Phys 2310 Mon. Dec. 4, 2017
Today's Topics

- Begin supplementary material: Lasers
- Reading for Next Time

Reading this Week

By Wed.:

Lasers, Holography

Homework this Week

No Homework this chapter. Finish previous one and

Study for the Final Exam

Supplementary: Lasers

- **Radiant Energy and Matter in Equilibrium**
  - **Blackbody Radiation**
    - **Conservation of Energy Requires Objects in Thermal Equilibrium Must Emit as Much Energy as They Absorb**
      - **More absorption means temp. rises and vice versa**
      - **Example: pottery in equilibrium with kiln walls**
    - **Molecules in a Solid Emit at a Broad Range of Frequencies**
    - **Spectral shape (Intensity vs. λ) is called a Blackbody**
      - **A perfect absorber in equilibrium with surroundings**
      - **Note that a mirror feels cool to the touch since it is not in equilibrium with its surroundings**
      - **Explanation by Plank required light be quantized (photons)**
  - **Stefan-Boltzmann Law**
    - **Total energy emitted per second (power):**

$$P = \text{Emissivity} \times \text{Area} \times \sigma \times T^4$$

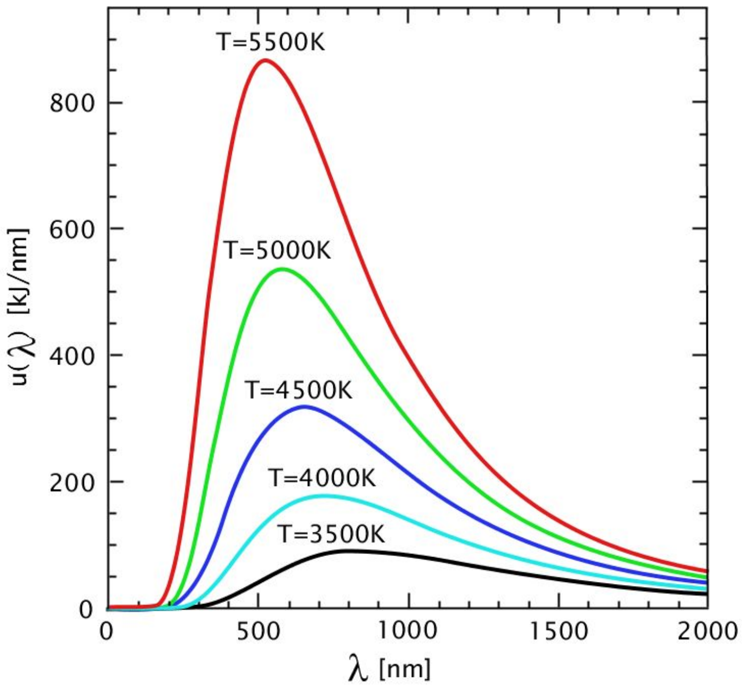
$$(\sigma = 5.67 \times 10^{-8}\ \text{W/m}^2\text{K})$$

Supplementary : Lasers

- **Radiant Energy and Matter in Equilibrium**
  - **Plank Radiation Law**
    - **Derived thermal emission spectrum by assuming atoms in solid follow a Maxwell-Boltzmann distribution in energy and can only emit radiation in discrete energies (photons).**
    - **Result is:**

$$I_\lambda = \frac{2\pi hc^2}{\lambda^5}\left[\frac{1}{e^{\frac{hc}{\lambda kT}} - 1}\right]$$

where h is Plank's constant, k is Boltzmann's constant



Wein's Displacement Law:
Describes the shift in wavelength of the peak with temperature.

$$\lambda_{\max}(\mu m)T(K) = 2898$$

Supplementary : Lasers

- **Stimulated Emission**
  - **Maxwell-Boltzmann Distribution**
    - **Equipartition of energy requires that atoms follow an exponential distribution in energy:**

      $N_i = N_0 e^{-E/kT}$ (k = 1.38 x 10^{-23} $m^2 kgs^{-1} K$)
  - **Einstein Coefficients**
    - **Describes the rate at which atoms absorb and emit energy. The first two (Bs) are strongly λ dependent and sensitive to the photon energy density (u_ν).**

$$\left(\frac{dN_i}{dt}\right)_{absorp} = -B_{ij} N_i u_\nu \quad \text{(stimulated absorption)}$$

