Chapter 9

Optimising the MOTs

"The major difference between a thing that might go wrong and a thing that cannot possibly go wrong is that when a thing that cannot possibly go wrong goes wrong it usually turns out to be impossible to get at or repair."
Douglas Adams

This chapter describes the initial results and optimisation process of the two MOTs. The fluorescence from the S-MOT is used to give an estimate for the number of trapped atoms.

9.1 P-MOT

Cold atoms were first observed in the P-MOT on 13th December 2004. This was shortly before the two chambers were combined together and re-baked. An image of the cold atoms is shown in Figure 9.1. The image is complicated by single and double reflections off the pyramid mirrors. The true cloud (circled) is determined by moving the cloud with the magnetic shim coils. When the cloud is moved close to the square hole at the pyramid apex, the cloud is seen to rapidly disappear down it. The cloud takes ~ 2 s to reform when the magnetic field centre has been moved away from the hole.

The P-MOT is a robust source of cold atoms and tolerates some misalignment before the cold atoms are lost. The $\lambda/4$ waveplate converting the incoming

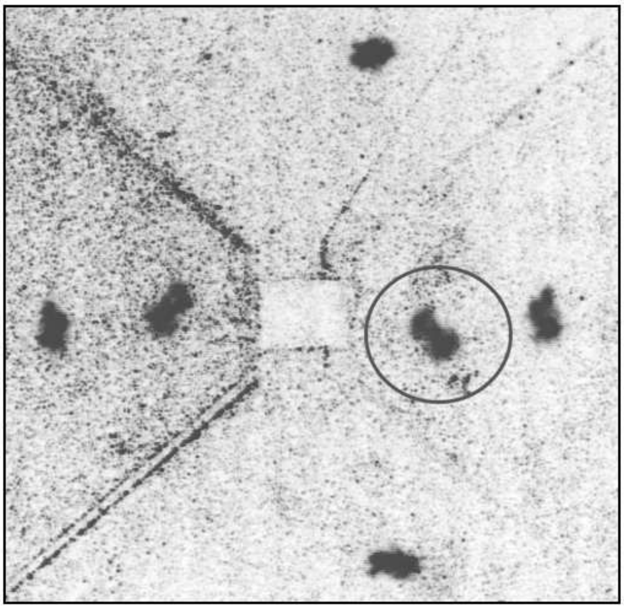

Figure 9.1: Inverted CCD image of the fluorescence from the cold atom cloud in the P-MOT. The image covers a 15×15 mm^2 area. The circle indicates the true cloud, and the five other clouds are reflections off the mirrors. The central faint square is the 2 mm hole at the apex of the pyramid. The darker diagonal lines occur at the prism-mirror interface.

linearly polarised light into circularly polarised light has a 45° tolerance on the rotation angle. The incoming angle of the light can be misaligned by up to 5° without losing the MOT. Laser cooling can occur at relatively low powers. The first P-MOT was obtained with 10 mW of cooling and 3 mW of repumping light. When the cooling light frequency detuning is brought closer to resonance the atom cloud becomes distorted and begins to oscillate before eventually being destroyed. A detuning of $-2\pi \times 12$ MHz produces an image of a large and stable cold atom cloud on the CCD camera. The repumping light detuning has a much higher tolerance and an atomic cloud is observed over a $2\pi \times 100$ MHz range. The detuning is set by optimising the fluorescence seen on the CCD camera.

9.2 S-MOT

After combining chambers and setting the experiment up in a new lab, cold atoms were first observed in the S-MOT on 31st July 2005. The first images obtained are shown in Figure 9.2. In this figure the left hand side shows the S-MOT being loaded by a flux of cold atoms from the P-MOT, the right image is with the P-MOT light shuttered off and therefore with the cold atom flux stopped. The lack of background scattering and multiple cloud images allows quantitative measurements to be made using the S-MOT fluorescence.

