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מנחה:

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Research Proposal for a Master of Science Thesis

מאת

בועז רז

תכנית מחקר לעבודת גמר

**לקראת תואר מוסמך למדעים**

By

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**Introduction**

תערובת בוזה-פרמי מנוונת קוונטית במלכודת הרמונית מגנטית

Quantum Degenerate Bose and Fermi Gases in a Harmonic Magnetic Trap

Recently, quantum Degenerate Fermi Gasses (DFG) have become increasingly intriguing, mainly due to their ability to probe an abundance of quantum phenomena in an easily tunable manner [1, 2].

One of the methods for reaching quantum degeneracy is sympathetically cooling of a Fermi cloud in a thermal contact with a Bose-Einstein Condensate (BEC), reportedly reaching temperatures as low as of the Fermi temperature [3, 4, 5, 6].

The gasses are trapped using a magnetic field, which interact with the atoms spin and exerts forces on them. [7, 8] The force can be either restoring or repulsive, depending on the orientation of the spin moment relative to the field. This means that a trapped atom could be pushed outside if its spin is flipped [9]. In order to avoid losses due to such Majorana spin flips, the magnetic trap minima should be non-vanishing.

One method that was used in our system, in order to cope with these losses, is a blue detuned laser beam at the center of the trap, which push the atoms away from the area that has zero magnetic field [10]. The results were not sufficient, since a DFG was not achieved, probably due to (?)

In this thesis, a different method will be tested, attempting to raise the minima of the magnetic field to some controllable finite value. The method introduce an additional Ioffe coil, to join the two already existing Quad coils in Anti-Helmholtz configuration, forming a magnetic trap called QUIC [11, 12, 13, 14].

**Research objective**

Our purpose is to achieve a quantum degenerate Bose-Fermi mixture, and to perform several experiments, such as fermi mediated boson-boson interaction.

Detailed description of the proposed research

An apparatus for cooling and trapping bosons, and fermions have been built. The atoms are captured using a 3D Magneto-Optical Trapping method (MOT), which is able to capture as many as atoms of, and atoms of at vacuum pressure of. The 3D MOT is feeding on a 2D MOT in a previous cell through a push beam, as well as a getter inside the cell. The atoms in the MOT reach a temperature of.

After loading time of, the MOT is compressed and further cooled using Polarization Gradient Cooling (PGC), reaching for, and for. Using an adiabatic magnetic transport made of a series of pairs of coils in an L shape, the atoms are then moved to the science cell, where the pressure drops down to, for evaporative cooling, reaching sub- temperatures.

In here, the fermions reach their cooling limit due to Pauli pressure, while the bosons continue to cool and thermalize. Bringing both species in thermal contact helps cool the fermions, while the significantly larger number of bosons serve as a heat bath.

During this process, the clouds are held via magnetic fields, and need to maintain their spin orientation in order to stay in the trap. In a Quad trap, the area near the origin has zero magnetic field and a Majorana spin flip can occur, causing a significant loss of atoms. The colder the atom cloud gets, the denser it is near the center, and the atoms will be lost at a faster rate [15].

In order to avoid this losses, on this theses, an additional Ioffe coil is places perpendicular to the Quad coils, creating a biased trap on the Y axis, as depicted in Figure 1. The Quad coils are the last pair of coils in the magnetic transport, and the Ioffe is mounted at a controllable distance from the center. When the atoms reach the final coils of the transport, the Ioffe is then adiabatically turned on in order to avoid heating of the atoms due to sudden change in the potential. Only then, will the evaporation and thermalization process of the fermions begin, hopefully reaching a fraction of the Fermi temperature.

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Figure 1: (a) QUIC trap configuration. (b) Simulation of the absolute magnetic field along the Y axis as defined in (a) Blue: Quad coils. Orange: Ioffe. Black: bias quad coils. Green: Vector summation of fields. Red: Fitted harmonic trap. Trap frequency and minima are indicated. (c) Possible pitfall of the method, when two minima are created in case the Ioffe coil is misplaced.

Our simulation of the resulting trap shows that, moving the Ioffe coil along the Y axis, we can control the location, bias and frequency of the trap. In order to further move the bias of the minima, an additional constant magnetic field can be applied using a pair of Quad coils in Helmholtz configuration along the Y axis.

After reaching a state of a DFG, we have a Fermi sea coupled to a BEC. The fermions can’t interact with each other due to Pauli blocking, but they can interact with the bosons. When a fermion interact with a boson, it is excited, and a fermion-hole pair is formed. After some time, the pair will scatter from another boson, and the fermion will return to its original state, leaving the Fermi Sea unchanged. This can act as an effective potential for interaction between bosons, mediated by the fermions.

