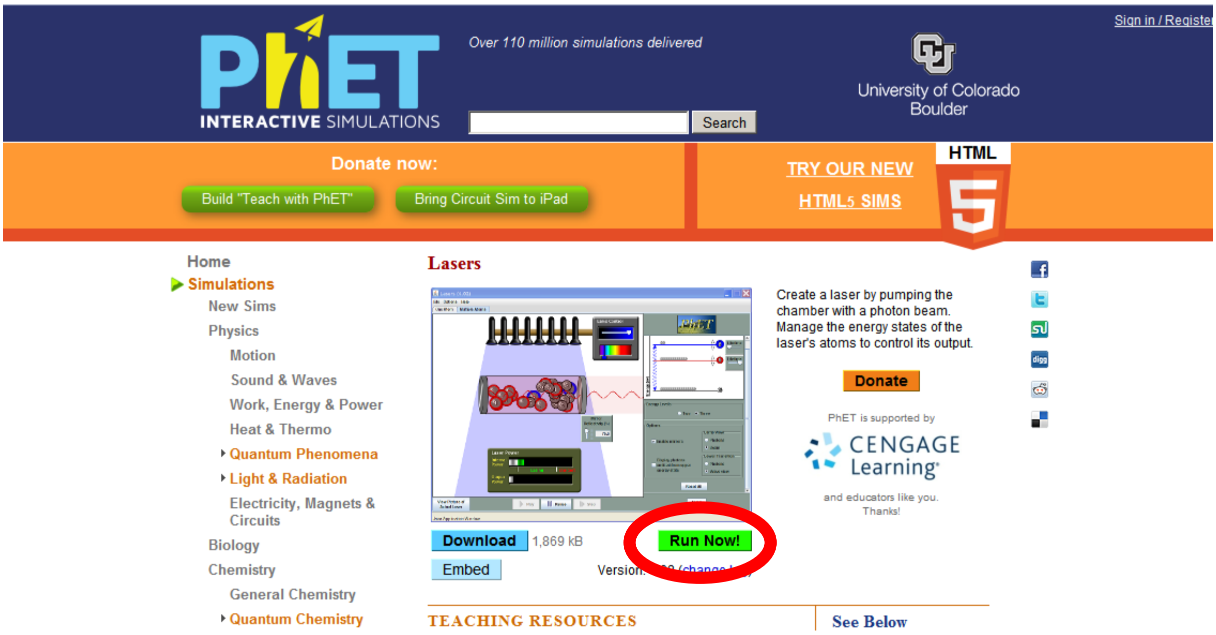
EEE 429/529 Photonics Homework

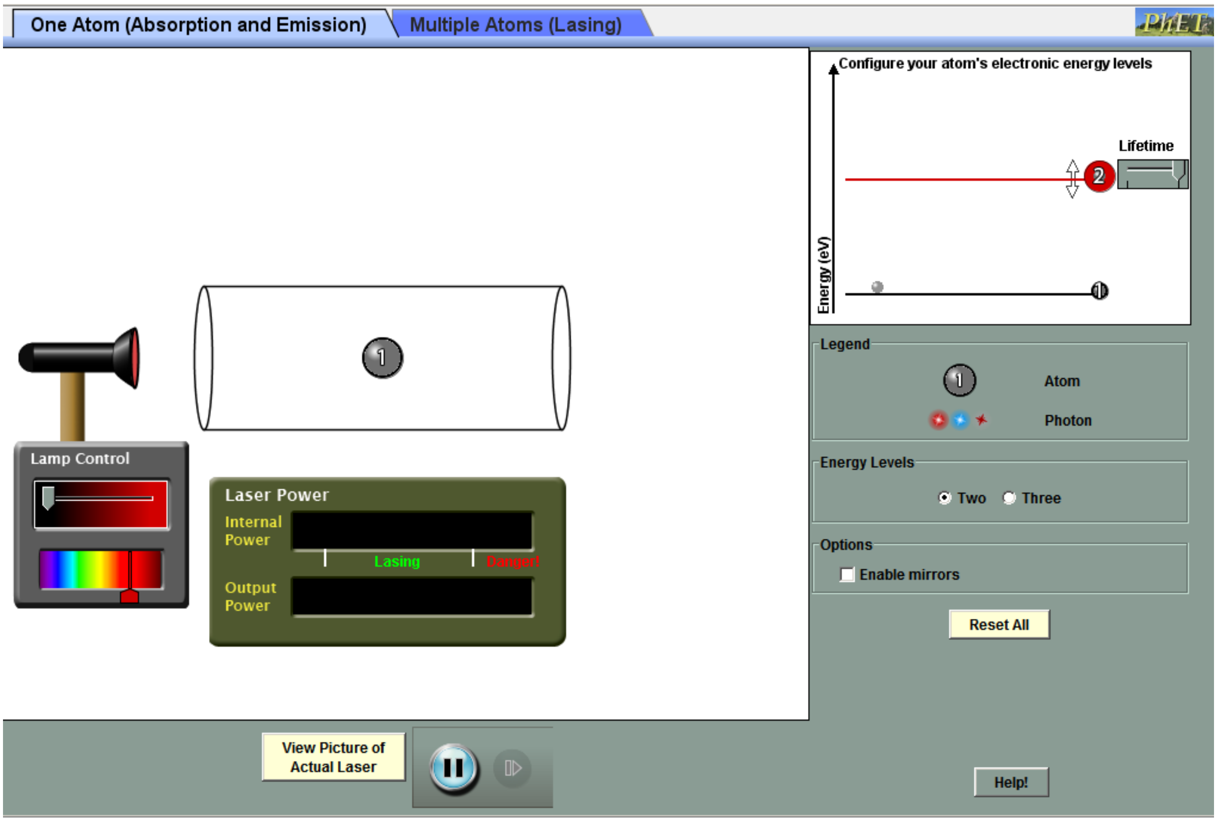
This homework uses java based laser simulator which visually simulates the operation of a three level laser. The program can be downloaded using the link:

