Laser Simulation
By: Alex Marshall

1. Laser: Pumping a two state system
   a. This simulation uses an optical pump as an energy source for a laser. Turn the light source on a medium level with the preset wavelength. What do you observe about the emitted photons? (Are they spontaneous emissions, stimulated emissions or both and how can you identify this?)

   Both are observed, but in order to identify the stimulated, it is the simple observation that there are emitted photons moving in the same direction as the incident photons. Whereas, spontaneous decay does occur from an excited state, but this was much more seldom and is perceived when the photon is released in a random direction. Also, how long the electron spends it the excited state (n=2) varies.

   b. When you change the intensity of the light source to a very low level, what do you notice about the emitted photons?

   At a very low intensity, the incident photons interact with the atom at a slow enough pace because they are spread apart and less rapid that the excited state will decay spontaneously before the next incident photon reaches it; therefore, the probability for them to be spontaneously emitted is increases to occurring much more often than the stimulated decay. Also, since the lifetime is at its max, any other possible lifetime would only hasten the spontaneous emission and not affect the possibility it being stimulated.

   c. When you change the intensity of the light source to a very high level, what do you notice about the emitted photons?

   Conversely, relative to a very low intensity, the incident photons are interacting with the atom at a rapid rate; therefore, the probability of an incident photon to reach an already excited atom increases drastically, leading to almost every emission being stimulated. As for lifetime, even though it is constant, to comment on it again, any other lifetime (it is still maxed) should results in an increased probability of random emission; in turn, this would reduce the possibility of it being stimulated, even at a high intensity.

   d. When you have the intensity at a medium level but decrease the lifetime, what do you notice about emissions?

   As I already stated, the lifetime reduction would hasten the decay of an excited atom thereby increasing the probability of spontaneous emission. Once the lifetime is minimized, the time it takes for an excited state to lower energy levels without stimulation is greatly reduced; in addition, since the rate of incidence is dependent upon the intensity, when the lifetime is still at a min, the medium level photons are not capable of interacting with the excited atom before spontaneous emission occurs.

   e. When you have the intensity at a medium level but increase the lifetime, what do you notice about emissions?

   An increase in the lifetime will reduce the probability of random emission, which will result in the excited states being more and more likely to be interacted with before the decay.

   f. When you tune the light to a color that has a lower energy than the preset color, what do you observe?
Shifting to the dark red color reduces the light’s energy; in turn, the electron does not get excited because of its current electronic energy level. Additionally, the distance between the potential movements (n=1 & n=2) is shortened.

**g.** When you tune the light to a color that has a higher energy than the preset color, what do you observe?

Shifting towards the dark blue end of the spectrum results with increases the energy of the photons; just as when the energy of the light was increased, no longer is the electron able to be excited. Also, the distance between the potential movements (n=1 & n=2) is lengthened.

In sum, being able to manipulate the variables and see the experimental outcome was a significant component of my current understanding of the two-state system. Perceiving and understanding the outcome of stimulation and spontaneous emissions enabled me to visualize the main difference between the two: spontaneous is a single emission and has a random direction, whereas, stimulated is a double emission and directionality is determined by the incident photon. From there, it was interesting to see how the intensity and lifetime are dynamic in the probability of the two emissions. Also, the fact that having two states results the only incident photon that is able to excite the electrons is one with a red wavelength.

2. **Laser: Pumping a three state system**

   **a.** When you change to a three state system, can you still only pump electrons to a higher energy level with the red light or is there another light energy that works now? Explain.

With a three state system, there are two separate energy levels that the photon, which therefore enables light with both blue and red. This is because the new introduced energy level (n=3) that is specific to the atom and is set at a level with equal energy as blue light; then, red is still able to be excited due to it being the electronic energy level (n=2), which is once again, dependent upon the specific atom, and is preset to having a level linked with red.

   **b.** Click on display photons emitted from upper state.) What transition do these photons represent, and what region of the spectrum are these photons in?
Purple - They are both dark red and a lime green, shown in the figure below. These represent the emitted photons from the one state to another since I made the energy difference between the excited states greater (from n=3 to n=2), the spontaneous emission is of a higher energy level, lime green. Then, when there is a spontaneous emission at the first upper state to the ground state (from n=2 to n=1), the dark red photon is emitted because it is a low energy difference; therefore, less energy needs to be emitted in order to reach a lower state, in this case, the ground state. From there, there is the possibility of any spontaneous emission with energy less than that of the third energy level: blue, teal, blue, yellow, orange red, and dark red.