We intend to measure the dynamics of the bosons due to the mediated interaction of the fermions, similar to what is proposed in [16], without taking the approximation of light fermions, and zero temperature.

References

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| [1] | B. a. D. S. J. DeMarco, " Onset of Fermi degeneracy in a trapped atomic gas , no. ():," *Science,* vol. 285, no. 5434, pp. 1703-1706, 1999. |
| [2] | J. W. C.-H. W. I. S. T. G. T. S. W. P. A. a. M. W. Z. Park, "Quantum degenerate Bose-Fermi mixture of chemically different atomic species with widely tunable interactions," *Physical Review A,* p. 051602, 2012. |
| [3] | G. G. F. G. R. R. J. B. A. S. a. M. I. Modugno, " Bose-Einstein condensation of potassium atoms by sympathetic cooling," *Science ,* vol. 294, no. 5545 , pp. 1320-1322, 2001. |
| [4] | B. J. K. P. J. J. a. C. C. DeSalvo, "Observation of a Degenerate Fermi Gas Trapped by a Bose-Einstein Condensate," *arXiv preprint,* vol. 1706, no. 01220 , 2017. |
| [5] | Z. C. A. S. K. D. S. G. M. W. Z. A. G. a. W. K. Hadzibabic, "Two-species mixture of quantum degenerate Bose and Fermi gases," *Physical review letters,* vol. 88, no. 16 , p. 160401, 2002. |
| [6] | M. K. S. S. R. G. a. F. S. Tey, "Double-degenerate Bose-Fermi mixture of strontium.," *Physical Review A,* vol. 82, no. 1, p. 011608, 2010. |
| [7] | T. G. E. a. H. J. M. Bergeman, "Magnetostatic trapping fields for neutral atoms," *Physical Review A,* vol. 35, no. 4, p. 1535, 1987. |
| [8] | D. E. Pritchard, "Cooling neutral atoms in a magnetic trap for precision spectroscopy.," *Physical Review Letters,* vol. 51, no. 15 , p. 1336, 1983. |
| [9] | W. M. H. A. J. R. E. a. E. A. C. Petrich, " Stable, tightly confining magnetic trap for evaporative cooling of neutral atoms," *Physical Review Letters,* vol. 74, no. 17 , p. 3352, 1995. |
| [10] | D. S. a. C. R. Naik, "Optically plugged quadrupole trap for Bose-Einstein condensates.," *Physical Review A,* vol. 71, no. 3, p. 033617, 2005. |
| [11] | T. I. B. a. T. W. H. Esslinger, "Bose-Einstein condensation in a quadrupole-Ioffe-configuration trap.," *Physical Review A,* vol. 58, no. 4, p. R2664, 1998. |
| [12] | R. L. R. P. S. N. T. S. B. S. M. a. Z. H. Campbell, "Efficient production of large K 39 Bose-Einstein condensates," *Physical Review A,* vol. 82, no. 6, p. 063611, 2010. |
| [13] | C. T. H. J. W. W. E. a. J. A. Klempt, " Transport of a quantum degenerate heteronuclear Bose-Fermi mixture in a harmonic trap," *The European Physical Journal D,* vol. 48, no. 1, pp. 121-126, 2008. |
| [14] | X. C. H.-X. W. P.-J. Y. X.-D. G. F. a. Z. J. De-Zhi, "Quantum degenerate Fermi–Bose mixtures of 40K and 87Rb atoms in a quadrupole-Ioffe configuration trap.," *Chinese Physics Letters,* vol. 25, no. 3, p. 843, 2008. |
| [15] | T. H. P. M. J. K. H. M. a. N. L. B. Bergeman, "Quantized motion of atoms in a quadrupole magnetostatic trap.," *JOSA B ,* vol. 6, no. 11, pp. 2249-2256., 1989. |
| [16] | S. a. I. B. S. De, " Fermion-mediated long-range interactions between bosons stored in an optical lattice," *Applied Physics B,* vol. 114, no. 4, pp. 527-536., 2014. |
| [17] | C. S. O. K. S. a. K. B. Ospelkaus, "Interaction-Driven Dynamics of K 40− Rb 87 Fermion-Boson Gas Mixtures in the Large-Particle-Number Limit.," *Physical review letters,* vol. 96, no. 2, p. 020401, 2006. |