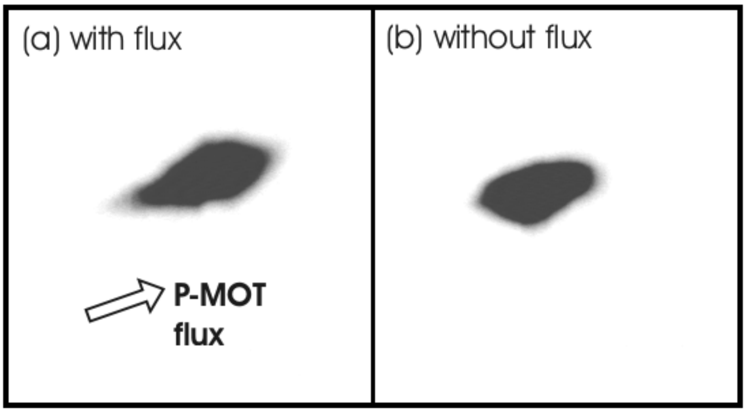

Figure 9.2: Inverted CCD image of the fluorescence from the cold atom cloud in the S-MOT. Image (a) is with the flux of cold atoms from the P-MOT present, and image (b) is without the flux and light from the P-MOT. The P-MOT flux is traveling in a north easterly direction. Each image covers approximately a 5×5 mm^2 area.

9.2.1 Fluorescence and atom number

The power emitted by the S-MOT is given by:

$$P_{\mathrm{MOT}} = \Gamma_{\mathrm{sc}} N E, \tag{9.1}$$

where Γ_{sc} is the scattering rate given by eqn. (2.9) on page 15, N is the number of atoms and $E = hc/\lambda_{\mathrm{C}}$ is the energy per photon (2.6×10^{-19} J at 780 nm).

A photodiode (Integrated Photomatrix Inc. IPL10050CW) is used to measure the fluorescence of the cold atom cloud in the S-MOT, see Figure 9.3. A pair of plano-convex 2" diameter lenses (f = 10 cm and 5 cm) focus the S-MOT light onto the photodiode. The photodiode is housed in a light tight box except for a 1" diameter 780 nm filter (transmission $T_{\mathrm{r}} = 0.65$) on the front. An OpAmp circuit provides a gain of $g_{\mathrm{n}} = 50$ to the measured voltage (circuit design described in ref. [187]).

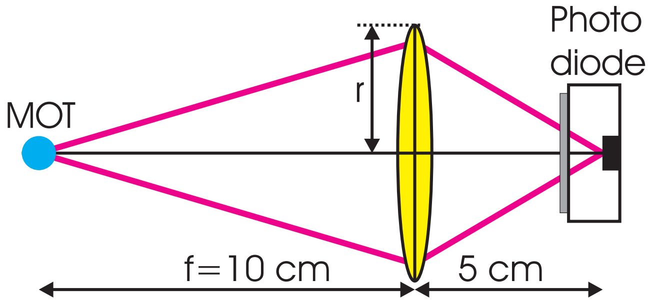

Figure 9.3: Photodiode, lens and filter used to collect S-MOT fluorescence.

The power measured by the photodiode is given by:

$$P_{\mathrm{PD}} = \frac{V}{\kappa g_{\mathrm{n}} G S T_{\mathrm{r}}}, \tag{9.2}$$

where V is the voltage, G is the total impedance of the photo diode circuit ($G = 1$ MΩ) and S is the photodiode sensitivity ($S = 0.45$ A W^{-1}). The fractional solid angle for a lens of radius r and object distance f is:

$$\kappa = \frac{\pi r^2}{4\pi f^2} \simeq 0.0156. \tag{9.3}$$

Equating the two powers (eqns. (9.1) and (9.2)) gives an estimate of the atom number within the S-MOT:

$$N = \frac{V}{\kappa g_{\mathrm{n}} G S T_{\mathrm{r}} \Gamma_{\mathrm{sc}} E}. \tag{9.4}$$

