Characterization of Cold Rb-87 Atoms in the Magneto-Optical Trap

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Abstract

Cold atoms in a magneto-optical trap (MOT) are crucial for quantum technology and high-precision sensors. This research focuses on analyzing the spatial distribution, temperature, and volume of the atomic cloud, while also investigating the effects of laser detuning and magnetic field gradients on MOT efficiency. The experiment was conducted using a standard MOT setup, which consists of counter-propagating laser beams, a quadrupole magnetic field, and an ultra-high vacuum (UHV) chamber. The atomic fluorescence signal was recorded using a Charge Coupled Device (CCD) camera and analyzed using two-dimensional Gaussian fitting method was applied to determine the $1/e^2$ radius and the MOT volume. The results indicate that the atomic cloud exhibits a Gaussian spatial distribution, with a $1/e^2$ radius of approximately 1.196 ±0.3 mm leading to a MOT volume in the range of 7.585±30% mm3, varying the laser detuning affects the trapping efficiency. This study provides essential insights into the properties of cold rubidium-87 atoms, which can be applied to the development of atomic cooling techniques and future quantum technologies.

Introducrtion

Rubidium-87 (Rb-87) atoms, cooled and trapped in a Magneto-Optical Trap (MOT), serve as a fundamental platform for high-precision measurements, quantum optics, and atomic physics research. The MOT combines laser cooling and a magnetic field gradient to confine and cool atoms to the microkelvin regime. By reducing atomic motion through Doppler cooling and utilizing the Zeeman effect for spatial confinement, Rb-87 atoms can be effectively trapped and manipulated with high efficiency.

Theory

The trapping of Rubidium-87 atoms is achieved using the Magneto-Optical Trap (MOT), a technique that use lasers and a magnetic field to confine atoms within a specific region. This method relies on Doppler cooling to slow down atomic motion and the Zeeman effect, combined with a magnetic field gradient, to generate a force that directs the atoms toward the center of the trap, ultimately cooling them to the microkelvin level.
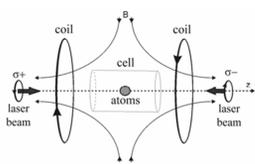
Fig. 1. Arrangement for a MOT in 1D. Atoms in the field of two counterpropagating beams and the magnetic field of quadrupole symmetry with zero in the trap centre
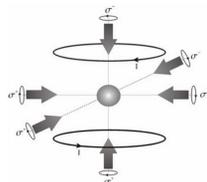
Fig.2.Scheme of a 3D MOT. Thick arrows denote three pairs of the circularly polarized cooling laser beams counter-propagating along three coordinate axes. Big loops of current I flowing in opposite directions generate magnetic field of spherical quadru- pole symmetry

Method

When setting up the equipment and obtaining the image for atom counting, the image must be cropped to include only the MOT region and saved as a BMP file. Then, using Python in Google Colab, the cropped image is processed by fitting a 2D Gaussian to extract sigma x and sigma y, which are used to determine the $1/e^2$ radius of the MOT. This radius is then used to calculate the MOT volume, leading to a graph showing the variation of volume for optimizing the laser frequency. Additionally, Python is used to analyze the number of atoms in the MOT from the cropped image and to calculate the MOT density

Result

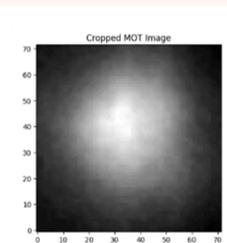Fig.3.Fit a 2D Gaussian to obtain sigma x and sigma y.

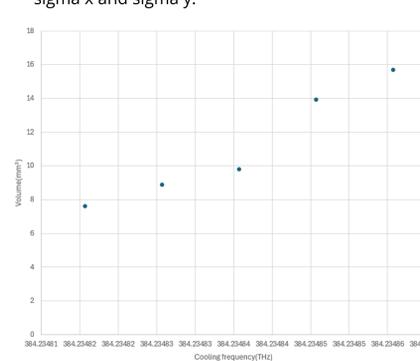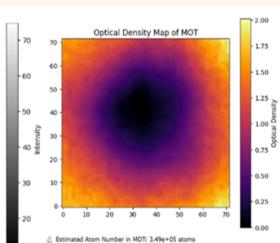Fig.4.Number of atoms in the MOT to calculate the MOT density.

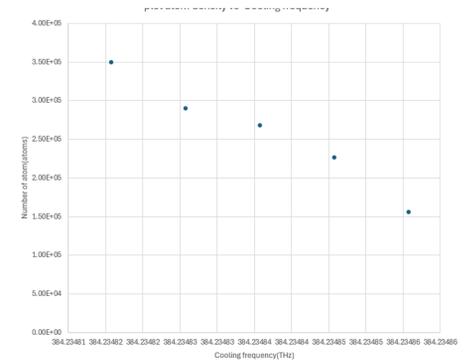Fig.5.plot volume vs cooling frequency
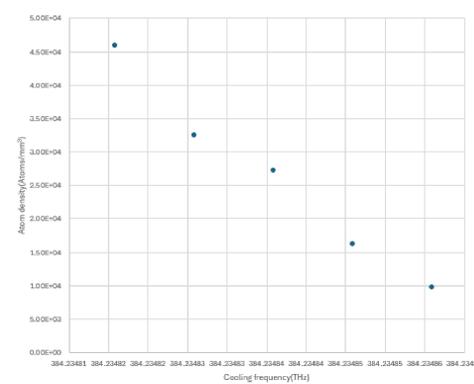
Fig.6.plot number of atom vs cooling frequency

Fig.7.plot atom density vs cooling frequency

Conclusion

Experiment demonstrates that increasing the cooling laser frequency causes the MOT volume (Fig. 5) to increase because atoms that absorb more energy from the laser move further from the MOT center, leading to a larger MOT size. This results in higher atomic energy and broader spatial distribution. Meanwhile, the number of trapped atoms (Fig. 6) and atom density (Fig. 7) decrease, which is attributed to the optical pumping effect, causing atoms to escape from the trapping cycle and reducing the efficiency of Doppler cooling.

References

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