Optics

Lasers

Problem 1.- True (T) or false (F):

( ) For laser action it is necessary to create an inverted population with negative absolute temperature.
( ) Laser light is blackbody radiation.
( ) Laser cavities typically have one full mirror at one end and a partial mirror at the other.
( ) He-Ne lasers emit blue light.

Solution:

(**T**) For laser action it is necessary to create an inverted population with negative absolute temperature.
(**F**) Laser light is blackbody radiation.
(**T**) Laser cavities typically have one full mirror at one end and a partial mirror at the other.
(**F**) He-Ne lasers emit blue light.

Problem 2.- True (T) or false (F):

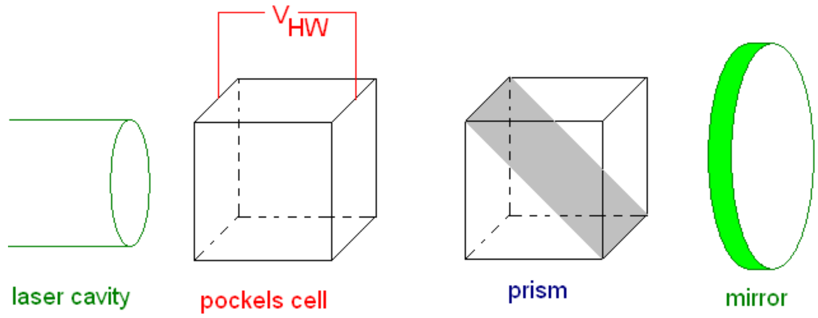
( ) Atoms absorb photons of light in a continuous spectrum.
( ) Excited atoms emit radiation only when stimulated by the presence of another photon of the same energy.
( ) Atoms in the ground state emit radiation spontaneously.
( ) Excited atoms emit radiation spontaneously.

Solution:

(**F**) Atoms absorb photons of light in a continuous spectrum.
(**F**) Excited atoms emit radiation only when stimulated by the presence of another photon of the same energy.
(**F**) Atoms in the ground state emit radiation spontaneously.
(**T**) Excited atoms emit radiation spontaneously.

Problem 3.- Sketch and explain any scheme in which a Pockels cell is used as a Q-switch in a laser.

Solution:



The prism has high transmission when the polarization is vertical and high reflectivity when the polarization is horizontal. The Pockels cell rotates the polarization 90º which builds energy in the laser cavity in the horizontal polarization. When the voltage is switched to zero the energy is dumped as a pulse.

Problem 4.- Suppose you have a laser with wavelength equal to 633nm. To generate that wavelength the gain medium has more of its atoms in the upper state than in the lower state. Calculate the absolute temperature that you would need to have a ratio of 3 to 1 thermally.
[*hint*: the absolute temperature needs to be negative]

Solution:

$$\frac{P_2}{P_1} = 3 = \exp\left[-\frac{hc/\lambda}{k_B T}\right] \rightarrow -\frac{hc/\lambda}{k_B T} = \ln(3)$$

$$\rightarrow T = -\frac{hc}{k_B \lambda \ln(3)} = -\frac{(6.62\times10^{-34})(3\times10^{8})}{(1.38\times10^{-23})(633\times10^{-9})\ln(3)} = \textbf{-20,700 K}$$

Problem 4a.- Getting an inverted population just thermally is not possible because Boltzmann factors always favor low energy states.
Calculate the temperature that would need to produce a ratio of 2 to 1 between the excited state and the ground state of an atom if the difference in energy is 1.5eV.

Solution: Using the Boltzmann factors:

$$2 = \exp\left(-\frac{E}{k_B T}\right) \rightarrow T = -\frac{E}{k_B \ln(2)} = -\frac{1.5\times1.6\times10^{-19}}{1.38\times10^{-23}\ln(2)} = \textbf{-25,100 K}$$

Problem 5.- Use the relation between the A and B coefficients to explain the reason why lasers with shorter wavelengths are more difficult to obtain than with longer wavelengths.

Solution: According to Einstein's work $\frac{A}{B} = \frac{8\pi hf^3}{c^3}$, where A is the spontaneous emission coefficient and B is the stimulated one. We notice that if the frequency increases the value of B drops as $1/f^3$, making it more difficult to produce stimulated emission. So making a laser at shorter wavelengths is much more difficult than at longer wavelengths.

Note: The difficulty is compounded by other effects. You can read an analysis in the Proceedings of the IEEE Volume 80, Issue 3, pages 342-347 (1992)

Problem 6.- An optical parametric oscillator is pumped by an Ar-ion laser (λ=514.5nm) Calculate the possible range of wavelengths of the idler.

Solution: As discussed elsewhere it will be **1,029 nm to infinity**.

Problem 7.- Getting an inverted population just thermally is not possible because Boltzmann factors always favor low energy states.
For example, calculate the probability of an atom to be in an excited state 1.8eV higher than the ground state if the temperature is 1,000K.
To simplify the problem assume there are no degeneracies and ignore any other higher states.

Solution: $\frac{P_2}{P_1} = \exp\left(-\frac{E_2 - E_1}{k_B T}\right) = \exp\left(-\frac{1.8\times1.6\times10^{-19}}{1.38\times10^{-23}\times1000}\right) =$ **8.6×10^{-10} K**

Problem 8.-

a) Why do you need at least three energy levels in a laser?
[The ammonia maser being the only counterexample]

b) What is the purpose of the mirrors in the cavity of a laser?

Solution:
a) In a laser we need to sustain an inverted population of excited atoms (more excited atoms than in the ground state), but with two levels it will not work, because the same excitation causes stimulated decay, that is why three levels are needed. The atoms drop to a metastable state where they will remain for a "long" time.

b) The mirrors in the cavity of a laser reflect the photons back and forth producing more and more stimulated emission in each pass.

Problem 9.- Which of the following lasers utilizes transitions that involve the energy levels of free atoms?

(A) Diode laser
(B) Dye laser
(C) Free-electron laser
(D) He-Ne laser
(E) Solid-state laser

Problem 10.- Which of the following statements about the absorption and emission of energy by an atom are correct?

I. An atom can only absorb photons of light that have certain specific energies.
II. An excited atom will emit a photon preferentially if stimulated by the presence of another photon of the same energy.
III. At low temperature, the lines in the absorption spectrum of an atom coincide with the lines in its emission spectrum that represent transitions to the ground state.

(A) I only
(B) III only
(C) I and II only
(D) I and III only
(E) I, II, and III

Problem 11.- The first maser (precursor to the laser) was based on the separation between the energy levels of ammonia. It was designed to work as a microwave amplifier. Explain briefly how it used the principle of stimulated emission for amplification.

Solution: The excited state of the ammonia molecule was separated from the ground state and then the beam that needed to be amplified was allowed to go through the excited ammonia. Stimulated emission processes multiplied the microwave beam producing amplification.

Problem 12.- Given that you know that the spontaneous radiative lifetime of the first excited state of hydrogen is 10^{-8} s, find the A and B coefficients of this transition (the transition is the first Lyman line).