A voltage can therefore be converted into atom number. The majority of the terms in eqn. (9.4) are constants given by the specific photodiode setup. However, the scattering rate has an intensity and detuning dependence. In ref. [57] it was recommended that the saturation intensity for random polarisation should be used in calculating the scattering rate ($I_{\mathrm{sat}} = 4.1$ mW/cm^2). Using eqn. (2.9), eqn. (9.4) and the values given in this section, the number of atoms per volt is estimated to be:

$$N/V = 1.5 \times 10^6 + 1.6 \times 10^{-9} \Delta^2. \tag{9.5}$$

9.2.2 Loading curves and optimisation

For a given S-MOT detuning, the atom number can be maximised by maximising the fluorescence (photodiode voltage). There are a number of parameters that can alter the final atom number captured: Rb dispenser current; shim coil currents; P-MOT current; loading time; P-MOT detuning. The remainder of this chapter optimises these parameters. Unfortunately most parameters are dependent on each other, which complicates the order of optimisation. LabVIEW was programmed to repeatedly load the S-MOT for a given time (usually 3 seconds) then release the cold atoms collected, see Figure 9.4. The average of the maximum voltage from ten loads is then plotted against the varied parameter.

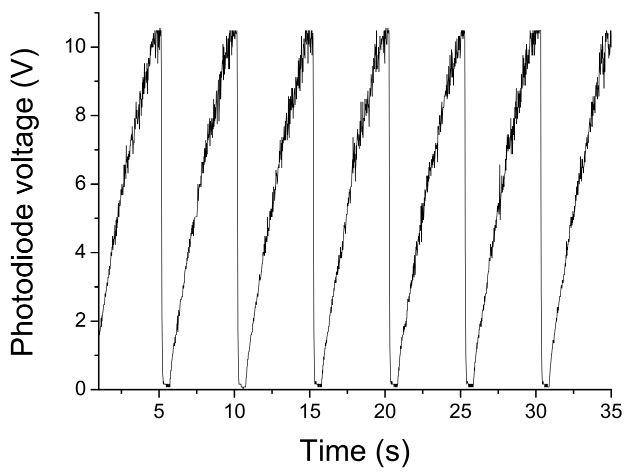

Figure 9.4: The photodiode voltage (fluorescence) from the S-MOT is plotted against time. LabVIEW was programmed to load and then release the cold atoms every 5 seconds.

The first step in optimisation is to determine the best Rb dispenser current. Figure 9.5 plots the photodiode voltage (S-MOT fluorescence) against dispenser current. Up to 2.5A the background Rb atoms create a small MOT and the dispenser does not contribute any atoms. Above the 2.5A threshold the dispenser releases Rb atoms that can be cooled in the MOT. The fluorescence begins to saturate at 3.5A. A compromise has to be made between obtaining high atom numbers and running the dispensers too hard, thus shortening their lifetime. Therefore running the dispensers at 3A was chosen.

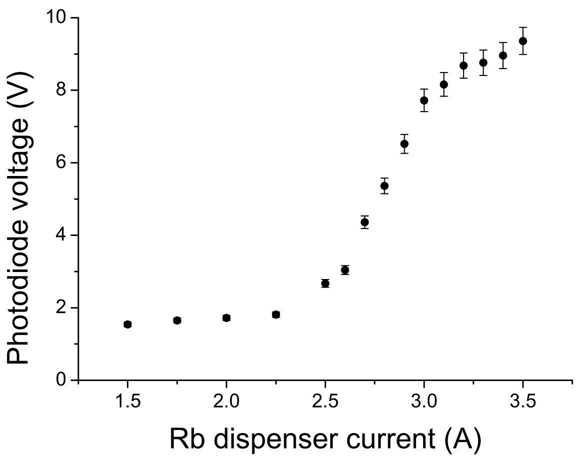

Figure 9.5: S-MOT photodiode voltage (fluorescence) is plotted against Rb dispenser current. A 3 s loading time was used.

The next stage is to optimise the position of the P-MOT cloud above the pyramid hole. By varying the current in the three independent shim coils (Up-Down, Left-Right and Forward-Back) the cloud can be moved. Figure 9.6 plots photodiode voltage against shim current for (a) the Left-Right direction and (b) the Up-Down direction.

