Application to Graduate with Honors

Student ID: 810 86 9301

I plan to defend in: FALL / [✓ SPRING] of 2011

Personal Information:

Name: Kayla Crosbie

Address: 2659 E Libra St
Gilbert, AZ 85234

CU E-mail: Kayla.Crosbie@colorado.edu

I am an: IN-STATE / [✓ OUT-OF-STATE] student

Academic Information:

☒ I plan to graduate with *Departmental Honors* in: Physics

☐ I plan to graduate with *General Honors*

Cumulative GPA:

Please attach a brief **PROSPECTUS**, **BIBLIOGRAPHY**, and **TIMELINE** of your thesis project to this application. When summarizing your work, consider the following:

- What is the problem you are investigating?
- What is the hypothesis you are testing?
- What is the focus of your study?
- What is your goal in this study?

Primary thesis advisor: Name: Murray Holland Dept: Physics

List the other members of your committee:

Name: John Cumalat Dept: Physics

Name: Martin Walter Dept: Math

Name: Dept:

Name: Dept:

Departmental and General Honors Committee Checklist:

✓ Applicant has a total of at least three committee members.
✓ At least one Honors Council Representative is included on committee.
✓ At least one committee member from an outside department.

APPLICATION CONTINUED ON BACK OF THIS SHEET

Please initial if you are pursuing Departmental Honors:

KC I have consulted with my department and have completed (or am completing) the requirements they have established.

For Honors Council Representative:

I have met with applicant and approve him/her for departmental honors.

Printed Name: ______________________ Signature: ______________________

Please initial if you are pursuing General Honors:

_____ I have completed (or am completing) the requirements for graduating with General Honors.
Please list the courses you have or are taking toward General Honors:

______________________ ______________________

______________________ ______________________

For General Honors Council Member:

I have met with applicant and approve him/her for general honors. I agree to be on his/her defense committee.

Printed Name: ______________________ Signature: ______________________

For the Thesis Advisor:

I have met with the applicant to discuss the proposed work and agree to provide the necessary help and direction for this thesis project.

Printed Name: Murray Holland Signature: Murray Holland

For the Student:

I have read the requirements for graduating with honors at the University of Colorado. I also understand that my designation will be sent to the CU email address that I have provided and will not be given out over the phone.

Signature: ______________________ Date: 12/12/2010

For additional graduation information including requirements, guidelines and deadlines, you can download them online at www.colorado.edu/honors

Prospectus

I worked individually on my project of Electromagnetically Induced Transparency (EIT) in optical lattices. My goal was to explore the characteristics of EIT in optical lattices or multiple wells, since EIT had only been performed in a single well. Additionally, I aimed to find perfect transfers of bosonic particles between well sites and EIT levels. I would then use these perfect transfers to study the possible applications of EIT in quantum computing.

EIT is an optical phenomenon which causes a material to become transparent over a small frequency range of light. It is responsible for slow light; however, I am using the quantum interference properties of the EIT level transitions for the perfect transfers. BECs must have a specific 3-level scheme in order to induce EIT. This 3-level scheme of the atom allows the state transitions |1> to |3> and |2> to |3> but forbids the transition |1> to |2> . In addition, the mechanism called adiabatic preparation is necessary to observe EIT. Adiabatic preparation requires two lasers of the same frequency and intensity, the probe light and the coupling light. Beginning with the atom in state |1>, the following sequence occurs: The probe laser is turned on and tuned to the |2> to |3> transition; next, the coupling laser is turned on and tuned to the |1> to |3> transition; and lastly, the lasers are turned off in the same order they were emitted. Note that it would appear that the probe laser (|2> to |3>) is not affecting the atom since it begins in state |1>. Remarkably however, after the adiabatic preparation, the atom transfers to state |2>. Rather than undergoing this mysterious transfer, it would seem more intuitive for the atom to take the path |1> to |3> to |2>, avoiding all forbidden transfers. However, when the atom is in state |3>, spontaneous emissions occur and the system would decay.