http://phet.colorado.edu/en/simulation/lasers

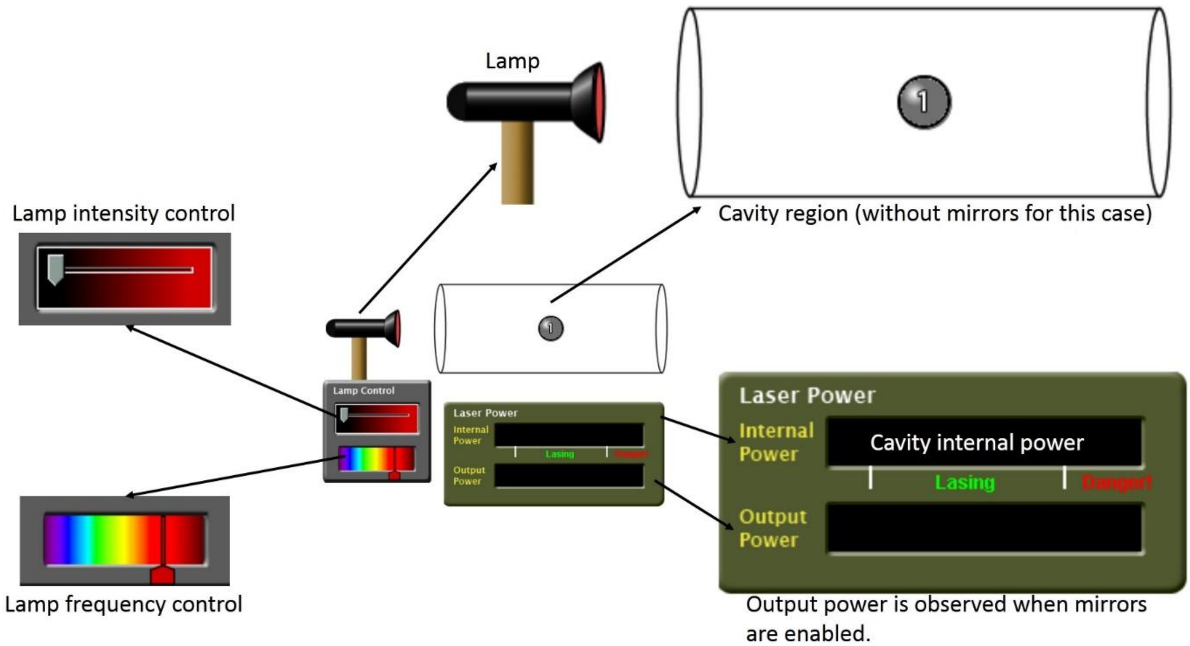
The program can be either downloaded or run directly as shown below:

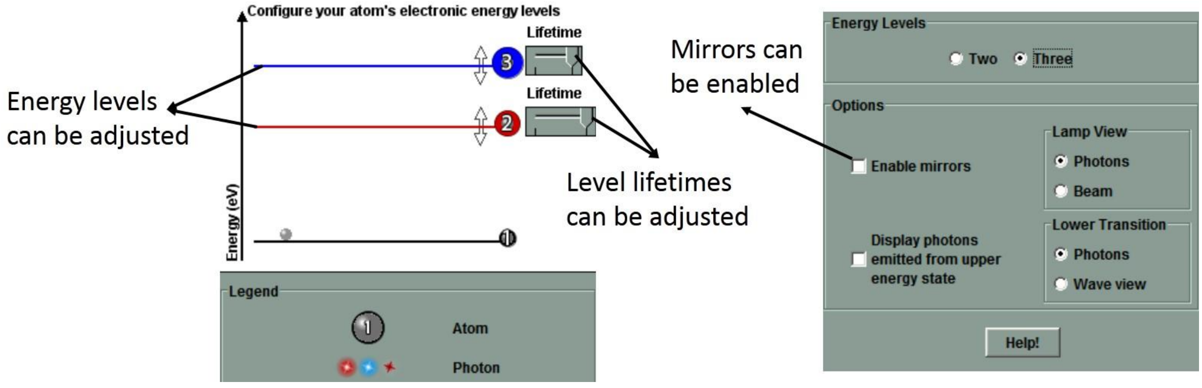


Website and download buttons for the required simulator.



