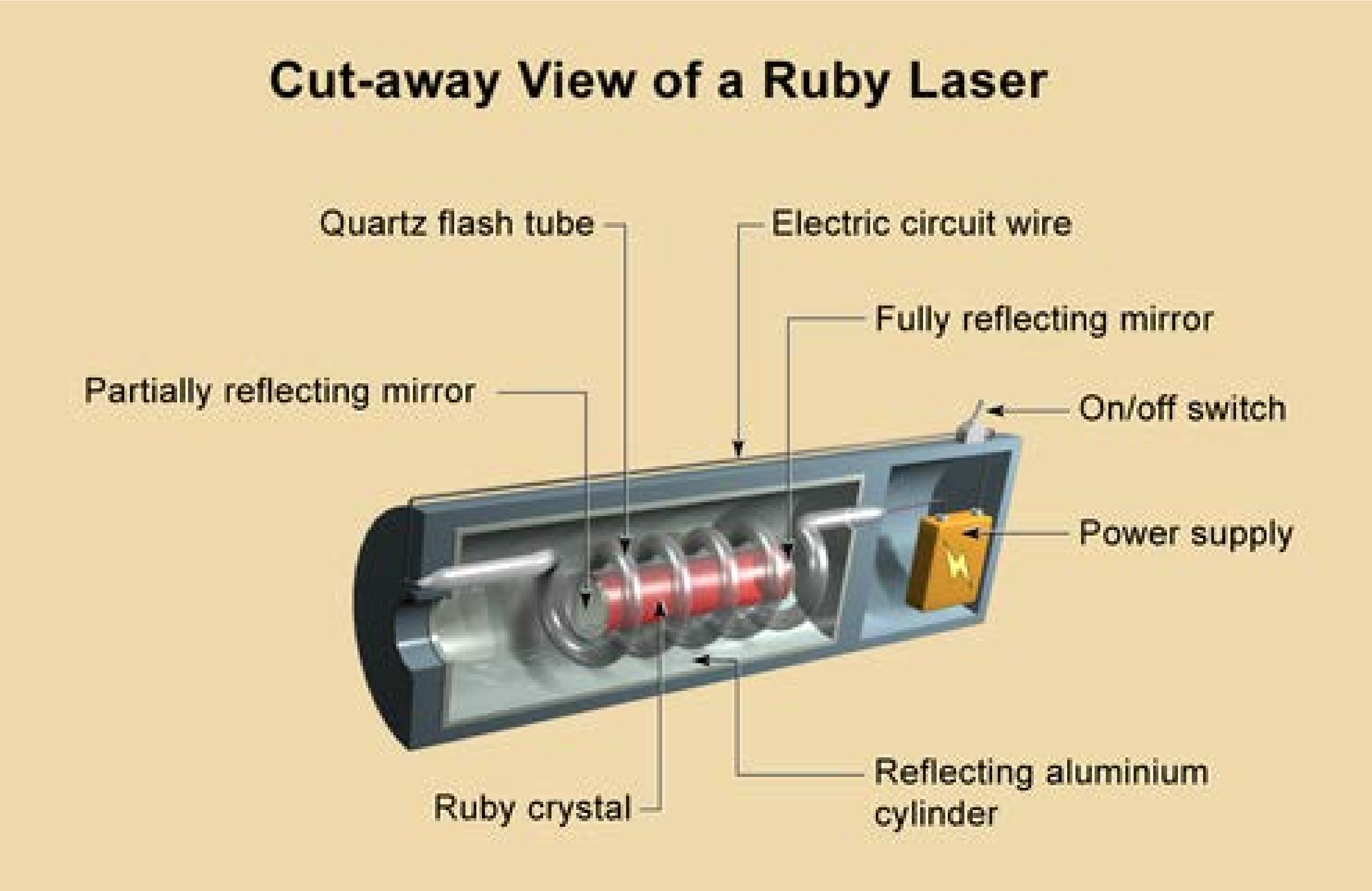


Applying what we've learnt to some real laser systems…

LASERS IN MICROSCOPY

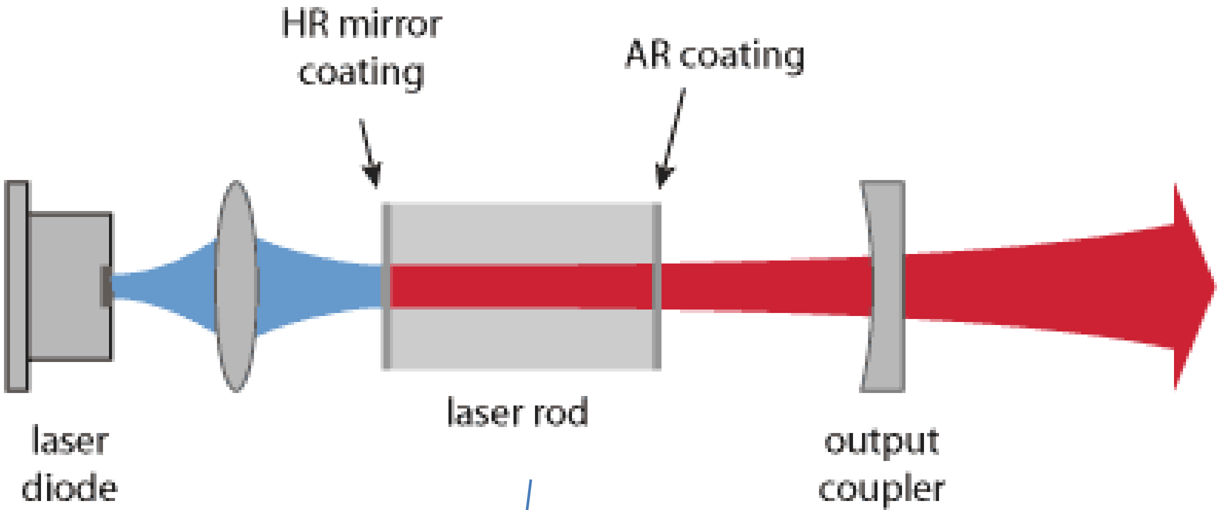
http://www.olympusmicro.com/primer/lightandcolor/lasersintro.html

THE FIRST LASER EVER MADE…



http://en.wikibooks.org/wiki/Wikijunior:How_Things_Work/Laser

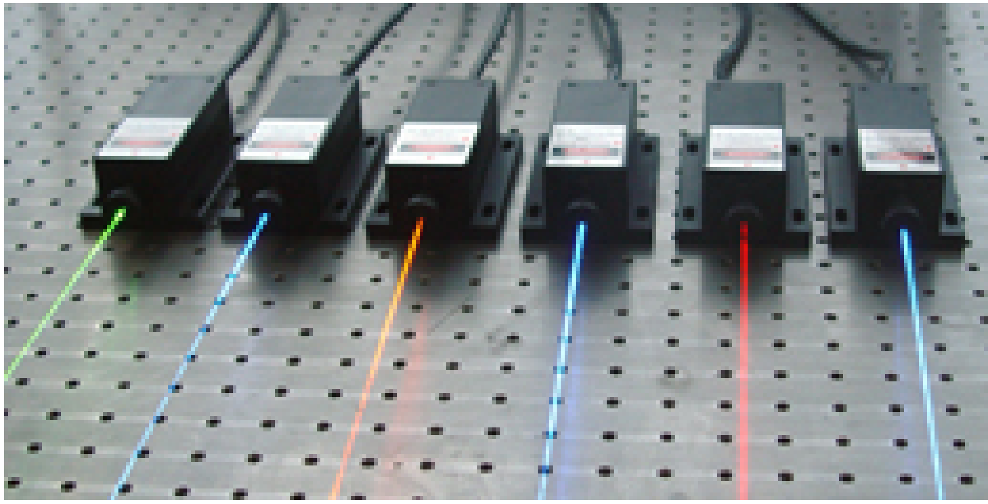
DIODE PUMPED SOLID STATE (DPSS)



