Introduction

TRIUMF's Neutral Atom Trap (TRINAT) is a magneto-optical trap that traps atoms in a cubic millimeter volume. It is used to examine fundamental symmetries in nature by studying neutrinos from beta decay of atomic nuclei, searching for physics beyond the Standard Model of particle physics.

Background

Shining a laser at an atom at the resonant frequency for a specific energy transition causes the atom to be absorbed. This gives a momentum kick to the atom in the direction of photon travel. Atoms absorb more photons closer to the resonant frequency.

Laser Cooling

- Laser frequency detuned below the atomic resonance
- If atom moves towards one beam, that light will be Doppler shifted closer to the resonance causing more photons to be absorbed, creating a slowing scattering force $F_{\text{scat}}$

Magneto-optical Trap

- 3 pairs opposing laser beams point towards atoms
- Quadrupole magnetic B field, 0 at origin
- If atom moves away, nonzero B field causes Zeeman shift in energy levels that increases photon absorption, kicking the atom back to center

Beta Decay

- Searching for forbidden right-handed spin neutrinos from beta decay
- Would provide evidence for physics beyond Standard Model

Temperature Measurements

- Temperature determined from the atom cloud expansion rate
- Used stable isotope Potassium 41

Control System Design

- Main control computer is a Raspberry Pi
- Interfaces with control and data acquisition systems
- Runs real-time Linux, timing to 15 μs precision
- Runs custom-written C++ programs for control
- Externally triggers camera
- Interfaces with control and data acquisition systems

Methods

- Design replacement atom trap control system with accurate timing capability
- Use system to determine lowest achievable temperature and trap size to improve accuracy of calculations of neutrino momenta from beta decay

Results

- Lowest temperature and size 141±12 μK, $v_{\text{max}}$ = 0.34±0.03 mm/s
- In range of theoretical Doppler cooling limit of 145 μK
- 144.7 MHz frequency, 1x saturation intensity; 30K atoms

Temperature dependence on frequency and intensity

- ~100K atoms, solid curves Doppler cooling predictions

Size dependence on frequency and intensity

- ~100K atoms

In design, implementation and usage of a replacement atom trap control system we were able to determine laser intensity, frequency and number of atoms settings to optimize the low temperature and small size of the atom trap for beta decay. With this new knowledge, the next beta decay experiments will be able to conclude more accurate results in calculation of the neutrino momenta.

Conclusions

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References