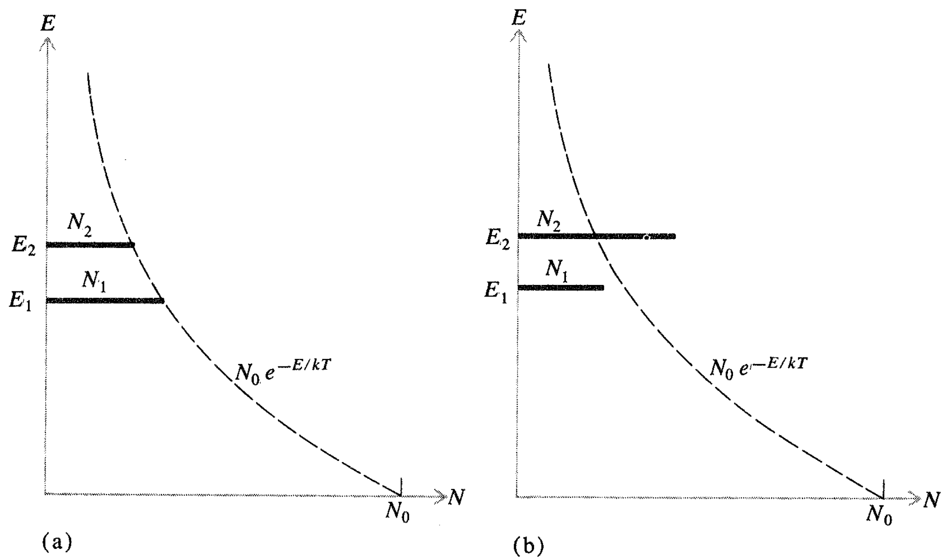
$$\left(\frac{dN_j}{dt}\right)_{stim} = -B_{ji} N_j u_\nu \quad \text{(stimulated emission)}$$

$$\left(\frac{dN_j}{dt}\right)_{spon} = -A_{ji} N_j \quad \text{(spontaneous emission)}$$

where u_ν is the spectral energy density. Note that in stimulated emission the E - field of the photon perturbs the atom such that it emits a matching photon in wavelength and phase (crucial).

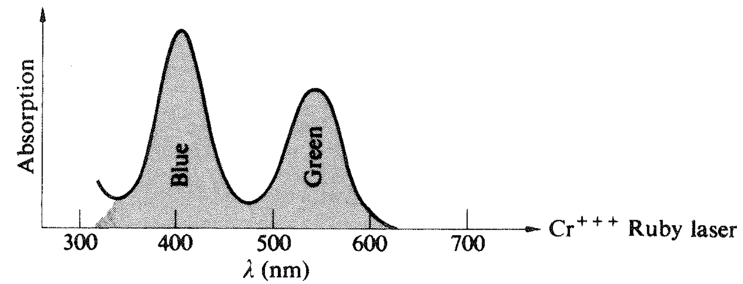
Supplementary : Lasers-I

– **Population Inversion**
  - **Quantum mechanical rules are used to calculate the Einstein coefficients.**
    - $B_{ij} = B_{ji}$ since prob. of stim. emission equals prob. of stim. absorption.
    - A_{ji} is a measure of the excited state lifetime: $1/A_{ji} = \tau$
      $1/A_{ji} \sim 100$ns but:
    - Some transitions are "metastable," meaning that $1/A_{ji} \sim 10$ ms (100 times longer).
    - Population inversion can occur if some process (collisions) can populate an excited, metastable state faster than A_{ji} can depopulate it.
    - Fluorescence and Phosphorescence
    - When spontaneous emission occurs the photon can stimulate the other metastable atoms to emit a cascade of photons.
      - » Result will be a burst of coherent radiation (laser).



Supplementary : Lasers-II

- **The Ruby Laser**
  - First optical λ laser
  - First solid-state laser
  - Fluorescence of Cr^{++} ion
    - Blue and Green absorption and then vibrational down-conversion to metastable state.
    - Spontaneous emission results in red fluorescent "glow" of ruby