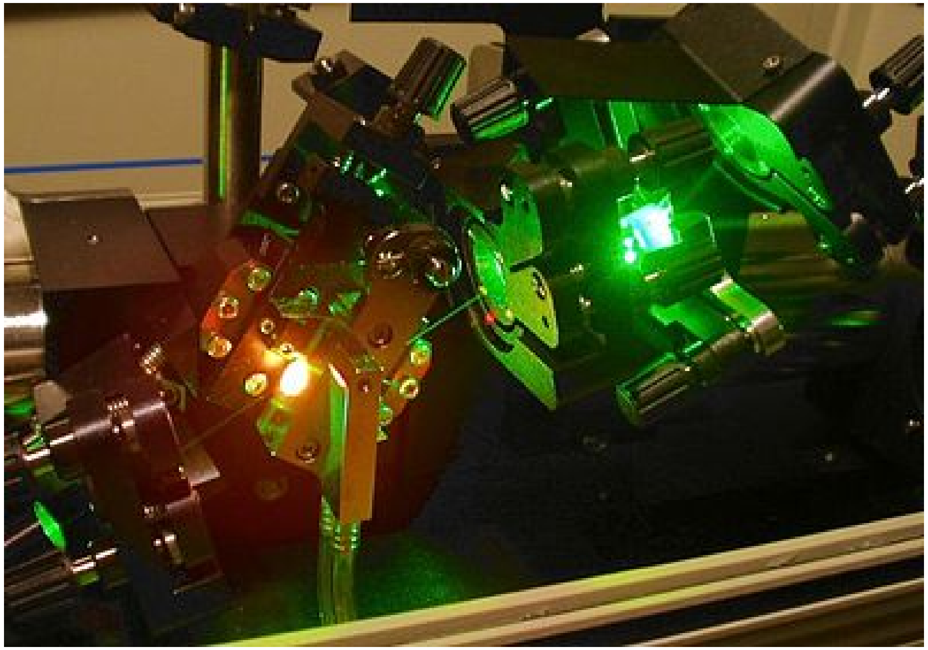
http://www.rp-photonics.com/solid_state_lasers.html

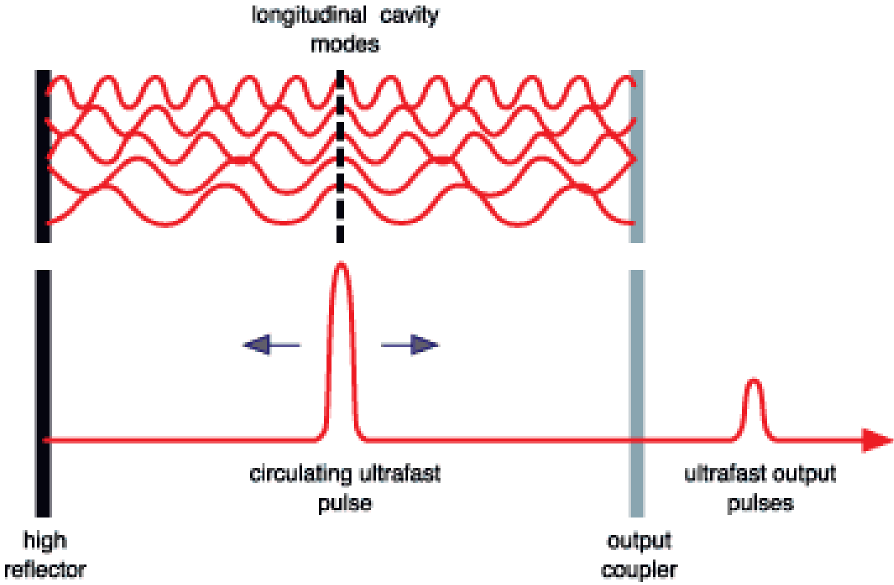
Sometimes a specially doped laser crystal that produces the desired spectra lines

http://www.laser2000.se/index.php?id=370735



TITANIUM SAPPHIRE (TI:SAPPH) LASER





http://spie.org/Images/Graphics/Newsroom/Imported/may04/practicalfig1.gif

- Produces intense ultrashort (fs - ps) pulses via mode-locking at MHz rep rate
- Tunable wavelength in the red-NIR range
- Often used for multiphoton microscopy and time-resolved fluorescence