Program graphical user interface.





While answering the questions below, keep in mind that we require short answers of about 2-3 sentences for each question. If you wish, you can paste in screenshots for the chosen parameters if you feel this is helpful. However, this is not required and in any case do not overdo the number of screenshots you paste.

One atom example - Two level system

1. Using lamp intensity control increase the intensity. Observe absorption and emission processes. What kind of emission do you expect under which conditions? Briefly explain each process.
2. Observe the frequency dependence of the absorption process by adjusting the frequency of the lamp. Then change the 2nd energy level of the atom and adjust the frequency of the lamp to match that level. What is the reason of the resonant behavior of the absorption process?
3. Change the lifetime of the 2nd level and observe effect on the emission processes. Under low illumination intensity, which emission process is dominant for maximum and minimum lifetimes?
4. Enable mirrors and observe the change in the stored light inside the cavity. By changing the output coupling mirror reflection control the emitted light out to the cavity. No explanation is necessary for this part.

One atom example - Three level system

1. While mirrors are enabled horizontal lamp does not work, using the vertical lamp intensity control, observe the effect on the absorption and emission processes when the lamp frequency is set to the 3rd energy level. You can observe the real time occupation of energy levels. Briefly list the expected and observed differences from the two level systems.
2. Can one atom having three energy levels lase in a cavity? If not clearly explain the physical reasons by stating the differences with multiple atoms system. If your answer is yes, again briefly state the differences between multiple atoms system and play with the system to observe the lasing. What are the conditions for lasing in terms of energy level lifetimes, cavity mirror reflections, lamp intensity, etc.? Briefly list and explain.
   (Note that during lasing, cavity internal power lies inside the Lasing region and avoid to pass Danger! region which you will eventually blow up your laser! If you enable the mirrors while horizontal lamp emits light at the 2nd energy level you may reach faster to lasing region.)
3. While there are enough photons inside the cavity adjust the lamp frequency to the 2nd level. Do you expect increase or decrease in the number of photons inside the cavity? Briefly explain your reasoning.

Multiple atoms example - Two level system

1. This time we have multiple atoms. Note the large number of electrons in the ground state at the energy diagram. Adjust the lamp frequency to the 2^{nd} energy level of the atoms and increase the intensity of the lamp. What kind of emission do you observe for which condition? In terms of emission processes, compare multiple atoms case with one atom case.
2. Another observation is the direction of emitted photons. While the lamp and the photon emission direction was mainly on the horizontal axis for one atom case, we have vertical photon emission for multiple atoms case with the vertical illumination direction. Can you correlate photon emission direction with the direction of incident pumping photons? What is the physical explanation? Briefly explain in a sentence.

Multiple atoms example - Three level system

1. Finally we have a system similar to a real laser operation! Lamp is set to the 3^{rd} level of the atoms by default. By adjusting lamp intensity illuminate the atoms and observe the emitted photons between the 2^{nd} and 1^{st} levels. What kind of emission do you observe? Briefly discuss considering the directionality of the emitted photons.
2. Adjust the frequency to the 2^{nd} energy level and observe the emitted photons. What kind of emission do you observe considering the directionality of the photons? Briefly explain and compare with the previous part.
3. Enable the mirrors. Keep lifetimes of the both levels maximum and output mirror reflection 100%. Compare and comment on the observations you made and your theoretical expectations.
4. Reduce the lifetime of the 3^{rd} level while keeping the lifetime of the 2^{nd} level maximum. Clearly state and briefly explain your observations and differences from the previous part.
5. Reduce the lifetime of the 2^{nd} level while keeping the lifetime of the 3^{rd} level maximum. Clearly state and briefly explain your observations and differences from the part 3.
6. Reduce both of the lifetimes to the minimum. Clearly state and briefly explain your observations and differences from the part 3. Comment on the effects of the lifetime parameters for a stable laser operation. How would you choose energy levels if you built your own laser?
7. Since it is not realizable to have an output coupling mirror having 100% reflectivity, reduce the reflectivity of the mirror. To visualize the lasing operation better, switch to the wave view for lower transition from the right bottom panel. Observe the wave amplitudes inside and outside. Select your parameters for mirror reflectivity, energy level lifetimes, lamp intensity, lamp frequency and corresponding energy levels for the 2^{nd} and 3^{rd} levels to have a stable laser operation. Try to make:
    a. Output power large,
    b. Starting time to lase short,
    c. Internal and output power fluctuation small (i.e.at a constant power level for about 10 minutes).

    Clearly state the parameters of your choice. You can give exact value of the mirror reflectivity but visually divide the lifetime bar to five portions and report the portion of your value. For lamp intensity use ten portions and report the relative color for the chosen frequency.