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# Full characterization of the loading of a magneto–optical trap from an alkali metal dispenser

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**Abstract.** We present an experimental study of the dynamics of a magneto–optical trap (MOT) loaded from an alkali dispenser current controlled source. In our experimental vacuum conditions and for a low trapping force MOT the trap loading process critically depends on the dispensers working regime. This allows to completely characterize the dispensers–MOT system and to determine the best loading conditions.

**PACS.** 32.80.Pj Optical cooling of atoms; trapping – 42.50.Vk Mechanical effects of light on atoms, molecules, electrons, and ions

## 1 Introduction

The recent progresses of neutral atoms trapping techniques have been obtained mostly thanks to the implementation of more efficient, compact and reliable laser–cooling systems. Conventionally the best compromise between the need for long trapping lifetimes and large atom number is obtained in double MOT systems [1]. An alternative solution has been the use of an optically slowed atomic beam as a controllable atom source [2]. In such a way it is possible to switch off the atomic beam when the loading procedure is finished, thus maintaining a low background pressure in the vacuum chamber. The same result can be obtained by using solid state alkali metal dispensers in the vacuum chamber. These are composed by a little metal oven containing a mixture of an alkali metal salt with a reducing agent. Heating the dispenser by a controllable current flow causes hot alkali atom emission from the dispenser into the vacuum chamber. The reducing agent is able to sorb almost all chemical active gases that are produced during the reaction, thus preventing them from contaminating the alkali metal vapor. By switching off the dispenser current ($I_d$) the emission can be rapidly stopped. This solution turned out to be the more reliable way to provide alkali atoms to load a MOT [3,4]. As an alternative light–induced atomic desorption (LIAD) [5] have also been used to load a rubidium MOT [6,7].

Different from the standard case of loading from a constant background vapor, the use of a controllable source such as the metal dispenser allows to study the behavior of the MOT with a varying background vapor pressure. In this way we can test the validity of the differential equation regulating the MOT loading process and involving the interaction between trapped atoms and non trapped atoms of the same element, trapped atoms and background vapor, and finally trapped atoms and trapped atoms themselves.

The experimental set-up and the vacuum parameters mostly determine the equation that describes the system. For example, the configuration in which a Rb dispenser source in placed at a very short distance from the center of the MOT and the vacuum pump is working at a very high pumping speed and very low pressure ($<10^{-9}$ mbar) has been studied in [3]. In this case the MOT can be considered directly loaded from the flux coming out from the dispenser, instead of loaded from the background vapor forming after the dispenser is switched on. This allows to simplify the equations and to easily study the system in this limit.

The purpose of this work is to apply to our system a more general equation describing the trapping and losses mechanisms (in the 2 body collisional regime) in a magneto–optical trap, and to test the validity of such a model comparing the theoretical predictions to our experimental results.

The work is organized as follows. In Section 2 we briefly describe our experimental apparatus and characterize the dispenser operation. In Section 3 we discuss the differential equation used to describe our atomic system and we apply it to two different MOT situations to test its validity.

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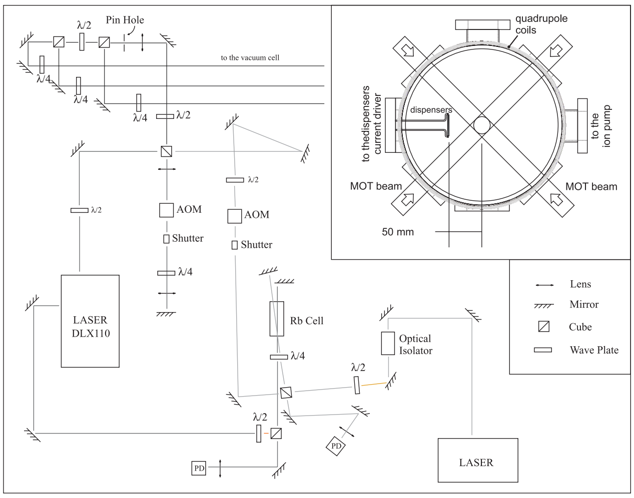


**Fig. 1.** The experimental set-up: two laser diodes provide the cooling and repumping beams. In the inset a schematic of our vacuum chamber is shown. The MOT forms at the center of the chamber, and the dispensers are positioned at a distance of about 5 cm.

