Observation of quantum diffractive collisions using shallow atomic traps

David E. Fagann¹, Jicheng Wang¹, Chenchong Zhu¹, Pavle Djuricinčič¹, Bruce G. Klaippel¹, James L. Booth¹, and Kirk W. Madison¹
¹Department of Physics & Astronomy, University of British Columbia, Vancouver, BC, V6T 1Z1, Canada
²Physics Department, British Columbia Institute of Technology, Burnaby, BC, V5G 3H2, Canada

INTRODUCTION

We investigate the use of trapped, lasercooled rubidium atoms to measure the cross section for ²⁴⁰Rb–Ar collisions. Motivated by the known role of small angle scattering in ensemble heating [1,2] due to collisions that do not directly result in particle loss, we studied the trap loss rate produced by room-temperature background collisions as a function of trap depth at 1 K and below 10 mK using a magneto-optic and a quadrupole magnetic trap. Using model interaction potentials for the Rb–Ar complex, we confirm that experimental measurements of loss rates at various trap depths are consistent with the known long range C₆ coefficient.

THEORY

To produce loss from a trap, an elastic collision must impact with a scattering angle that transfers enough energy for the particle to escape. This is given in terms of trap depth (U₀),

\[ \sigma_{\text{loss}} = \frac{4}{\pi} \left( \frac{4 M}{\mu} \right)^{1/2} \left[ \frac{\mu T}{\pi \hbar^2} \right]^{1/2} \beta \sin \theta \sqrt{\Gamma} \theta \frac{d\Gamma}{d\theta} \]  

(1)

where Mₓ is the mass of the trapped atom, μ is the reduced mass of the particles, and νₛ is the relative speed of the collision.

For a beam of incident scattering particles with wave vector k, the cross section for loss inducing collisions from a trap of depth U₀ is

\[ \sigma_{\text{loss}}(k) = \int_{\nu_{\text{loss}}(k)}^{\infty} 2 \sin \theta f(k, \theta) \left( \frac{1}{\beta} \sin \theta \sqrt{\Gamma} \theta \frac{d\Gamma}{d\theta} \right) d\theta \]  

(2)

where θ is the scattering angle and f(k, θ) is the scattering amplitude of the outgoing wave.

Given a background temperature T, the velocity averaged loss rate is

\[ \nu_{\text{loss}} = \int_{\nu_{\text{loss}}(k)}^{\infty} \nu_{\text{loss}}(k) \frac{dv}{v^2} \frac{d\nu_{\text{loss}}}{dv} \]  

(3)

EXPERIMENTAL RESULTS

• Atom number is measured by capturing and detecting the fluorescence of atoms in the MOT

• Measuring the atom number during loading of a MOT and decay in a magnetic trap allows us to extract the loss rate (Γ) of each trap.

• As the controlled background gas density nₓ is increased, the total loss rate Γ increases with slope <νₓσₓ> = b/x (see Fig 4). The slope is different between the two trap depths as a result of the difference in trap depth.

EXPERIMENTAL SETUP

Our apparatus uses a standard 3-beam retroflective MOT shown in Fig. 1 trapping rubidium atoms in a glass cell (12mm x 12mm x 60 mm)

• The magnetic coils, in anti-Helmholtz configuration, (Fig. 1) are operated at 6 A in the construction of the apparatus.

• The use of trapped, laser cooled rubidium atoms to measure the cross section for ²⁴⁰Rb–Ar collisions is investigated. Trap loss rates produced by background collisions as a function of trap depth at 1K and below 10 mK using a magneto-optic and a quadrupole magnetic trap are studied. Contrary to the findings of Matherson et al.[6], the retention of atoms due to a finite trap depth (i.e. larger than the quantum diffractive collision energy scale) is found to significantly reduce the measured loss rate in comparison with the total collision rate. These results highlight the importance of minimizing the trap depth when attempting to infer the total collision cross section from measurements of atom trap loss rates. The variation of loss rate with trap depth allows a determination of both the differential and integral cross sections.

THEORETICAL RESULTS

• We then write the radial equation for the partial wave as,

\[ \frac{d^2 \psi}{dr^2} = \left( \frac{1}{2} \frac{\mu}{k^2} - \frac{\lambda}{k} - \frac{\lambda^2}{k^2} \right) \psi \]  

(5)

where V(r) is a Leonard-Jones potential with cited C₆ and C₁₂ values[4].

• The solution to the radial equation is then independently computed using the log-derivative method [5]. The phase shift is determined by matching this numerical solution in the asymptotic region to the spherical Bessel and Neumann functions.

CONCLUSIONS

The measured (black square) and computed slope of the loss rate (red trace) as a function of the trap depth for ⁸⁷Rb-40Ar collisions. The experimental data below 10 mK were collected from the magnetic trap and the 1K data point came from the MOT. The horizontal blue line indicates total collision loss rate extrapolated from zero trap depth.

ACKNOWLEDGEMENTS

We thank Dr. Roman Kremen for stimulating discussions. This work was supported by the Natural Sciences and Engineering Council of Canada (NSERC), the Canadian Foundation for Innovation (CFI), the BCIT SCAS and Professional Development Fund, and UBC. We also thank Roberto Romano for his contribution to the construction of the apparatus.

REFERENCES