Simulation of Optical Bloch Equations for two and three level atoms*.

Jose Mawyin, Harold Metcalf, A.G.E.P., Laser Teaching Center.

*Based on the optics rotation project of Dan Li and the Master Thesis of Benjamin Dietzek.

Abstract

- The overall goal of this project is to create computer models based on the Optical Bloch Equations to help visualize the population transfer processes between energy levels of atoms induced by light fields of varying frequency.

- We have first considered the simplest case of a two-level atom exposed to a light field of constant intensity whose frequency is swept through the resonance frequency given by the energy difference between the two levels. (This process is called adiabatic rapid passage.) The solutions of the Optical Bloch Equations are represented by a moving image of the Bloch vector as it evolves through time on the surface of the Bloch sphere. Various commercial mathematics and graphics packages were used for the calculations until we settled on MatLab as the optimum choice. Currently we are testing the validity of our simulations against what we think should happen in certain situations; for example, the population transfer to the excited state should be complete once the light-field frequency has passed through the resonance to a large detuning.

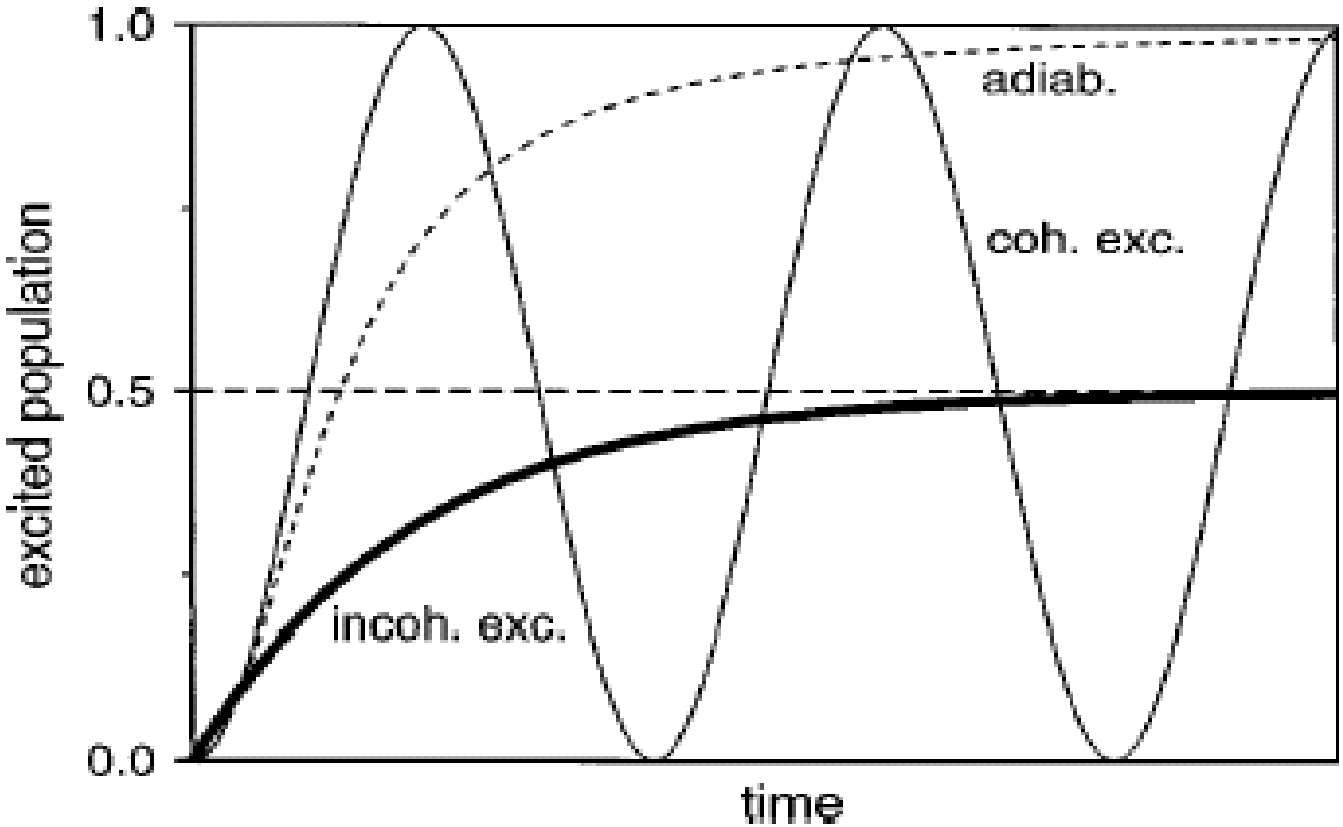
- Once we are sure that the two-level simulations agree with expectations we will consider the case of a three-level atom under STIRAP (STImulated Rapid Adiabatic Passage) conditions. Under STIRAP we seek to transfer all atoms from state |1> to state |3> with the help of an intermediate state |2>. This considerably more complicated process involves two different light sources with varying frequencies. If we can succeed in modeling such a system, the model could provide a valuable reference or guideline for the light-field parameters to use in actual lab experiments, such as those that seek to populate highly-excited Rydberg states in metastable helium atoms.