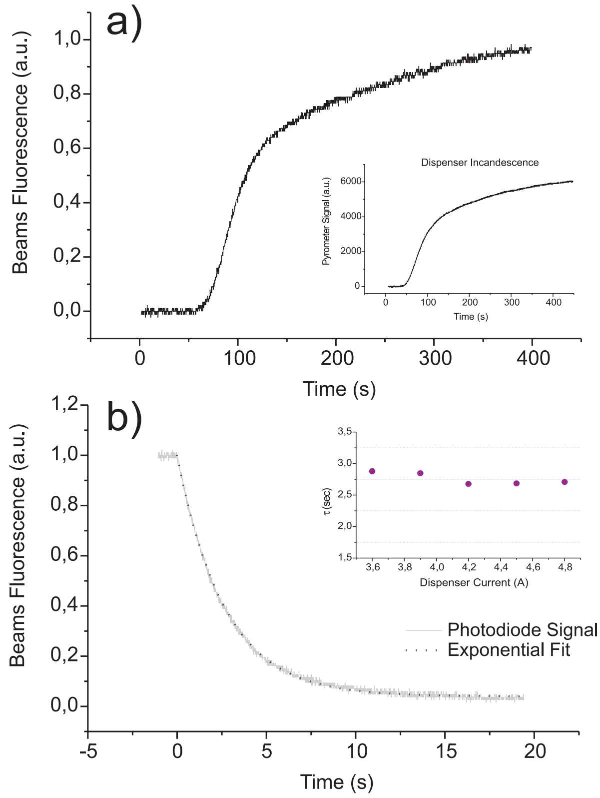


**Fig. 2.** The beams fluorescence acquired by the photodiode is proportional to the density of Rb atoms introduced in the vacuum chamber by the dispenser. (a) A time $t = 0$ s the dispenser current is switched on, but only after a a few seconds the Rb emission begins. The curve reaches a stationary level in tens of seconds. Inset shows the dispenser incandescence monitored on an independent photodiode. (b) The dispenser current in switched off, and the exponential decay of the beam fluorescence starts immediately. The decay time constant $\tau$ is measured for different values of the dispenser current.

## 2 Experimental apparatus

Our $^{87}$Rb MOT system is composed by a cylindrical chamber with two main CF210 windows and 8 little CF35 secondary apertures around the perimeter. The axis of this cylinder coincides with the axis of the external quadrupole coils. One of the lateral apertures is used to connect the chamber with a 20 l/s ion pump, continuously operating at $p \approx 10^{-8}$ mbar, a second one hosts an electric current feedthrough. Three Rb dispensers are crimped to the pins of this feedtrough and can be independently driven by external current supplies (see inset of Fig. 1). The working principle of these dispenser is described elsewhere [3]. After a careful degassing procedure, carried out at sequential steps of increasing operating current, our dispensers are used in continuous mode, to provide the formation of the background Rb vapor necessary to load the magneto–optical trap.

In Figure 1 we show the experimental layout: our laser apparatus is composed by a Toptica DLX110 laser providing a beam detuned by 15 MHz from the $5S_{1/2}(F = 2) \rightarrow 5P_{3/2}(F' = 3)$ cooling transition, and a home made extended cavity diode laser in resonance with the $5S_{1/2}(F = 1) \rightarrow 5P_{3/2}(F' = 2)$ transition, used to avoid the population depletion of the atomic level $5S_{1/2}(F = 2)$. Both lasers are frequency–stabilized by a an electronic feed–back loop to the first derivative of a saturation absorption spectrum. The MOT is realized by 3 pairs of counterpropagating beams. Each beam is collimated with a diameter of about 2 cm and a central intensity of about 8 mW/cm$^2$ for the cooling laser.

