Chapter 7

Summary and suggestions for future work

7.1 Summary

In this thesis we have reported some work on laser cooled atoms on ^{85}Rb.

A magneto-optical trap was built with home built components including external cavity diode lasers, temperature and current controllers, lock-in circuits. A cloud of Rubidium atoms was cooled and trapped successfully, and several experiments were performed.

Extensive experiments were carried out in which the cooling or repumper laser beams were ramped up and down. The results of such dynamic operations are discussed in the thesis.

The repumper laser was set on the transition F = 2 to F = 3 and the cooling laser frequency was ramped up and down from 120 to + 35 MHz at different periods varying from 200 seconds to 2 seconds. It was found that the fluorescence peaks occurred at different detunings while the laser was ramped up and down. Not only the positions of the peaks, but also their full widths at half maximum and their heights varied as the rate of ramping was changed. In particular the ratio ρ of the heights of the peaks when the laser was ramped down and when the laser was ramped up was found to be a sensitive function of the ramp period. The behaviour was understood in terms of the detuning-dependence of the loading rate in the MOT and the the decay rate of the cloud. Our calculations showed that the dependence of the parameter on the ramping period was not sensitive to such parameters as the radius of the MOT beams, the intensity of the MOT beams and the magnetic field gradient. It was sensitive only to the ratio of the ramp period T to a parameter τ_0 which determines the value of the decay time (in seconds or tens of seconds). The experimental results for ρ as a function of T/τ_0 fitted the calculated curve well if τ_0 was chosen as 1.25 s. The life time τ in the trap at $\delta_c = -2\Gamma$ calculated with this value of τ_0 came out to be 0.7 s, a value consistent with the pressure of 1×10^{-9} mbar in the chamber. It is shown that the measurement of ρ provides an alternative and simpler method for the determination of the life time of the atoms in the MOT compared to the conventional method of switching off the source of atoms and measuring the fluorescence decay rate.

The temperature of the cloud in the MOT was measured by a non-destructive method used by Kohns et al. The cloud was set into forced oscillations by an alternating magnetic field and the phase of the oscillations was measured relative to the phase of the applied magnetic field using a photo-detector and lock in amplifier. The variation of the phase with the frequency of the magnetic field was fitted to a forced damped linear harmonic model to obtain the force constant of the atoms in the trap. From the Gaussian profile of the intensity of the intensity of the cloud imaged in fluorescence, the radius of the cloud was determined. Using the equipartition theorem, we deduced a temperature of 200±20 μK for the cloud. The cooling is in the Doppler regime.

In Chapter 5 we describe experiments in which the cooling beam detuning was kept fixed and the repumper detuning was ramped slowly and the fluorescence of the cloud monitored. The fluorescence showed peaks whenever the repumper detuning δ_r was equal to δ_c, the cooling beam detuning. What was surprising was that (a) the fluorescence peaks occurred whether the cooling beam was blue detuned or red detuned and (b) the fluorescence peaks had a line width of the order of 30 MHz. The first observation showed that the qualitative results of the experiment were independent of whether the atoms was cooled or not. If the atoms are not cooled the observation of sharp fluorescence peaks was surprising since the Doppler width of the Rb atom vapour at room temperature is around 2 GHz.

Further careful experiments were done in a 3-D optical molasses, a cold cloud, in an 1-D optical molasses in a vapour cell. It was observed in the 3-D configuration as well as the 1-D configuration that two pairs of sharp fluorescence peaks were obtained which occurred whenever the repumper detuning δ_r was equal to $\pm\delta_c$ and $\pm(\delta_c + 63\text{MHz})$.

