A248: Magneto-optical Trap

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We adjusted some mirrors to get MOT. We did some measurements.

1 Introduction

Magneto-optical traps (MOT) are an important apparatus in modern atomic physics experiments, used to slow and trap a neutral atom cloud to temperatures as cold as several microkelvin. They are achieved by combining radiation pressure from laser beams and a quadropole magnetic field inside a vacuum cell rid of other gasses. Their use ranges from probing atomic properties, quantum optics, cold collision, quantum information processing, and acting as the preliminary stage to achieving even colder atom traps, namely Bose-Einstein condensates. This experiment aimed at obtaining a MOT and finding its size, population, and loading behaviour as well its fluorescence dependence on the magnetic field strength, quarter waveplate angle, and laser frequency detuning.

2 Theory

The central process by which atomic gasses are cooled are via radiation pressure from lasers. When a photon is absorbed by an object, particle, or atom, its energy as well as its momentum, equal to $p = \hbar k$, is absorbed as a result of momentum conservation. This radiation pressure can be used to slow down moving atoms if the atoms absorb photons travelling in the opposite direction. That said, only photons resonant to a transition of the absorption spectrum of the atoms are absorbed. As a result, the absorption spectrum of the atoms to be cooled needs to be known and a particular transition chosen such that the required frequency of the cooling laser can be determined.

2.1 Saturation Spectroscopy

Atoms can only absorb photons with frequencies that are resonant to their excitation transitions. That said, a moving atom will not be able to absorb photons with these frequencies as their frequency will be Doppler shifted and no longer resonant to the atom transitions. The moving atom will only be able to absorb light which has been Doppler shifted such that it is resonant with one of its excitation transitions. In an uncooled gas, the atoms are all travelling in different directions with different speeds. As a results, light incident on the gas from one direction will be Doppler shifted differently for all the different atoms. An absorption spectrum obtained from such a gas will thus be Doppler broadened, making it difficult to determine the energy levels and transitions of the atoms. In order to obtain a spectrum with high resolution, Doppler-free spectroscopy such as saturation spectroscopy needs to be used.

Saturation spectroscopy utilises two lasers. One laser

2.2 Polarisation Spectroscopy

2.3 Optical Cooling

2.4 Magneto-Optical Trap

2.4.1 Optical Trap

2.4.2 Magnetic Trap

2.5 Rubidium

3 Experimental setup

3.1 Diode Laser

3.2 Laser Detuning

3.3 MOT setup

4 Procedure

5 Measurements

5.1 Laser beam diameter

Using a movable razor blade and a powermeter, we measured the intensity as a function of the displacement of the blade along an axis perpendicular to the beam

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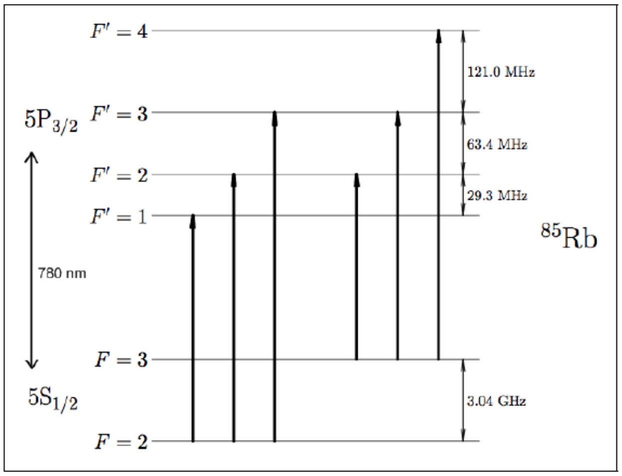

Figure 1: The dependency of MOT luminosity on the current flow through the coils and thus the strength of the magnetic field.

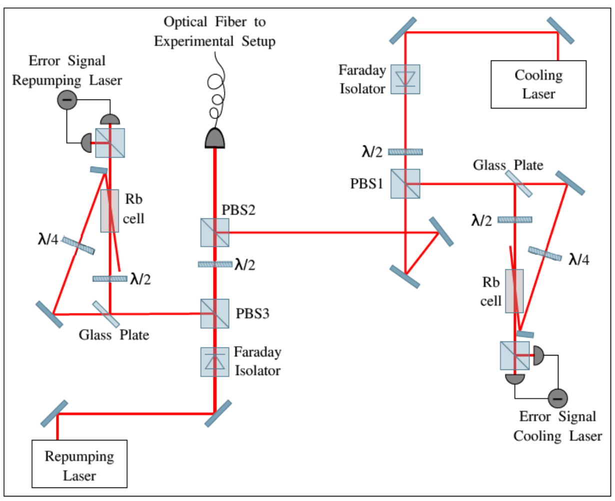

Figure 2: The dependency of MOT luminosity on the current flow through the coils and thus the strength of the magnetic field.