- We wish to thank physics graduate students Dan Li and Benjamin Dietzik for sharing their previous work on this topic, and SUNY AGEP for their financial support.

Methods for population transfer in a two level atom.

- Incoherent excitation (ie. Lamp discharge) cannot provide more than half the atoms from an assemble into the excited state.
- Coherent excitation (ie. Laser) would make the assemble oscillate between the ground and the excited state.
- Adiabatic rapid passage is the optimum method to transfer the most atom to the excited state.

Comparison of the efficiency of population transfer methods.



*From K. Bergmann et al., Rev. Of Mod. Phys., 17, 3 (1998)

Goal and overview of project.

- The goal is to provide a tool for visualizing population transfer between two and three level atoms through adiabatic passage.
- For the simulation various computational packages were tested and we found that MatLab was the optimum choice.
  - MatLab has a C++ analog computer language. Which makes it easier for people with programming knowledge to modify the code.
  - MatLab also provides tools for making the simulation easy to use for researchers and students alike.

Parameters of Optical Bloch equations.

$$Cg = \left(Cos\left(\frac{\Omega' t}{2} \right) - i \frac{\delta}{\Omega'} Sin\left(\frac{\Omega' t}{2} \right) \right) e^{+i\delta/2}$$

$$Ce = -i \frac{\Omega}{\Omega'} Sin\left(\frac{\Omega' t}{2} \right) e^{-i\delta t/2}$$

$$Cg^* = Cos\left(\frac{\Omega' t}{2} \right) + i \frac{\delta}{\Omega'} Sin\left(\frac{\Omega' t}{2} \right) e^{-i\delta t/2}$$

$$Ce^* = i \frac{\mathrm{Re}|\Omega| - \mathrm{Im}|\Omega|}{\Omega'} Sin\left(\frac{\Omega' t}{2} \right) e^{+i\delta/2}$$

These parameters are the coefficients for the probability of population for the ground (Cg) and excited state (Cg) of the two-level atom.

Parameters of the Bloch Sphere.

$$\vec{R} \equiv \{r1, r2, r3\}$$

$$r1 \equiv CgCe^* + Cg^* Ce$$

$$r2 \equiv i(CgCe^* - Cg^* Ce)$$

$$r3 \equiv |Ce|^2 + |Cg|^2$$

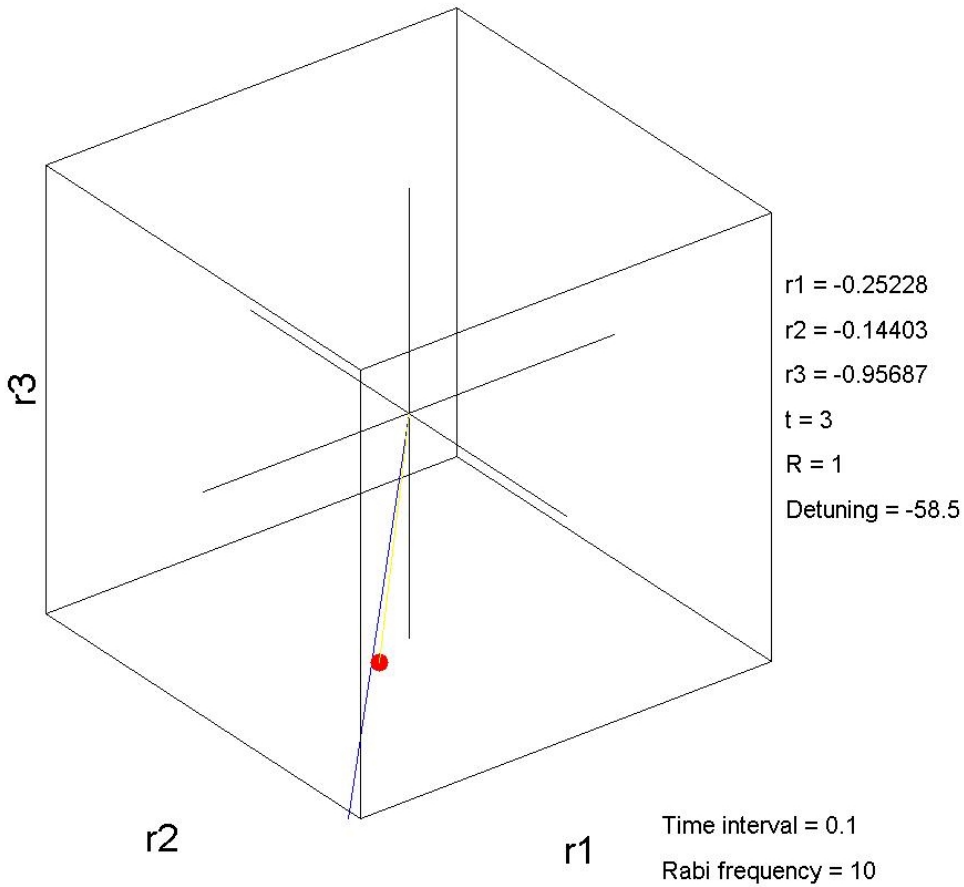
The Bloch Vector (R) has three different components that depend on the probability of population for the two states. The Bloch sphere is the plot of the time varying components of the Bloch Vector in R3 space.

