

# Interactions of ${}^6\text{Li}$ and ${}^{133}\text{Cs}$ at Ultralow Temperatures

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We study the interactions between lithium and cesium in a magneto-optical trap (MOT) and an optical dipole trap. These collisions are interesting both in terms of their physical properties and due to their ability to either inhibit or aid in the cooling of these two species into degenerate states. In particular, we will study the dependence of the collision properties on the external magnetic field and identify Feshbach resonances between the two species. For this study, I will be involved in the design and construction of the controller used to modify the magnetic fields, and the investigation of interspecies collisions.

## 1 Introduction and Background

Interactions between cesium and lithium, which include inelastic collisions, elastic collisions, and the creation of bound molecular states, are interesting for at least four reasons. First, to study lithium and cesium at ultracold temperatures and especially in degeneracy, inelastic collision losses from the trap must be minimized. Second, elastic scattering can influence the performance of sympathetic cooling, which may aid in bringing lithium to degeneracy through its collisions with the typically colder cesium atoms.

Third, bound molecular states may be of fundamental physical interest. One use of ultracold atomic systems is as a model system for more complex quantum phenomena, such as high-temperature superconductivity or quantum chromodynamics. The ability to create and study bound molecular states in this controlled system is therefore extremely important as it opens up a richer set of systems to study. For example, a pairing gap related to superfluidity has been observed using Feshbach resonances with ultracold lithium [1]. Finding different molecular states of lithium and cesium should provide other opportunities for exploring physical theories.

Finally, by loading both lithium and cesium into optical lattices, we hope to perform scalable quantum information processing by using the cesium atoms as messengers between lithium qubits [2]. Realizing this scheme, however, necessitates the implementation of controlled quantum gates, which require a coupling between the lithium and cesium atoms. A weakly bound molecular state

could provide this desired coupling.

Weakly bound molecular states are the result of Feshbach resonances, which occur at specific magnetic field strengths [3]. The resonances for cesium and lithium are quite different, with cesium having sharper resonances at smaller magnetic field strengths. Similarly, mixing lithium and cesium may lead to new Feshbach resonances, which would be correlated with currently unknown molecular states. This study necessitates building a controller, presented below, for our magnetic coils. With the controller, we can seek Feshbach resonances over a large range of field strengths.

## 1.1 Previous Work with Bosonic Lithium

Some of the above phenomena have been explored with  ${}^7\text{Li}$  and  ${}^{133}\text{Cs}$  [4, 5, 6]. Early experiments used a magneto-optical trap to evaluate the interspecies collision properties. In these studies the excited Li state repelled the ground-state Cs state, so these interactions did not result in trap losses. Ground-state Li, however, can inelastically collide with excited Cs to produce trap losses. If both species are in the ground state, the dynamics present do not result in trap loss until the lithium trap depth is below about 9 GHz, at which point hyperfine collisions are significant [4].

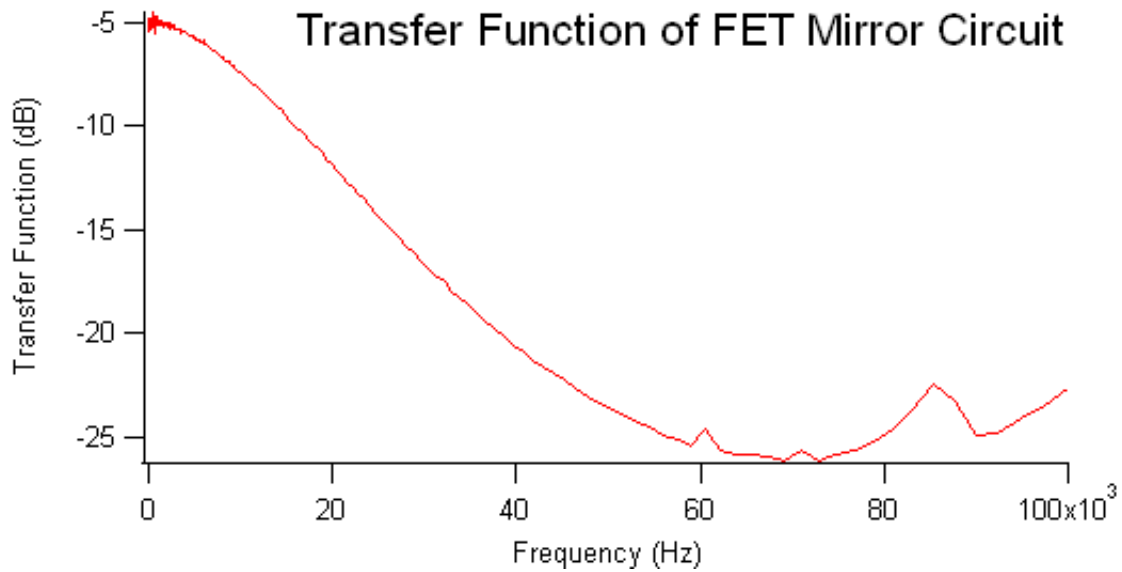
The group went on to study collisions in a dipole trap. They were able to detect the sympathetic cooling of lithium, as well as hyperfine interactions that can result in trap loss [5, 6]. However, we expect many of these interactions to change with  ${}^6\text{Li}$ . Furthermore, Feshbach resonances are also isotope specific, and were not studied in these experiments.