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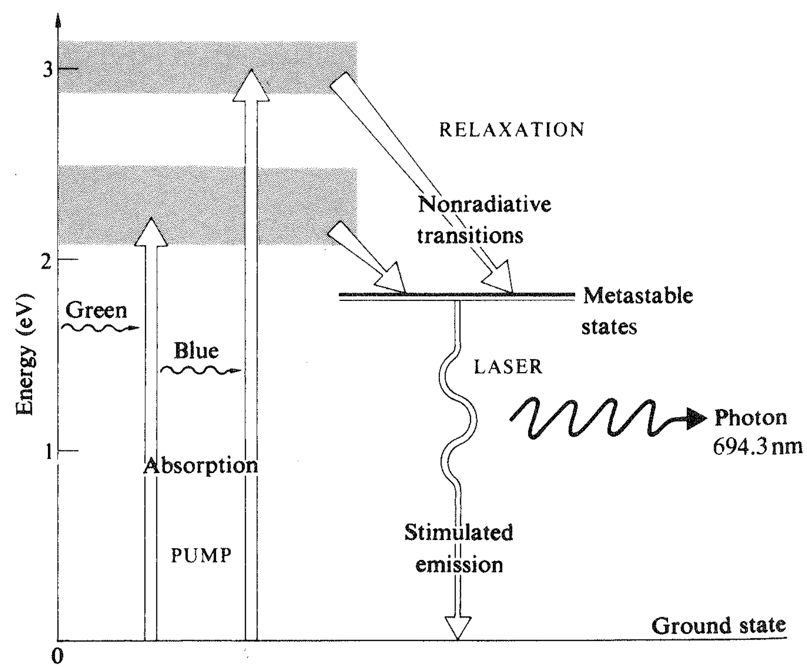

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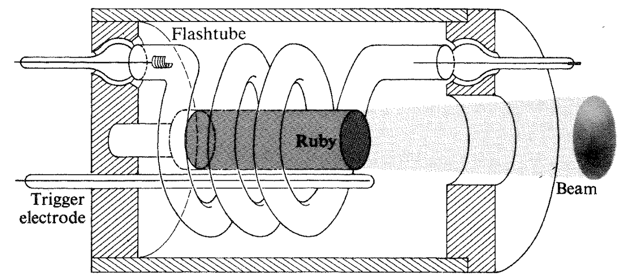
Supplementary : Lasers-II

- **Ruby Laser**
  - A flashtube containing Xe gas, etc. creates optical light to pump the ruby crystal (optical pumping). Vibrational relaxation populates the metastable levels.
  - Spontaneous emission of a few atoms creates stimulated emission in others.
  - Constraining radiation to a cavity results in more stimulated emissions and an "avalanche" of coherent radiation.
  - Radiation escapes as a beam but in pulses
  - Ruby can be grown in lab but expensive
  - Ruby laser can be very powerful
  - Relatively inefficient due to heat losses



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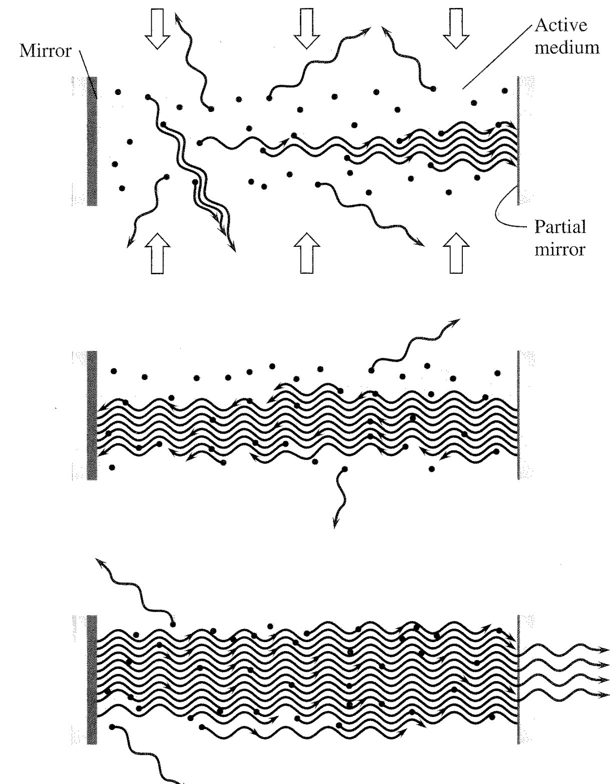

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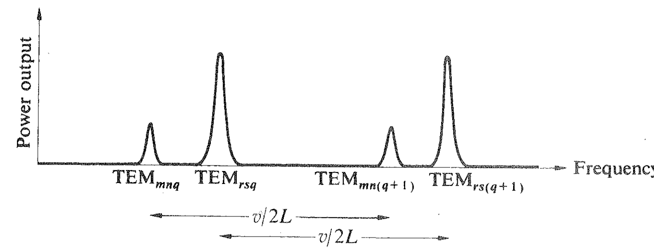
Supplementary : Lasers-III