$$\frac{d\vec{R}}{dt} = \vec{T} \times \vec{R}$$

$$\vec{T} = [\mathrm{Re}(\Omega), \mathrm{Im}(\Omega), \delta]$$

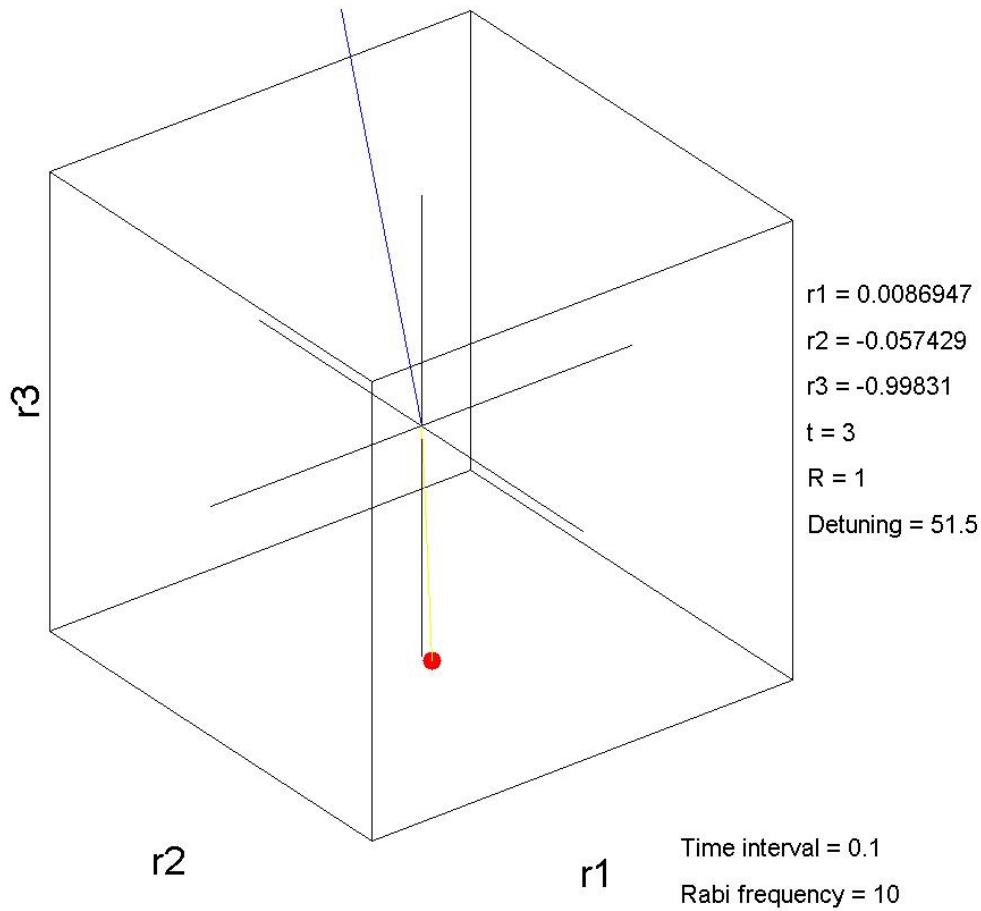
The Bloch vector obeys the previous equation where T (Torque vector) depends on the characteristics of the light field (Rabi Frequency and detuning).

Images from the two level Bloch Sphere simulation.



Under a large negative detuning most of the population is in the ground state. With the Torque vector (yellow line) pointing to the south of the sphere and the Bloch vector (blue line) rapidly processing around it.

Images from the two level Bloch Sphere simulation.



When the frequency sweep reaches resonance we find the Torque vector at the equator of the sphere with the Bloch vector making large precessions around it touching the poles of the sphere (Rabi Oscillation). However, once we pass through and reach a large positive detuning we find most of the population trapped in the excited state.

The 3-level atom and STIRAP

- The next phase of the project is to tackle the problem of the 3-level atom under STIRAP conditions.
  - Under STIRAP we transfer populations between 2 different states (|1>, |3>) without losing any through an intermediate state |2>.
- The simulation of this process could be done by different methods. The ones that we are considering are:
  - Two superimposed Bloch Spheres.
  - Eigenenergy surfaces representation.

Current status and future work.

- We are polishing the MatLab code that we have and we are testing it to see if the simulations correspond to what it is expected.
- Once we finish the two-level simulation we will start working on finding the proper way to simulate the three-level system.