## 2 Current Controller Construction

In order to study the interactions across a variety of magnetic fields, one focus of this project is to build an electronic controller for the main magnetic coils in our experiment in order to both access different field strengths easily, and keep the field stable. As  ${}^6\text{Li}$  has a broad Feshbach resonance at about 834 G, and accessing this region requires about 200 Amperes each in our two coils, this is a very challenging electronics and cooling task [3].

Outline of section:

- Design of controller, including a schematic of the current supply layout and of the feedback circuit. I will note novel design elements, including especially the FET mirror used and the use of 5 power FETs.
- Transfer functions for the electronics to determine bandwidth, and other graphs and text to analyze other performance characteristics.
- An analysis of ways to improve the supply in the future, and if it can possibly be made to operate at better stabilities, higher bandwidths, or higher currents in the future.



**Figure 1:** Dummy figure for future transfer functions for the current controller. This is actual data from the mirror FET design I am using.

### 3 Study of Collisions Between Lithium and Cesium in a Magneto-Optical Trap

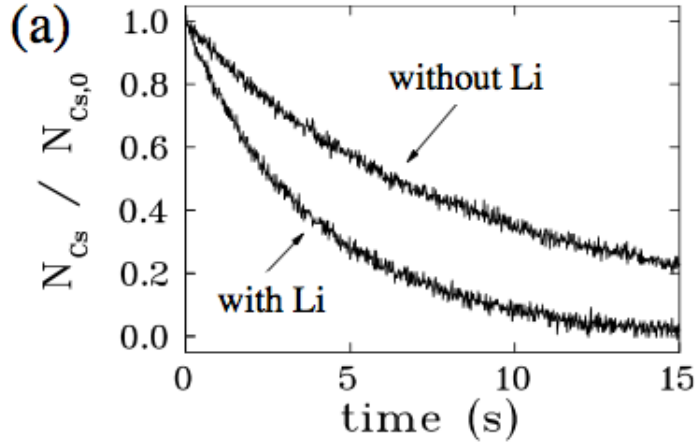
Outline:

- Present procedure for taking data
- Present graphs of particle number while only one species is present, or when the two are overlapping. Use this to determine probable interactions between the species.
- Connect observed interactions to theory of particle interactions.

### 4 Study of Interactions in an Optical Dipole Trap

Outline: - Present procedure for taking data

- Again present graphs of particle number, and hopefully density distributions if our imaging is adequate.
- Present data at a number of magnetic field strengths to determine influence of Feshbach resonances and if interspecies resonances can be located.
- Again discuss theory if relevant interactions are found.



**Figure 2:** Dummy figure for future data of particle interactions in the MOT. This is actual data from the above  ${}^7\text{Li}$  experiment [4].

## 5 “Conclusions”

We have found trap losses in a magneto-optical trap due to  $\text{---}$  and  $\text{---}$ , with cross sections of approximately  $\text{---}$  and  $\text{---}$ . Surprisingly,  $\text{---}$  interaction does not seem to contribute to losses. This suggests that  $\text{---}$  is an optimal way to load the magneto-optical and dipole traps.

I have also presented the design and testing of a current controller which can successfully output a 200 Ampere current with 10 mA noise, and 1 ms response time. Using this, we have explored particle interactions in an optical dipole trap. There does seem to be strong evidence of sympathetic cooling in the dipole trap, which may help in cooling these atoms. At the same time, the hyperfine collisions cause  $\text{---}$ , which must be avoided by  $\text{---}$ . Most excitingly however, there seems to be evidence of a Feshbach resonance at about  $\text{---}$ .

(In general, I definitely hope to have results for the current controller and the magneto-optical trap. Because we are still working on the MOT, I am not certain whether the experiment will be in a position to acquire data in the optical dipole trap for this project.)

## References

- [1] Chin, C. *et al.* Observation of the Pairing Gap in a Strongly Interacting Fermi Gas. *Science* **305**, 1128–1130 (2004).
- [2] Brickman Soderberg, K.-A., Gemelke, N. & Chin, C. Ultracold molecules: vehicles to scalable quantum information processing. *ArXiv e-prints* (2008).

- [3] Chin, C., Grimm, R., Julienne, P. & Tiesinga, E. Feshbach Resonances in Ultracold Gases. *ArXiv e-prints* (2008).
- [4] Schlöder, U., Engler, H., Schünemann, U., Grimm, R. & Weidemüller, M. Cold inelastic collisions between lithium and cesium in a two-species magneto-optical trap. *The European Physical Journal D-Atomic, Molecular and Optical Physics* **7**, 331–340 (1999).
- [5] Mosk, A. *et al.* Mixture of ultracold lithium and cesium atoms in an optical dipole trap. *Applied Physics B: Lasers and Optics* **73**, 791–799 (2001).
- [6] Mudrich, M. *et al.* Sympathetic Cooling with Two Atomic Species in an Optical Trap. *Physical Review Letters* **88**, 253001 (2002).