- **The Laser**
  - **Resonant (Fabry-Perot) Cavities**
    - **Standing waves exist within a cavity (l) when:**

      l = m $\lambda/2$ where m is an integer
    - **Thus the cavity can be tuned to isolate a particular emission line from the atom if more than one are involved.**
    - **Other cavity geometries are possible.**



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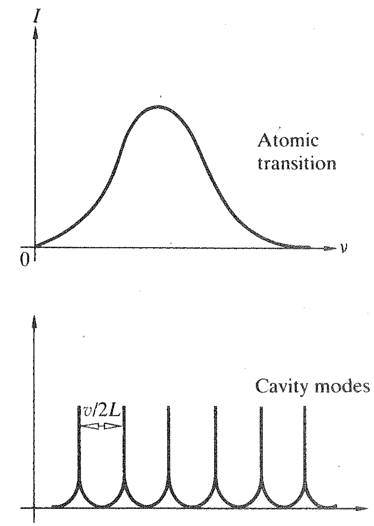

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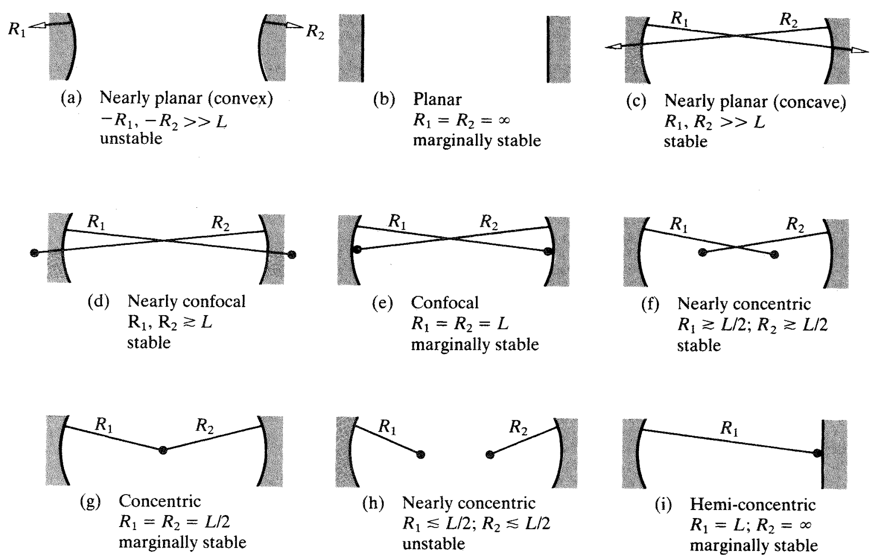
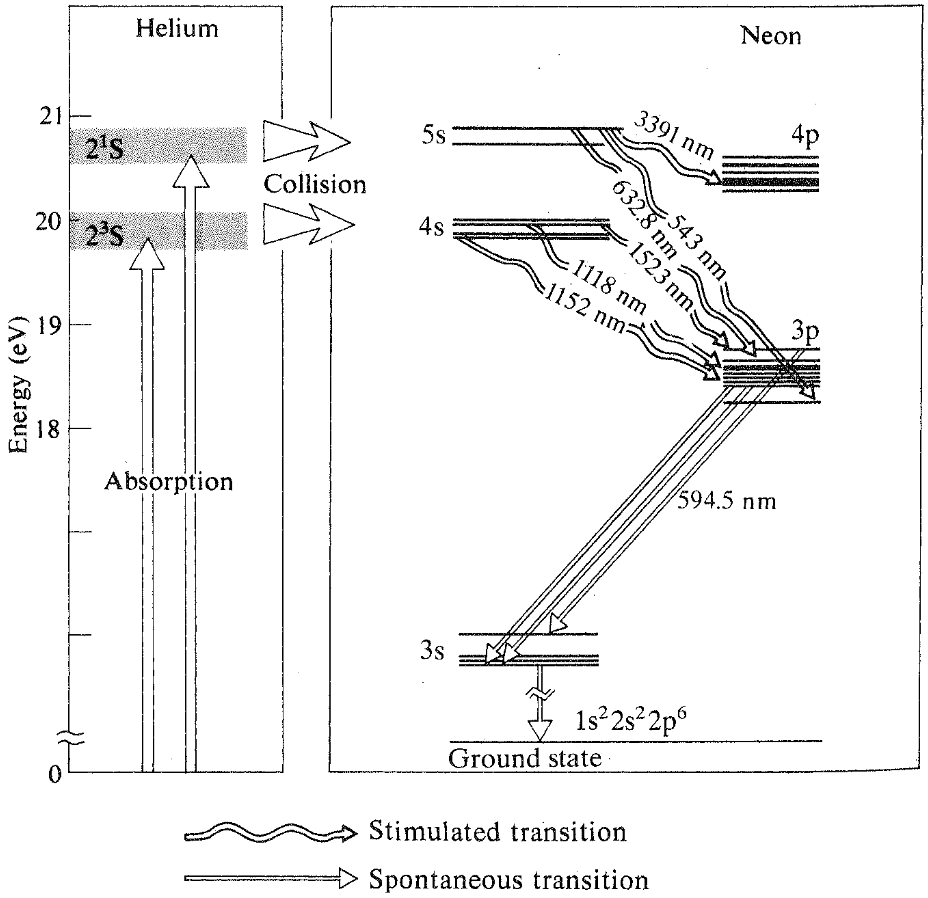