A pair of coils in the anti–Helmoltz configuration provides the necessary quadrupole field for the MOT. The coils radius is 13.5 cm and the produced gradient is around 8 Gauss/cm in the strong direction.

A lens and an amplified photodiode are positioned immediately out of the vacuum chamber, 13 cm away from the laser beams crossing region. We use high amplification (∼4 mV/nW) in order to monitor the fluorescence of the laser beams, even with a very small quantity of Rb atoms in the chamber. As the region seen by the photodiode is the same in which the cold atoms cloud forms when switching on the quadrupole coils, the same photodiode in used to measure the trapped atom fluorescence in the presence of the MOT.

In Figure 2a is shown the laser beams fluorescence building up in the vacuum chamber after switching on the Rb dispenser at time $t = 0$. The behavior is reproducible but not completely understood. It seems to depend in a critical way from the slow heating of the whole dispenser, as we can conclude after monitoring with a second photodiode the incandescence light emitted by the same dispenser (see inset).

The switching off behaviour is much more comprehensible (Fig. 2b): Rb atoms emission is very likely to stop immediately after switching off the dispenser current, and the fluorescence curve shows a pure exponential decay, due to the effect of the pump and the absorption by the cell walls. From exponential fits performed on many curves acquired for different values of $I_d$ (from 3.6 A to 4.8 A) we estimated the time constant $\tau$ value. We can thus write the simple equation that regulates the behavior of the Rb atoms density $n_c(t)$ in the vacuum chamber after switching off the dispensers:

$$n_c(t) = n_{cs}\, e^{-\frac{t}{\tau}}. \qquad (1)$$

where $n_{cs}$ is the stationary density that depends on the dispenser current value. The time constant $\tau$ represents the pumping rate of our system and is almost independent of $I_d$. More precisely, for higher currents $\tau$ slightly decreases, and a long-time tail in the fluorescence decay process appears. We will take it into account for a best description of our system in Section 3.

## 3 MOT operation

Starting from this characterization we want now to discuss a simple model to describe the loading process of the magneto–optical trap. We first note that the trapping rate will depend on the fraction of slower thermal Rb atoms in the chamber, and thus will be proportional to the density $n_c(t)$. At the same time the loss rate will depend on two factors: the fraction of faster Rb atoms in the cell (proportional to $n_c(t)$ too) and the amount of all background atoms that have not been pumped out by the ion pump. This last contribution can be considered constant and depending principally on the pump speed and the general vacuum properties of the system.

We can thus write the differential equation regulating the number of cold trapped atoms $N(t)$ in the MOT:

$$\frac{dN}{dt} = +\alpha n_c(t) - (\beta n_c(t) + \gamma)N(t). \qquad (2)$$

The first term is positive, thus describes the trap loading, with $\alpha$ a coefficient proportional to the trapping cross section. The first term in the parenthesis takes into account trap losses due to collisions between trapped and untrapped Rb atoms. The last term is responsible for losses due to collision between trapped atoms and the background gas (not considering thermal Rb atoms). This equation will now be used to describe two different regimes regarding the loading and the unloading of the MOT.

The procedure is the following. First the dispenser current is switched on at a chosen current value, and we wait the time (typically 500 s) necessary to reach the equilibrium value $n_{cs}$ for the Rb atoms density $n_c(t)$ in the cell. Then we switch on the quadrupole coils current and observe with the photodiode the loading signal of the MOT. When the MOT is loaded, i.e. when the number of trapped atoms stops growing, we switch off the dispenser current, and observe the time evolution of the fluorescence of the MOT during the depletion of the chamber. Since in our system the two loss terms are comparable, we are able to test the complete features of the model equation without simplifying it with some approximations.