Blue – As shown below, one color of the emitted photons is dark red; this is because the spontaneous movement to a lower energy level (n=3 to n=2) or (n=2 to n=1) only emits the difference in the energy levels and a dark red photon carries that difference. From there, it is the typical pattern, the possibilities are the colors with less energy than the 3rd energy level, which are green, yellow, orange, red, and dark red.
Teal – There is the possibility of orange, red, or dark red spontaneous emissions. The picture below shows the orange and dark red photons, which the dark red is due to that being the lowest energy color and that makes up the difference from the second energy level to the ground state. As for the orange, it possesses equal to the energy it requires to jump from the third energy level to the second energy level. After shifting the second energy level up near the energy level for teal, it has the exact same emission, but in the opposite order. Then, Red is the only other possibility, which is logical because it has less energy than orange. These same colors can be done with a lower 2nd energy level. Conservation of energy is very apparent with these experiments.
Yellow- Red and dark red
Orange – Dark red only
Red – They are single dark red photons released in random directions. These represent the emitted photons from the one excited state to another (from \( n=3 \) to \( n=2 \)). As you can see in the figure below, there is a dark red emission and the energy level \( n=2 \); therefore, there is a spontaneous emissions from one excited state to another. Also, it makes sense that it is dark red instead of red, dark red has less energy and is identical to the difference between the energy levels (\( n=3 \) & \( n=2 \)).

c. When you increase the lifetime of the upper state what happens to the emission events?

When the lifetime is increased for the upper energy level, the time that it takes for the decay and henceforth, the spontaneous emission of this the upper level is increased. It simply spends more time excited at the upper level.

d. When you in increase the lifetime of the lower state what happens to the emission events?

When the lifetime is increased for the lower energy level, the time that it takes for the decay and henceforth, the spontaneous emission of the lower level is increased; resulting in a longer time spent in the lowest energy level.

In sum, it was interesting to be able to use different wavelengths to enact excitation. On top of that, the conservation of energy was seen and explained for when we manipulated the wavelength. There is a threshold for interaction for the energy, which is determined by the third energy level; by simply how high that energy level is (closer to blue’s energy) and manipulating the second state would emit nearly the entire spectrum, other than blue.
3. **Making a laser with a three state system** You studied a two and three state laser. What about a four state laser? Put all your learning together and find conditions that make a good laser. Describe them below. (Good equals continually running with decent in the green lasing power.)

4. A small helium-neon laser produces a light beam with an average power of 3.5 mW and a diameter of 2.4 mm. We know:
   \[ P = 3.5 \times 10^{-3} \text{W} \]
   \[ r = 1.2 \times 10^{-3} \text{m} \]
   
   a. How many photons per second does the laser emit?
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\[ \lambda = 633\text{nm} \]

\[ P = \frac{E}{t} = nh\frac{v}{t} \]

Therefore:

\[ \frac{P}{hv} = \frac{n}{t} \]

Which is the same as:

\[ \frac{P\lambda}{hc} = \frac{n}{t} \]

Let \( \lambda = 632.8 \times 10^{-9} \text{ m} \) be the wavelength of the light emitted from He-Ne laser:

\[ \frac{n}{t} = \frac{P\lambda}{hc} = \frac{(3.5 \times 10^{-3}W)(632.8 \times 10^{-9}m)}{(6.625 \times 10^{-34}Js)(3 \times 10^8 \frac{m}{s})} = 1.114 \]

b. What is the amplitude of the electric field of the light wave? Compare this result with the electric field at a distance of 1 m from an incandescent light bulb that emits 100 W of visible light.

Since we know that the relationship is that of the intensity, we can write:

\[ \frac{P}{A} = I = \frac{E_o^2}{2\mu c} \]

Thus:

\[ E_o = \pm \sqrt{\frac{P2\mu c}{A}} \]

Taking the absolute value to get the magnitude of the amplitude:

\[ E_o = abs \left( \pm \sqrt{\frac{P2\mu c}{A}} \right) = \sqrt{\frac{(3.5 \times 10^{-3}W) * (2 \times 4\pi \times 10^{-7} \frac{H}{m}) * (3 \times 10^8 \frac{m}{s})}{\pi * (1.2 \times 10^{-3}m)^2}} = 763.76 \frac{N}{C} \]