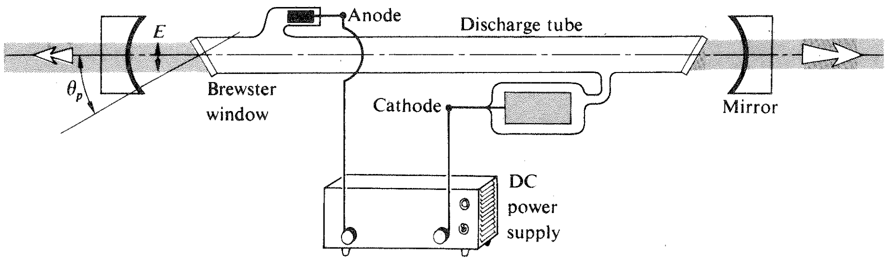
Supplementary : Lasers-IV

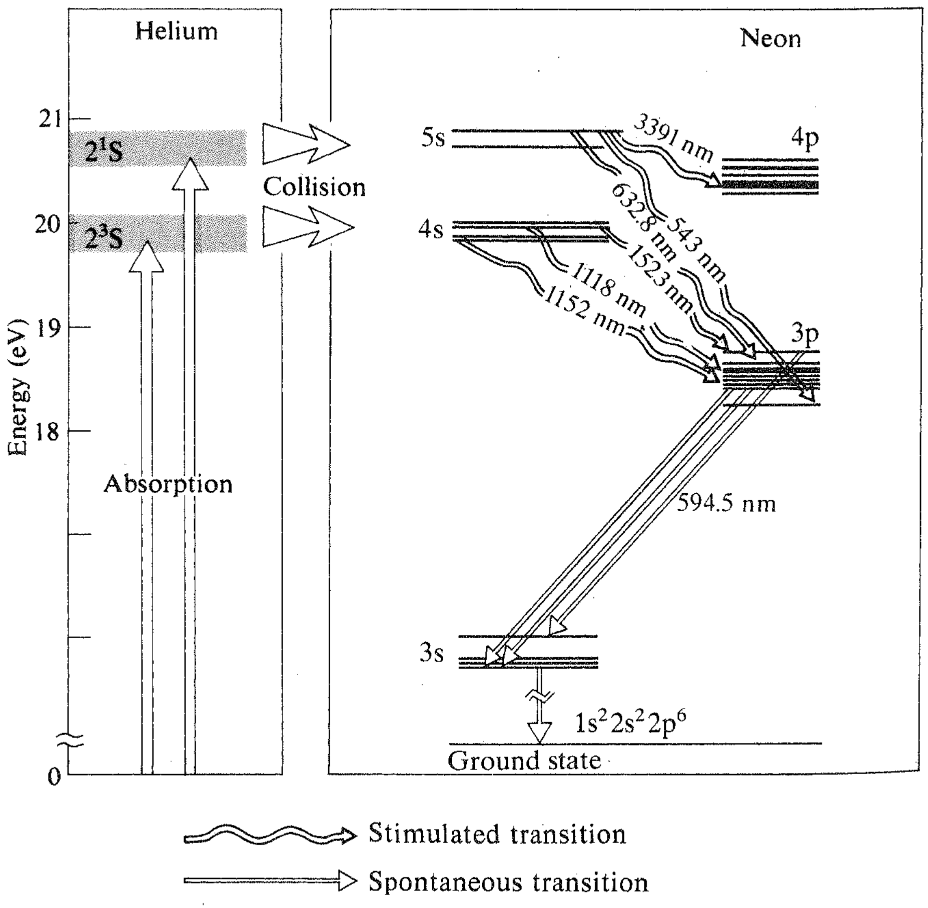
- **Gas Laser**
  - **HeNe Laser**
    - **Excited levels of He and Ne are close in energy**
      - **Energy in He is transferred to Ne via collisions**
      - **High voltage strips electrons off He and recombination results in excited state.**
      - **If Ne collisions occurs quickly enough it populates metastable states (4s and 5s)**
      - **Spontaneous emission then results in lasing**



