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. $\lambda$) 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.

\[\lambda_{\text{max}} \mu m T(K) = 2898\]
Supplementary : Lasers

• Stimulated Emission
  – Maxwell-Boltzmann Distribution
    • Equipartition of energy requires that atoms follow an exponential distribution in energy:
      \[ N_i = N_0 e^{-E/kT} \quad (k = 1.38 \times 10^{-23} \text{ m}^2\text{kg}^{-1}\text{K}) \]
  – Einstein Coefficients
    • Describes the rate at which atoms absorb and emit energy. The first two (Bs) are strongly \( \lambda \) dependent and sensitive to the photon energy density \( u_\nu \).

\[
\left( \frac{dN_i}{dt} \right)_{\text{absorp}} = -B_{ij} N_i u_\nu \quad \text{(stimulated absorption)}
\]
\[
\left( \frac{dN_j}{dt} \right)_{\text{stim}} = -B_{ji} N_j u_\nu \quad \text{(stimulated emission)}
\]
\[
\left( \frac{dN_j}{dt} \right)_{\text{spon}} = -A_{ji} N_j \quad \text{(spontaneous emission)}
\]

where \( u_\nu \) 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: $1/A_{ji} = \tau$
      $$1/A_{ji} \sim 100\text{ns but:}$$
    - Some transitions are “metastable,” meaning that $1/A_{ji} \sim 10 \text{ ms (100 times longer)}$.
    - 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 $\lambda$ 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
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
Supplementary: Lasers-III

- **The Laser**
  - Resonant (Fabry-Perot) Cavities
    - Standing waves exist within a cavity (l) when:
      \[ l = m \frac{\lambda}{2} \text{ where } m \text{ is an integer} \]
    - 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.
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
    - N₂ lases in UV, CO₂ 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 \( \lambda \) 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
    • NdYVO₄ or NdYAG are most common
    • Typical $\lambda \sim 1.064 \mu m$
  – 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
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 $\lambda$
- 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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