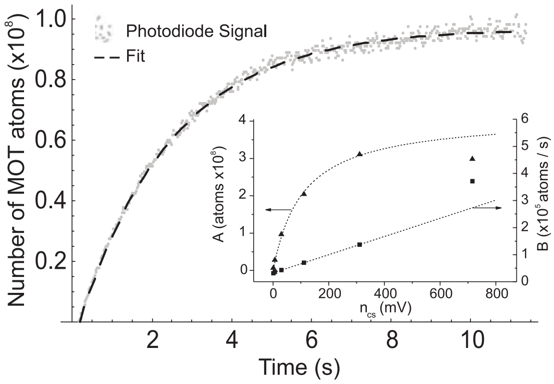


**Fig. 3.** Figure shows the MOT loading curve from a background Rb vapor pressure corresponding to $I_d = 3.9$ A. At time $t = 0$ s the quadrupole current is switched on and atoms start immediately to be trapped into the laser beams crossing region. The loading follows a pure exponential law, with the loading rate $B$ increasing linearly with the dispenser current, as is shown in the inset (see inset). The steady state number of trapped atoms $A$ also increases with dispenser current, and tends to the asymptotic value $\alpha/\beta$. At large current values both behaviors deviate from the expected curves.

In Figure 3 we show the MOT loading curve for $I_d = 3.9$ A. This phase is well described by equation (2) with $n_c(t) = n_{cs}$:

$$\frac{dN}{dt} = +\alpha n_{cs} - (\beta n_{cs} + \gamma)N(t). \qquad (3)$$

This equation can be easily integrated and gives the exponential growth function:

$$N(t) = A(1 - e^{-Bt}), \qquad (4)$$

with $A = \alpha n_{cs}/(\beta n_{cs} + \gamma)$ and $B = \beta n_{cs} + \gamma$, respectively the stationary number of trapped atoms in the MOT and the MOT loading rate. From the fit of our loading curves for different dispenser currents we obtain the values of $A$ and $B$ as functions of $n_{cs}$, as plotted in the inset of Figure 3. From these points we can then extract the parameters $\alpha, \beta$ and $\gamma$. As we suggested above (see Sect. 2), we note an evident disagreement with the expected behavior for high $n_{cs}$ values, as confirmed by the last point of each curve. This means that in the high dispenser current regime the differential equation (Eq. (2)) starts to be inadequate. There can be various possible explanations for this deviation; with our parameters the importance of light–assisted collisions between trapped atoms could introduce a new loss channel. On the other hand a larger trapped atomic cloud is also going to cast a shadow in the trapping beams thus reducing the loading efficiency of the MOT. Both these effects could explain the decrease of trapped atoms for very high dispenser current values.

We are not interested in determining absolute values for the above parameters as much as in verifying the validity of equation (2). To do this we study a second dynamical situation: the MOT slow decay after switching off the dispenser current. The curve is shown in Figure 4.

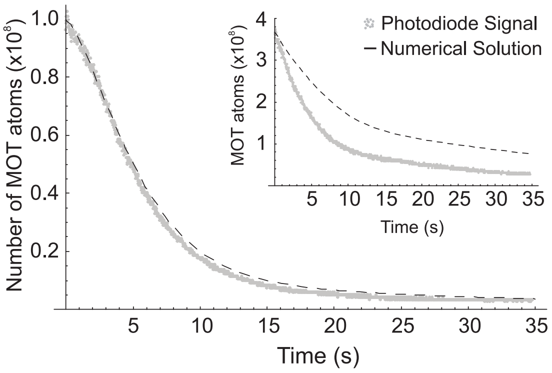


**Fig. 4.** The figure shows the decay of MOT population after dispenser current being switched off at $t = 0$. The starting steady state is the final state of Figure 3, corresponding to $I_d = 3.9$ A. In the inset is shown the same trace for $I_d = 4.8$ A; the according with the numerical solution is not good. Indeed, as the model does not take into account the new loss channels, the calculated number of trapped atoms is larger than the measured one.