Supplementary : Lasers-IV

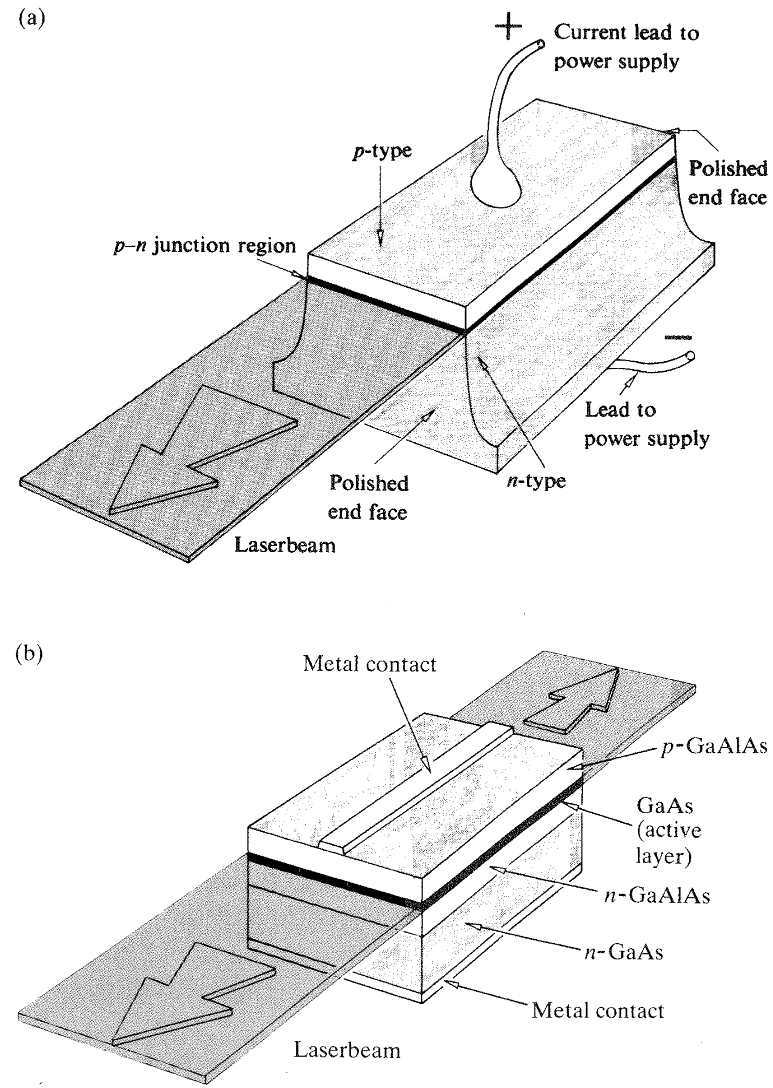
- **Gas Laser**
  - **HeNe Laser**
    - **Inexpensive to make**
    - **Produces visible light**
    - **Relatively stable**
    - **Low efficiency**
  - **Argon Laser**
    - **Similar to HeNe laser**
    - **More lines so cavity can be tuned to different λ.**
    - **Low efficiency**
  - **Other Noble Gas Lasers**
    - **Kr and Xe useful for blue λ**
    - **N_2 lases in UV, CO_2 in IR**