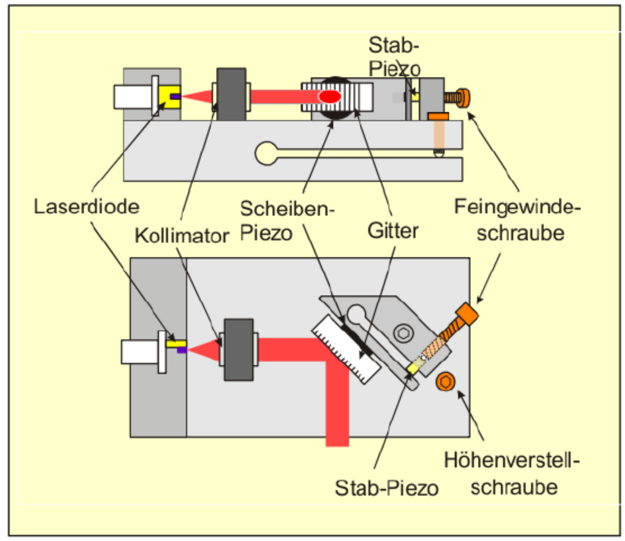

Figure 3: The dependency of MOT luminosity on the current flow through the coils and thus the strength of the magnetic field.

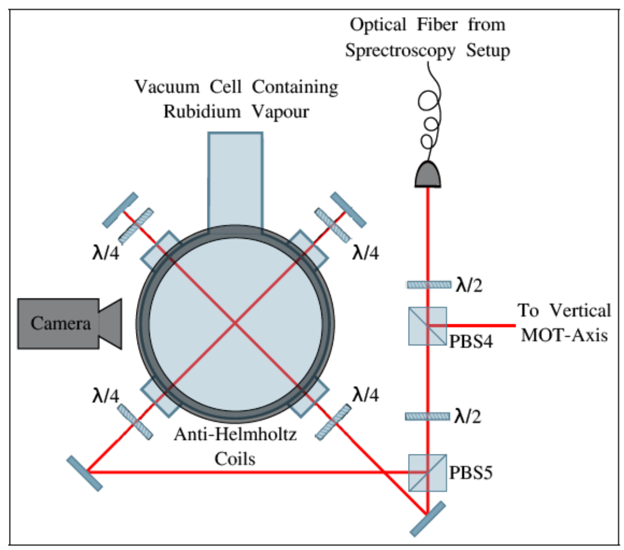

Figure 4: The dependency of MOT luminosity on the current flow through the coils and thus the strength of the magnetic field.

propagation direction. The results are collected in Table 1. Fitting a function of the form

$$f(x) = P + A \cdot \text{erfc}(B \cdot x - C),$$

we found

$$\begin{aligned} P &= \quad 0.012 \pm 0.009, \\ A &= \quad 0.735 \pm 0.007, \\ B &= \quad 4.942 \pm 0.133, \\ C &= 198.039 \pm 5.317. \end{aligned}$$

This results in a width

$$w = 0.2860 \text{ cm } \pm 0.0077 \text{ cm}$$

5.2 Size of MOT

To get an estimate on the MOT size we took a picture of, we used a scale put in the focus to convert distances in pixels to centimeters. By choosing two points (30.0 ± 0.5) mm from each other in the image (the error due to the width of the millimeter lines on the scale and the two points not at the same distance from the edge of the ruler), the image viewer software showed 742.2 pixels. Then

$$1 \text{ px} = (40.42 \pm 0.67)\,\mu\text{m}$$

Position (cm)	Power (mW)
39.4 ± 0.05	1.58 ± 0.01
39.5 ± 0.05	1.57 ± 0.01
39.6 ± 0.05	1.52 ± 0.01
39.7 ± 0.05	1.40 ± 0.01
39.8 ± 0.05	1.07 ± 0.01
39.9 ± 0.05	0.62 ± 0.01
40.0 ± 0.05	0.25 ± 0.01
40.1 ± 0.05	0.10 ± 0.01
40.2 ± 0.05	0.04 ± 0.01
40.3 ± 0.05	0.01 ± 0.01
40.4 ± 0.05	0.00 ± 0.01

Table 1: Beam power as a function of position of the razor blade. Clearly visible

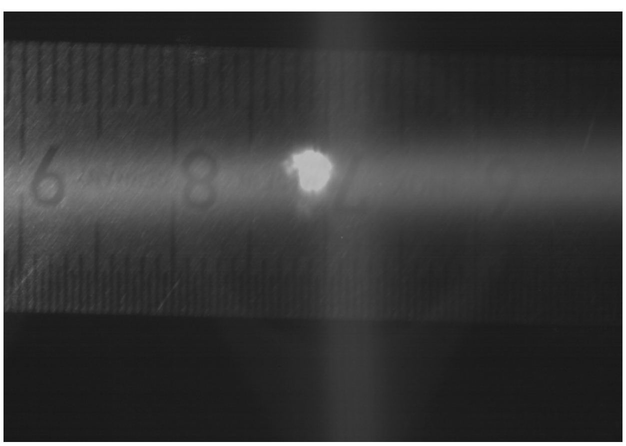

Figure 5: Photo of the MOT merged with photo of the scale.