The above results were understood on a double resonance model. Considering an one dimensional situation an atom moving with a velocity v parallel to a laser beam will have a Doppler shift kv, depending on whether the atom is moving parallel or antiparallel with the laser beam. The cooling laser beam, which has a detuning δ_c in the laboratory frame, will have a detuning $\delta_c\pm$ kv in the rest frame of the atom. For atoms with a velocity v_c, for which the Doppler shift matches the detuning, the atom will see the light from one of the beams to be exactly in resonance with the excited state. Then these velocity class of atoms will be excited in large numbers from the ground state F = 3 to the excited state F′ = 4 and the resultant fluorescence will be a maximum. The repumper which serves to pump atoms from the F = 2 to the F = 3 via the F′ = 3 becomes very effective only when the detuning of the repumper is such that $(\delta_r \pm kv_c)$ becomes zero for the same velocity class of atoms. Thus when $\delta_r = \pm\delta_c$ both the cooling and repumper beams are in resonance, the first with the transition F = 3 to F′ = 4 and the second with the transition F = 2 to F′ = 3. Then within about a few tens of a microsecond of the atom entering the molasses region almost all the atoms are transferred to the state F = 3 and the fluorescence is a maximum. A calculation using this Double resonance model showed such fluorescence peaks with widths of the order of 30 MHz in agreement with experiment. This accounts for a pair of peaks.

The excited level F′ = 2 also can act as an intermediate state in transferring atoms from the ground state F = 2 to the ground state F = 3. This state F′ = 2 is lower in energy from the state F′ = 3 by 63 MHz. This will give rise to a second pair of fluorescence peaks shifted from the first pair by 63 MHz. This accounts for the experimental observations.

This explanation is also supported by experiments on a Rb vapour cell in which the repumper beam is allowed to propagate co- or counter- to the “cooling beam and also by recording simultaneously the absorption of the repumper beam.

When the detuning δ_c becomes very large either towards the red or towards the blue, many more peaks are seen. Their positions are also explained by an extension of the double resonance model.

A four level density matrix calculation was made to see if our analytic model is supported. The four levels are F = 2, F = 3, F′ = 3 (or 2) and F′ = 4. The populations in the states and coherences are calculated for a given detuning δ_c for various values of δ_r. In each case the calculations are averaged over the one dimensional Maxwellian distribution of velocities. These calculations substantiated the occurrence of narrow fluorescence when $\delta_r = \delta_c$ and $\delta_r = \pm(\delta_c + 63$ MHz) when calculations were made for F′ = 3 and F′ = 2 respectively. The density matrix calculations also accounted for a small peak occurring at $\delta_r = \delta_c + 121$ MHz, which our simple analytical calculation of the Double resonance model did not show. The level F′ = 3 will show an AC Stark splitting due to the cooling beam. The positions of the two Autler Townes peaks being shifted by zero and ($\delta_c + 121$) from the unperturbed position of level F′ = 3. When the repumper beam comes into resonance with the second of these peaks we get the additional small peak in fluorescence. The second Autler Townes peak for level F′ = 2 and level F′ = 3 caused by the same cooling beam fall on one another. Thus the density matrix calculations fully confirms the expectations of the Double resonance model.

7.2 Suggestions for further work:

In the loading experiments described in Chapter 3, there were two small peaks humps seen neighbouring the main peaks in fluorescent intensity when the cooling beam was ramped down and up. The origin of these peaks needs to be understood.

It will also be interesting to vary the life-time of the atoms in the MOT by varying the pressure from 1×10^{-9} mbar to 1×10^{-11} mbar to see over what range of life times the curve of the anisotropy parameter vs the ramping period will be valid. At lower pressures the lifetime will increase to large values (approximately 100 s) and so even at a ramping period of about 10 seconds the adiabaticity condition assumed in the present calculations will be invalid.

In the bouncing experiment to determine the temperature we obtained a value for the damping coefficient which was one order of magnitude less than the theoretically expected value. It is suggested in the thesis that the unbalanced intensities of the retroreflected beams push the cloud to one side of the centre where the intensites of the beams are low resulting in a low value for the damping constant. It would be interesting to validate this suggestion on a theoretical model.

In the Double Resonance work, additional peaks were noted when the cooling laser detuning was made large. While nine of the observed peaks could be explained by an extension of the double resonance model, there were a few additional peaks which could not be explained. It will be interesting to make a five state density matrix calculation to see if some of these peaks can be explained in terms of the coherence $\rho_{2'3'}$.