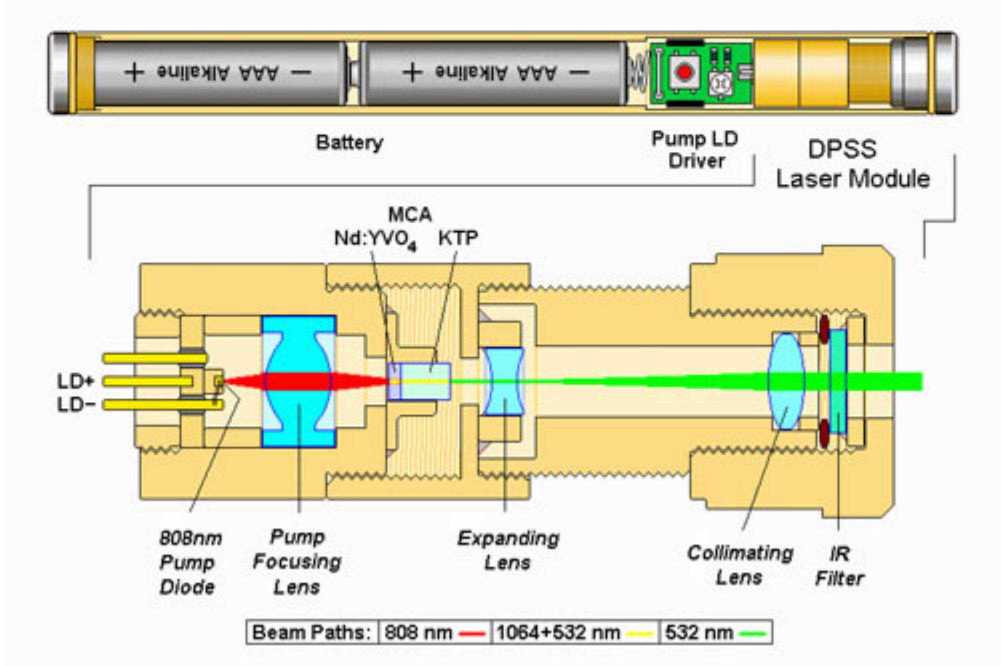
Supplementary : Lasers-IV

- **The Semiconductor Laser**
  - Interface of n-doped and p-doped interface of semi-conductors can produce light upon electron-hole recombination (LED).Gallium-Arsenide is most common for IR.
  - NdYAG (Neodymium Yttrium Arsenic Garnet) lasers common too (next slide).
    - Add frequency doubling crystal to produce green
  - Laser results if surfaces are polished
  - Basis for all laser pointers and CD-ROM and DVD readers and writers and BlueRay players
  - Lasing λ is in the infrared
    - Ideal for fiber optic communication
    - Can be mass produced
    - Rectangular beam profile



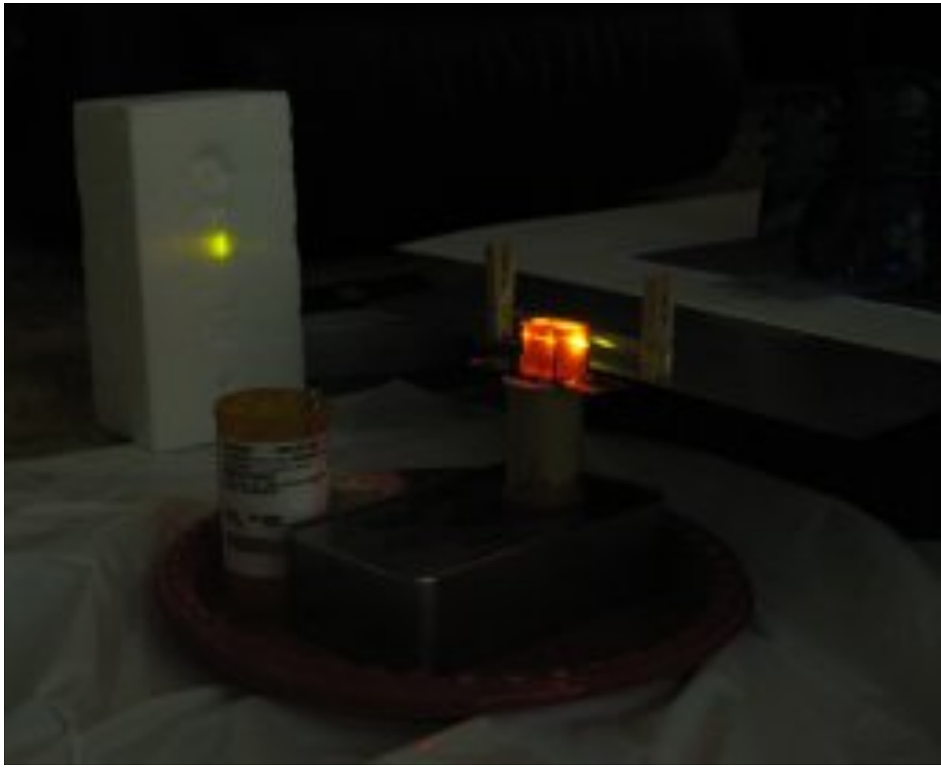
Supplementary: Lasers-V

- **Other Solidstate Lasers**
  - Diode lasers can be used to pump a crystal to produce high power output
    - $NdYVO_4$ or NdYAG are most common
    - Typical $\lambda \sim 1.064$ µm
  - An optically active crystal "cavity" can be added to double (532nm) or triple (355 m) the input frequency
    - KTP most common
    - Result is visible green or even blue laser
  - Ideal for lab lasers and laser pointers
  - BlueRay lasers