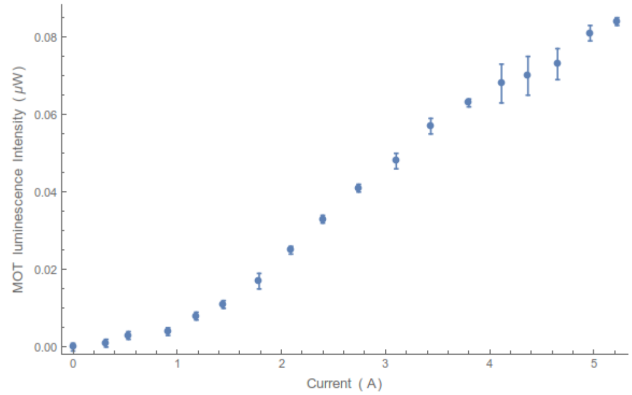

Figure 6: The dependency of MOT luminosity on the current flow through the coils and thus the strength of the magnetic field.

As visible on Figure 5, the MOT has different horizontal and vertical size values. The directly measured width and height for the MOT are

$$h = (72 \pm 2)\,\mathrm{px}$$
$$w = (57 \pm 2)\,\mathrm{px}$$

We chose to approximate the volume by an ellipsoid with one axis half the height (c) and two axes half the width (a, b) each.

$$a, b = (1.15 \pm 0.04)\,\mathrm{mm}$$
$$c = (1.46 \pm 0.05)\,\mathrm{mm}$$
$$V = \frac{4}{3}\pi abc = (8.09 \pm 0.52)\,\mathrm{mm}^3$$

5.3 Changing the magnetic field

To measure the MOT fluorescence as a function of the magnetic field, we changed the current flowing through the coils. Figure 6 shows our results. To get a visible MOT, we had to set the current to a minimal value of around 0.9 A, below this the system fails to trap the moving atoms; from this point, the fluorescence grew proportional to the current to a good approximation, up to 4.6 A. The background fluorescence has been previously measured and substracted from the data.

5.4 Loading behaviour

After replacing the powermeter with a photodiode and showing its signal on an oscilloscope, we used the data from 6 MOT buildup events to find the loading time. As it is known,[1] the number of trapped atoms changes as

$$N(t) = N_0\left(1 - e^{-\frac{t}{\tau}}\right), \tag{1}$$

where τ is the loading time, N_0 is the maximal number of atoms in the trap. The cross-section is related to τ

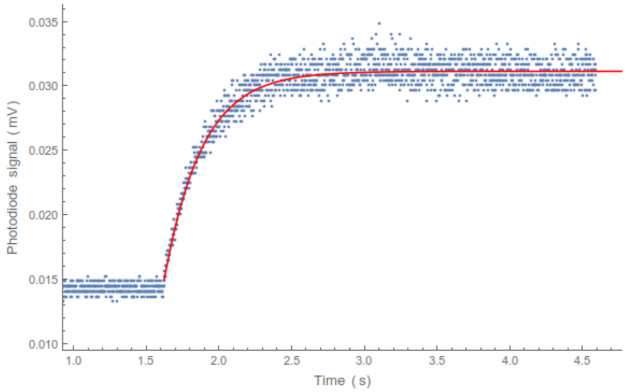

Figure 7: Example of data points exported from the oscilloscope, with fitted function (red).

if there is only Rb in the vacuum chamber (which we assume):

$$\frac{1}{\tau} = n_{\mathrm{Rb}}\sigma_{\mathrm{Rb}}v_{\mathrm{Rb}}, \tag{2}$$

where n_{Rb} is the number density, v_{Rb} is the average velocity of the Rb vapor (in the following, the subscript Rb is ignored).

As the luminescence-time signal also follows Eqn. 1, by fitting such a function to the oscilloscope data we have gathered yields τ:

$$\tau = (0.268 \pm 0.006)\,\mathrm{s}$$

With the recorded temperature $T = (293.55 \pm 0.05)\,K$ and pressure $p = (8.09 \pm 0.01) \cdot 10^{-8}\,\mathrm{mbar}$,

$$v = \sqrt{\frac{2kT}{m}} = (293.545 \pm 0.025)\,\frac{\mathrm{m}}{\mathrm{s}}$$

The number density n can be calculated from the ideal gas law:

$$n = \frac{N}{V} = \frac{p}{kT} = (1.99704 \pm 0.00250) \cdot 10^{15}\,\frac{1}{\mathrm{m}^3}$$

Finally, the cross-section:

$$\sigma = \frac{1}{n\tau v} = (6.355 \pm 0.131) \cdot 10^{-18}\,\mathrm{m}^2 \tag{3}$$

6 Conclusion

References

[1] C. Wieman, G. Flowers and S.Gilbert, Am. J. Phys. **63** (1995).

[2] Unspecified Author, *FP Experiment: Rubidium MOT* (University of Bonn, 2014).

[3] H. Metcalf and P. van der Straten, *Laser Cooling and Trapping* (Springer, 1999).