Heating of atom ensembles in magnetic traps due to collisions with hot background gases

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INTRODUCTION

We present measurements and simulations for heating of cold ⁸⁷Rb atoms in a magnetic trap due to elastic background collisions. Our analysis employs differential scattering cross sections obtained from quantum scattering calculations, and specifically takes into account the effect of non-zero ensemble temperature. We compare our simulations with a previous theoretical analysis of heating rates by Beijerinck [¹] based on a semi-empirical model for the small-angle differential cross section.

THEORY

Elastic collisions between trapped atoms and background gases can result in either trap loss [²] or ensemble heating. For a single background gas species (of number density n₀ and speed v), the rate of collisions, i, is:

\[ i = n_n n_0 v \sigma(v) \]  

(1)

For a central potential, the heating cross-section, dσ/dΩ, is given by:

\[ \frac{d\sigma}{d\Omega} = \frac{2m v^2}{\pi \hbar^2} \sin(\theta_0) \]  

(2)

where θ₀ = v/|v₀| - (v₀/|v₀|) sin(θ). These formulae agree with those given by Beijerinck [¹]. This theory, however, does not consider:

• Trapped atoms have a distribution of energies

• Collisions can reduce trapped atom energy (“cooling collisions”)

Therefore we expect this theory to result in an over-estimate of (dE/dt).

MEASUREMENT OF HEATED FRACTION

To determine the number of atoms remaining in the trap, we use a trap simulation. Beijerinck’s model predicts that the heated fraction data are determined from the trap simulation. These results are in agreement with a trap simulation, which can also be used to predict per-atom heating rate (dE/dt). The heating rate for an ensemble with non-zero temperature is significantly smaller than the heating rate for an ensemble with zero temperature. Future work includes refining the differential cross section (the direction of momentum is random).

EXPERIMENTAL APPARATUS

A MOT is used to cool ⁸⁷Rb atoms. The atoms are then transferred to a magnetic trap created by RF coil and quadrupole coils. After holding the atoms for a given time, the MOT lasers are pulsed to determine the number of atoms remaining in the magnetic trap.

PROCEDURE

1. Define Bin 0 (low energy) and Bin 1 (high) as two energy ranges within the trap. E is the depth of the magnetic trap.
2. At the beginning of trap hold time, use the MOT laser to cool atoms in Bin 1.
3. Allow the trap to evolve. Ensemble heating will result in atoms moving from Bin 0 into Bin 1. The total number of atoms in the trap η₀ will decrease due to trap loss.
4. At time t, measure η₁ by pulsing the lasers, or measure η₀ by using the RF coil to eliminate atoms in Bin 1, then pulsing the lasers. Determine heated fraction η₁/η₀.

RESULTS

Heated fraction data were taken at various trap depths and Rb background number densities. Results show that Fₜ increases linearly with time. The heated fraction rate dFₜ/dt increases linearly with Rb background density n₀, which is expressed from Eq. 1.

\[ \frac{dF}{dt} = \frac{\eta_0 - \eta_1}{\eta_0} \]  

(3)

Above, experimental Fₜ as a function of trap depth is compared to the predicted Fₜ from a simulation of the trap. The two are compared to Fₜ predicted by Eq. 6, and Fₜ given by Eq. 9.

\[ \frac{dF}{dt} = \frac{\eta_0 - \eta_1}{\eta_0} \]  

(4)

We thank David Fagman and Dallas Clement for their contributions to the differential cross section calculator. This work was supported by the National Sciences and Engineering Council of Canada (NSERC), the Canadian Foundation for Innovation (CFI), the BCIT NSAS and Professional Development Fund, and UBC.

TRAP SIMULATION

To address the limitations of the theory, a trap simulation was designed. The simulation computes the trajectory of N trapped atoms within a model of the magnetic trap potential well. Each atom is subjected to random collisions. The magnitude of the momentum imparted to the trapped atom is determined using the numerically calculated differential cross-section (the direction of momentum is random).

CONCLUSION AND FUTURE WORK

Heating in a magnetic trap was observed through measurements of heated fraction. These results are in agreement with a trap simulation, which can also be used to predict per-atom heating rate (dE/dt). The heating rate for an ensemble with non-zero temperature is significantly smaller than the heating rate for an ensemble with zero temperature. Future work includes refining the differential cross section (the direction of momentum is random).