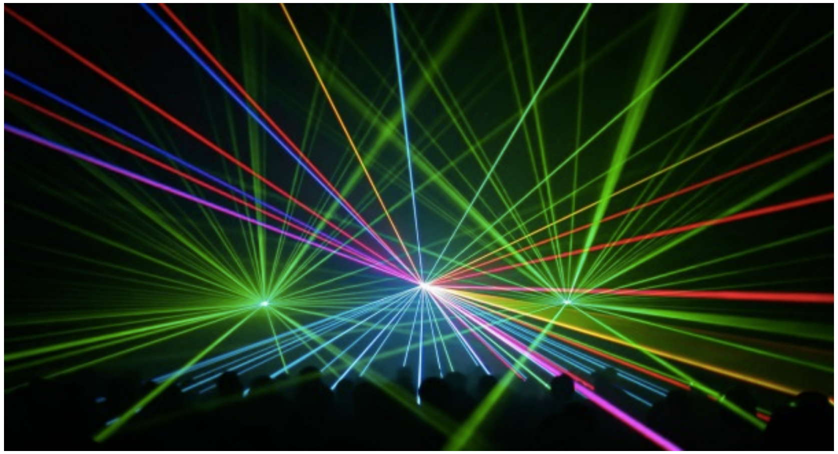
Supplementary : Lasers-V

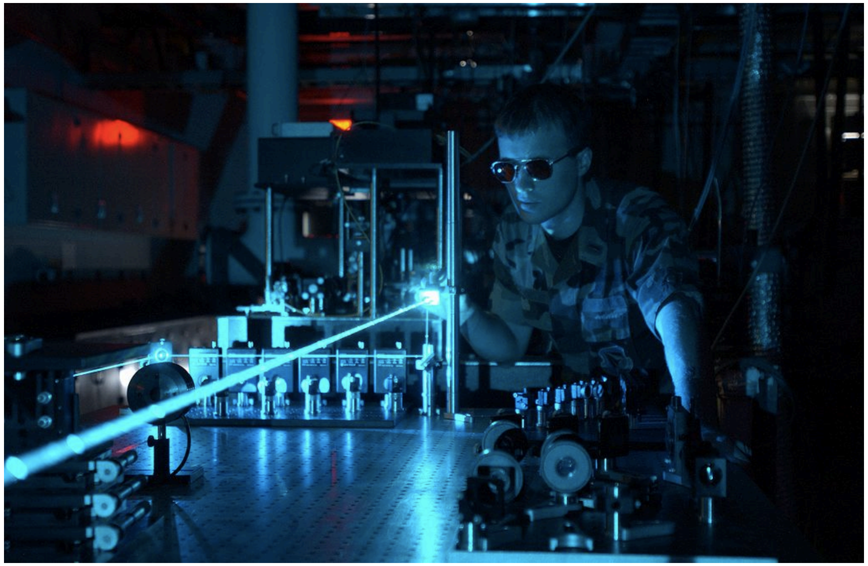
- **The Dye Laser**
  - **Fluorescent dyes usually have many metastable states**
    - **They can be pumped by another laser (e.g. N_2) or via flashlamp**
    - **The lasing cavity can be tuned via a grating for one of the mirrors**
    - **Result is a laser that can produce a broad range of λ**
    - **Lots of stuff with organic dyes will lase, even JELLO!**
    - **See internet for lots of examples of homebuilt ones.**



Supplementary : Lasers-VI

- **Laser Applications**
  - Lasers Come in Variety of Packages for Research
  - Diode Lasers Now Inexpensive
    - They can be used for entertainment
    - Lasers used in Manufacturing





Supplementary : Lasers-VII

- The Laser
  - More Applications
    - Manufacturing
    - Surveying
    - Raman Spectroscopy
      - Fluorescence and Phosphorescence
    - Cosmetics
    - Communication
    - Fusion & Weapons

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