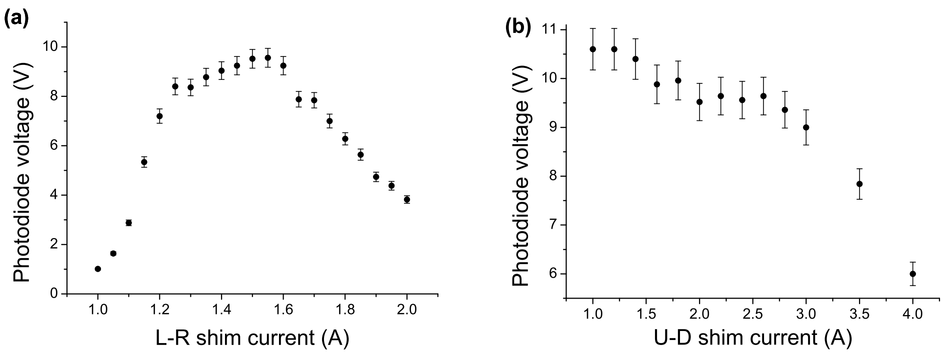

Figure 9.6: S-MOT photodiode voltage (fluorescence) is plotted against shim coil current in (a) the Left-Right direction and (b) the Up-Down direction (increasing the current lowers the cloud's position). A 3 s loading time was used.

In the Left-Right direction, the plateau between 1.25A and 1.8A is where the cloud is directly above the pyramid hole. A similar plot is obtained for the Forward-Back direction. The Up-Down plot displays a different behavior. The fluorescence is maximised when the cloud is formed higher up in the P-MOT chamber (increasing the current lowers the cloud's position). A possible explanation for this is the higher cloud experiences more transverse cooling before exiting through the hole. A beam exiting the chamber will therefore diverge less, and produce a higher flux at the S-MOT.

Figure 9.7 plots photodiode voltage against the current in the anti-Helmholtz configuration coils on the P-MOT. The optimum fluorescence is achieved when a current of 10A is used, which corresponds to a magnetic field gradient of 5.2 G/cm.

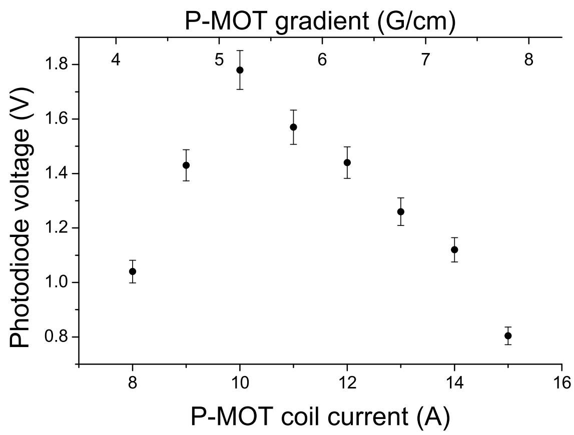

Figure 9.7: S-MOT photodiode voltage (fluorescence) is plotted against the current in the anti-Helmholtz configuration coils on the P-MOT. The corresponding magnetic field gradient is also shown on the additional x-axis. A 1 s loading time was used.

Attention is now turned to optimising the detuning of the S-MOT cooling light. As explained in Section 9.2.1, the maximum fluorescence does not necessarily correspond to the maximum atom number. Figure 9.8 (a) shows the photodiode voltage plotted against S-MOT detuning. Small detunings, being close to resonance, cause the MOT to oscillate and hence account for the large error bars on the right hand side of the figure. The maximum stable fluorescence occurs at $-2\pi \times 12.5$ MHz. The data is converted into an estimate of the atom number using eqn. 9.4, the result is plotted in Figure 9.8 (b). The maximum atom number is now achieved with a frequency detuning of $-2\pi \times 17$ MHz. Fluorescence is therefore a misleading measurement of atom number.