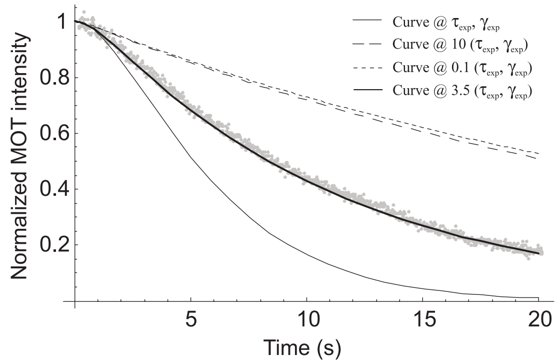


**Fig. 5.** The MOT decay behavior depends critically on the $\gamma$ parameter. The thin solid line reproduces the numerical solutions for our experimental curve ($\gamma = 0.32 \pm 0.02$ s$^{-1}$). Dashed and dotted lines simulates respectively the same curve for $\gamma = 3.2$ s$^{-1}$ and $\gamma = 0.032$ s$^{-1}$. The pumping rate $1/\tau$ of equation (1) changes proportionally in the two cases. The graph shows also an experimental curve recorded with a higher pumping speed, and the numerical solution for this case (the thick solid line).

To describe this evolution we apply equation (2) again, but this time the $n_c(t)$ parameter follows its exponential decay (see Eq. (1)) starting from its steady value $n_{cs}$. Equation (2) becomes:

$$\frac{dN}{dt} = +\alpha n_c e^{-\frac{t}{\tau}} - (\beta n_c e^{-\frac{t}{\tau}} + \gamma)N(t). \qquad (5)$$

In order to test our fitted parameters and the validity of equation (5) we perform a numerical integration using for $\tau, \alpha, \beta$ and $\gamma$ their previously fitted values. The agreement between such obtained numerical solution and the experimental curve is shown in the same Figure 4, and can be considered very good. Our fitted value for $\gamma$ is $\sim$0.3 s$^{-1}$ and strictly depends on the vacuum system characteristics, since it is related with the spurious background vapor pressure and it is proportional to the pumping speed.

The same procedure has been followed for different values of $I_d$, to test the validity of equation (2) in the whole range of variation of the dispenser current. As already observed, for higher values of $I_d$ the numerical solution does not reproduce the experimental curve as well as in the lower range of $I_d$, as the inset of Figure 4 shows clearly.

When the MOT decaying law in equation (2) is dominated either by $\gamma$ or by $n_{cs}$, in both cases the expected decay is slower and exponential–like. Figure 5 shows the simulations for these two cases. One of these behaviors (for smaller $\gamma$) has been observed in a similar experiment [3]: after switching off the dispenser, a very good vacuum condition is fastly recovered inside the cell and the MOT lives longer and decays exponentially. Such condition has also been directly verified in our laboratory by substituting the 20 l/s ion pump with a 40 l/s model. The thick line in the graph of Figure 5, as well as the corresponding experimental data, shows that an improvement of the pumping speed produces longer MOT lifetimes. The second limit (larger $\gamma$) is easily understandable: background vapor disturbs the MOT so much that its lifetime falls to zero. MOT population then depends directly on the Rb vapor pressure in the cell, which after switching off the dispensers decays exponentially (see Eq. (1)). In both cases we obtain an exponential decay law for the MOT population, different from what we have observed in our experiment.

## 4 Conclusions

In summary, we explained with a simple model the effects of a controllable Rb vapor pressure inside the cell on the loading rate of our magneto–optical trap and on its decay law after switching off the dispenser current. This model allowed to confirm the dispenser current value for a best load, and to understand the importance of high pumping speed necessary to fastly recover high vacuum situation after the current pulse, in order to obtain longer MOT lives.

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