Chapter 1

Introduction

The achievement of Bose-Einstein condensation (BEC) in dilute atomic gases was in part achieved due to the incredible thermal isolation between the atoms and the environment. The atoms in the gas communicate to their environment only through a series of narrow spectral lines, and through their energy dependence on DC magnetic and electric fields. In conventional BEC experiments, where the room-temperature vacuum walls are at least several centimeters away, the atoms experience practically no interaction with the bulk room-temperature materials surrounding them. To date, experiments with BEC have primarily focused on the study of the extremely non-trivial properties of the BEC itself, but it is clear that an interesting question to ask is at what point will the environment effect the BEC, or in particular, if a BEC is brought in very close proximity to a room temperature surface, what effects from the surface will be seen?

The interaction of an atom with a surface has a long, and important, theoretical history. An attractive force between a neutral atom and a perfectly conducting wall was first postulated by Lennard-Jones in 1932 [5]. This attractive force is resultant from the fluctuating dipole moment of the atom interacting with its image in the surface. Then, in 1948, Hendrick Casimir and Dik Polder [6] extended this force to larger separations and found that retardation effects weaken the force, and thus the attractive atom-surface force at large distances scales with a different power law than in the more simple, short range, Lennard-Jones case. This effect of retardation also occurs for the closely related van der Waals force between two neutral atoms. This, somewhat surprising result, lead Casimir to extend his work to the case of two perfectly reflecting parallel mirrors [7]. In this case he again found an attractive force, the now famous "Casimir force", which is typically attributed to the presence of zero-point electromagnetic vacuum fluctuations inducing a net inward pressure on the plates.

Finally, in the late 1950's and early 1960's Evgenii Lifshitz took up the problem, taking into account the dielectric properties of the media and thermal fluctuations of the electromagnetic vacuum, and developed a general theory for van der Waals type forces [8, 9], of which Casimir-Polder is a limiting case. It is from this theoretical framework that most modern calculations of Casimir-Polder and Casimir forces are performed.

Although there has for a long time been experimental evidence of an attractive force between neutral atoms, and between neutral atoms and surfaces, it was not until 1993 that Ed Hinds' group at Yale [10] was able to measure the atom-surface force in the large distance retarded, or Casimir-Polder regime. Since that measurement a number of measurements have followed [11, 12, 13, 14]; however as of yet no experiment has tested some aspects of the Lifshitz theory, in particular those resulting from thermal fluctuations of electromagnetic fields.

Recent proposed extensions to the Standard Model have provided additional reasons to study atom-surface interactions [15]. Many of these extensions to the Standard model include forces, due for instance to compact extra dimensions, that would modify Newtonian gravity on sub-mm scales. By performing extremely careful force measurements near surfaces, the experimentalist can hope to obtain more stringent limits on the presence of such forces, and thus more strongly constrain such theories.

Another effect on cold atoms near surfaces is due to the presence of Johnson noise in warm conductors. Carsten Henkel, Sierk Pötting, and Martin Wilkens in a 1999 paper [16] predicted that the thermal current, or Johnson noise, in warm conductors would result in the presence of a broad spectrum of electric and magnetic fluctuations near the surface of the conductor. For magnetically trapped atoms, magnetic fields fluctuating at the Larmor frequency will induce transitions to untrapped states, and thus cause loss of atoms from the magnetic trap.

This effect is interesting not only scientifically, but because it has important implications for the rapidly growing subfield interested in manipulating atoms with "microtraps". The key idea driving this subfield is to couple ultracold atoms to trapping potentials generated by small, lithographically fabricated wires and other interesting structures on surfaces. Because the atoms are very close to the elements generating the trapping fields, very strong trapping potentials and small scale trapping features should be realizable. Additionally, the promise of possibly coupling atoms to micro-fabricated cavities, such as microspheres [17] or photonic bandgap crystals [18], is attractive. This could permit access to strong atom-cavity coupling regimes, and the correspondingly interesting physics of such systems.

There clearly is significant motivation to work with ultracold and condensed atoms near surfaces, however the initial work with microtraps in this direction has elucidated that many problems, known and unknown, remain to be solved. Soon after Bose-Einstein condensation was first achieved in a microtrap [19, 20] the first problems were encountered. As the BEC was brought closer and closer to the trapping wires, and correspondingly close to the surface, the BEC "fragmented" [21]. Essentially, the trapping potential developed significant spatial inhomogeneity on the order of the distance to the trapping wire as the BEC was brought close to the wire. It is currently thought that this can completely be attributed to inhomogeneities in the wire, leading to inhomogeneous current flow, and thus an inhomogeneous trapping potential.

This problem of BEC fragmentation, although essentially just a technical issue, illustrates a recurring theme of ultracold atom-surface experiments. Previous ultracold atom work typically occurred in a vacuum system with all solid objects several centimeters or more away. Maxwell's equations require that electric and magnetic fields can only change on distance scales on the order of the distances to the objects generating the electric and magnetic fields, which if several millimeters away, means that fields must change only very gradually over the typical distance scales of the BEC.[1] By bringing ultracold atoms within several microns of a surface, suddenly the allowed spatial variation of fields is on the micron scale, and fields may now radically change over distance scales of the BEC. Further, ultracold atoms are extremely sensitive to potential variations. This is good if one is interested in probing surface potentials, but bad if studying spurious electric and magnetic fields from surfaces is not the final goal. An alternative way of viewing the problem is that in typical ultracold experiments the only other atoms near the trapped atoms are from the background gas, so typically there is not a single background gas atom within $\sim$10 microns of the trapped atoms. Now, if the same cloud of trapped atoms is brought within $\sim$10 microns within a surface, then there are $\sim 10^{15}$ atoms of the surface within several microns of the trapped atoms. The probability that every one of those $\sim 10^{15}$ atoms is exactly where it should be, and thus contributing no significant electric or magnetic field, is very low.

Prior to the work of this thesis there were already many experiments with microtraps, so we certainly are not the first to pursue atom-surface studies. The reason we thought we could contribute to this field was that our interest is primarily in the study of atom-surface interactions, rather than most microtrap groups who are pursuing greater technological goals. This has freed us from some of the restrictions of microtraps, allowing us to design our experiment exclusively for the study of atom-surface interactions.

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[1] This of course is not the case for optical frequencies, but again any small scale structure is typically very regular.

1.1 Thesis Organization

This thesis is organized as follows. Chapter 2 reviews the entire apparatus and discusses the experimental changes and upgrades necessary to modify the apparatus for atom-surface interaction studies. Chapter 3 discusses the first experiments we performed where magnetic trap lifetime reduction caused by Johnson noise in a warm conductor was measured. Chapter 4 details our experiments documenting the issues related to alkali atoms adsorbing on conducting surfaces. Chapter 5 describes the measurement of the Casimir-Polder force. Finally, Chapter 6 reviews the restrictions on non-Newtonian short range forces that our Casimir-Polder measurement permits, and discusses possible future directions of these experiments.