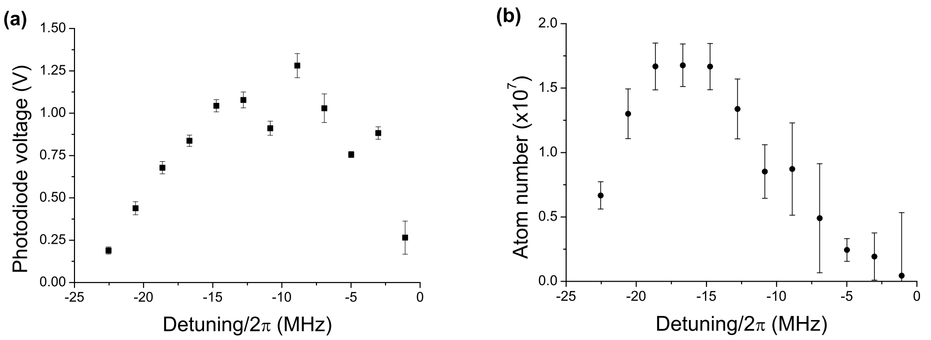

Figure 9.8: Plot (a): S-MOT photodiode voltage (fluorescence) is plotted against cooling light detuning. Plot (b): S-MOT atom number is plotted against cooling light detuning. The data from (a) are converted to atom number using eqn. 9.4. A 1 s loading time was used.

Figure 9.9, shows atom number against loading time for the now optimised S-MOT. The atom number saturates for a loading time greater than 5 seconds. 100 million cold atoms can be collected by the S-MOT. The trapping is not indefinite and Figure 9.10 shows the decay of the S-MOT fluorescence once the P-MOT flux has been extinguished. The exponential decay has a $1/e$ lifetime of 7 seconds. However, the lifetime of interest is that of the cold atoms trapped within the dipole trap. Due to the trapping light being far-off resonance, lifetimes in excess of 300 s have been measured in similar experiments [188].

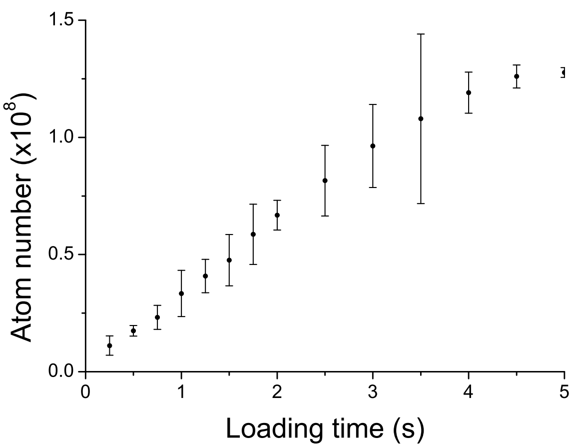

Figure 9.9: S-MOT number of atoms is plotted against loading time. The number of atoms saturates above 5 s loading time.

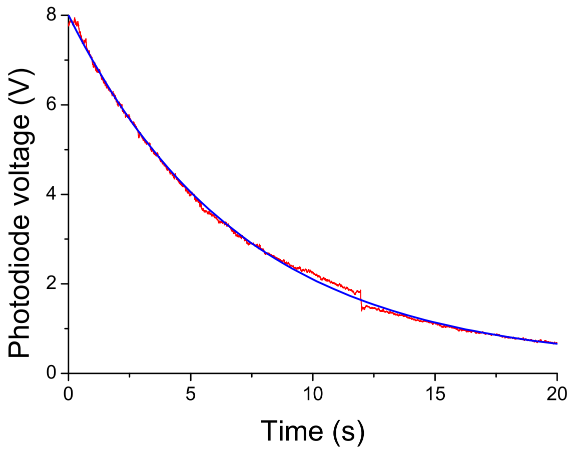

Figure 9.10: The photodiode voltage is plotted against time. The P-MOT flux was switched off at $t = 0$ s and therefore the curve represents the decay of the S-MOT fluorescence. The fitted $1/e$ lifetime (blue line) is 7.0 ± 0.5 s.

Chapter 9 summary

- An image of cold atoms fluorescing within the P-MOT was shown. The design is tolerant of misalignment and proves to be a good method of laser cooling atoms.
- A method of converting a measured fluorescence in the S-MOT to an estimate of atom number was presented. This was then used to optimise parameters to maximise the atom number collected in the S-MOT.
- 100 million atoms can be collected, and the atomic cloud has a $1/e$ lifetime of 7 seconds.