7 Summary and Future Directions

This chapter summarizes the projects described in this dissertation and provides some thoughts on possible extensions based on the finished projects.

Electron dynamics in DD coupled Rydberg atoms show some unique properties that do not exist in individual atoms. The goal of the research in this dissertation is to reveal the electron dynamics influenced by DD interaction in cold Rydberg gases. This research helps us answer some fundamental problems in atomic physics as well as benefits practical applications in the quantum control of few- and many-body systems, quantum information processing, quantum computing, etc.

The project in Chapter 4 examines the decay of *ns* and *np* Rydberg states with high principal quantum numbers (form 26 to 40) in a cold Rb gas. The measured time dependence of the Rydberg population is well described by numerical simulations which consider only spontaneous emission and population transfer by blackbody radiation. No evidence for collective decay is found at atom densities up to $3 \times 10^{9} \mathrm{cm}^{-3}$. Our conclusion is that the suppression of collective emission is likely due to variations in transition energies within the atom sample, dominated by inhomogeneities in dipole-dipole exchange interactions for initial *s* states, or by a combination of dipole-dipole and electric field inhomogeneities for the initial *p* states.

The project in Chapter 5 characterizes the role of DD interaction in the evolution of Rydberg wavepackets. As the wavepackets evolve they are influenced by dipole-dipole interactions, predominantly pairwise excitation-exchange processes of the form $|s\rangle|p\rangle \leftrightarrow |p\rangle|s\rangle$. The coherent electronic evolution of the ensemble dephases due to the variation in dipole-dipole coupling strength between atom pairs in the MOT. An extension of this experiment is to measure the macroscopic coherence in an ensemble which has better controlled separations between atoms than a random ensemble. The expectation is that the macroscopic coherence keeps longer in a separation controlled ensemble (depending on how well the separations are controlled) than a random ensemble, since the variation in dipole-dipole coupling strength is smaller. Brian Richards is currently utilizing controlled

DD interactions to manipulate the position correlation function of cold trapped atoms. If his project works, this extended experiment can be put on track.

The project in Chapter 6 utilizes the resonant energy transfer $25s33s \leftrightarrow 24p34p$ to show that electron correlations, induced by controlled DD interactions, can enable the coherent transfer of electronic wavepacket motion from atoms to their neighbors. The mixed-parity wavepacket composed of $25s$ and $24p$ on one set of atoms induces wavepacket generation on another set of atoms, which are initially on state $33s$, via DD interactions. The coherence transfer is proved by measuring the phase difference between the initial and induced wavepacket oscillations. An extended experiment based on this project is to investigate the disappearance of coherence transfer due to the varying separation between atom and many-body effects. As density or the collision phase (as mentioned in Chapter 6) increases, the transfer of coherences should disappear.