Quantum interference is one of many theories that explains EIT. Quantum interference has nothing to do with optical interference, but rather deals with probability amplitudes of quantum events. In EIT, two possible paths can drive the atom from state |1> to |2> . The two possible paths are the direct path |1> to |2> , and the alternate path |1> to |2> to |3> to |2>. The probability densities of each path interferes destructively, which cancels out the probability for the atom to transfer to state |3> . This cancellation results in a transfer from state |1> to |2> by avoiding the state |3>. Moreover, quantum interference causes a perfectly coherent transfer, meaning the state has 100 percent probability of occupying the state |2>.

While EIT is the internal state of the system, optical lattices or finite multiple wells are the external state. Optical lattices are robust and controllable systems which serve the purpose of a quantum simulator. The optical lattices trap cold atoms so that they can be manipulated and easily observed. Prior to optical lattices, ultracold atoms were stored in magnetic traps, however, only atoms with a certain spin state could be trapped. To allow more degrees of freedom, a periodic potential was constructed to trap the cold atoms which do not have this limitation. This periodic potential is made by simply overlapping laser beams traveling in opposite directions, which makes a standing wave. The atoms are trapped in the negative peaks of the wave, similar to an atom in a harmonic oscillator. In addition, if the light intensity is not too high ,then the atom can tunnel between lattice sites.

The methodology of my theoretical research includes deriving the Hamiltonians, solving their eigenvalues and time-evolved Schrödinger equations in Mathematica, and using these solutions to explore characteristics of EIT in lattices. I wrote code to produce probability density plots versus parameters of the system to search for interesting transitions.

I began my exploration with a double potential well and one bosonic particle with an EIT internal state. After optimizing the tunneling rates and EIT laser pulse frequencies, I found a perfect transfer from the ground state of the left well to the 2nd state of the right well. More importantly, I mathematically characterized this transfer verses the tunneling rate, which was a sinusoidal function. I generalized this transfer up to five potential wells but with any more wells, the transfer was imperfect. I used the perfect transfers and the sinusoidal transfer vs. tunneling plot to explore the possibilities of making a quantum exclusive OR (XOR) gate with a double particle double well system.

I am still conducting research on possible XOR gate conditions. So far I have found that an XOR gate cannot be modeled if the interaction energy is much greater than the tunneling rate, because the particles are in the Mott insulating phase and uniformly distribute within the wells. I propose to introduce more parameters for the external state to further look for XOR gate behavior. In addition, I may try to generalize my findings of EIT in multiple wells to infinite lattices.

Schedule of Thesis

May 2010 week 1:	Met with advisor to discuss topic.
June 2010 week 1:	Narrowed down research topic and read articles about research topic.
June 2010 week 2:	Worked out Hamiltonian for single well EIT, time evolved with mathematica, looked at eigenvalue curves for adiabatic transfers.
June 2010 week 3-4:	Did same procedures from the single well for a double well, found tunneling tunneling rates for a (|Energy,well>) |1,1> to |2,2> state change.
July 2010 week 1:	Looked at the same situation for 3, 4, 5 wells to try to generalize to a lattice.
July 2010 week 2:	Looked at two distinguishable particles in a single well and a double well.
July 2010 week 3-4:	Explored possibilities for making a XOR gate with the double well double particle system.
Sept 2010 week 1-3:	Eliminated possibility of a XOR gate with logic element A, B being the well number. Trying A, B as the state 1 or 2 (in EIT internal states).
Sept 2010 week 4:	Discuss findings with advisor to see if possibilities have been exhausted well enough.
Oct 2010 week 1-2:	XOR gate, Trying to add parameter of different interaction energies per EIT state Write the background to thesis.
Oct 2010 week 3-4:	Write introduction to thesis. Make useful graphics of data.
November -December 2010 week 2 :	Continue with XOR gate, add parameter of energy difference in well site. Try to find phase shift in sinusoidal probability density plots.
December -January 2010 week 2:	Write more of thesis, edit introduction and background, add mathematics/derivations with LaTex. Edit graphics.
January 2010:	Finish up XOR gate, or move on to infinite lattices.
February 2010:	Meet with mentor for editing of Thesis, final draft done.
March 2010:	Honors Defense.