# A fast, deterministic source of single Cr atoms

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**Abstract:** We produce single Cr atoms on demand by feedback control of loading and loss from a magneto-optical trap. We observe single-atom occupation probabilities of over 98% and efficient ejection at rates up to 10 Hz.

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Recent advances in diverse fields such as nanotechnology, quantum information processing, and molecular spectroscopy have shown that significant technological and scientific benefits can be obtained by exerting absolute control over individual atoms and molecules. Such control offers, for example, the possibility of fabricating new nanoscale devices, manipulating the quantum phase and entanglement of single-atom qubits, and investigating molecular interactions with unprecedented detail.

A key step along the way to absolute atomic control is the development of a way to reliably produce single atoms "on demand" – that is, exactly when and where they are desired. Such deterministic production is hampered, however, by the fact that in nature atoms are almost always produced in random, thermal ensembles. To demonstrate a truly deterministic source, a means of suppressing the stochasticity associated with these ensembles must be implemented.

We have shown that feedback control of loading and loss in a magneto-optical trap (MOT) can be used to effectively suppress the random nature of the loading and loss processes to the point where single-atom occupancy can be guaranteed with over 98% probability. Furthermore, we have shown that single atoms can be ejected from the MOT at rates up to 10 Hz without significantly reducing the probability of obtaining a single atom.

Our demonstration makes use of a Cr MOT[1] with high-efficiency fluorescence detection. In the MOT, Cr atoms are cooled and trapped using 425.55 nm laser light tuned just below the $^7S_3$ – $^7P_4^o$ atomic resonance. Fluorescence photons from the trapped atoms are collected with large-numerical-aperture optics and counted with a single-photon-counting photomultiplier. Typical detected count rates are several thousand $s^{-1}$ for each atom in the trap, with a background rate of a few hundred $s^{-1}$. These signal levels allow us to easily discriminate between zero, one, two, or more atoms in the trap within a measurement time of a few milliseconds. Thus we can use the fluorescence signal to close a feedback loop on the number of atoms in the trap: loading is turned on only if the fluorescence falls below the single atom level, and the trap is dumped if it goes above the single atom level.

Figure 1 shows an example of the performance of our feedback-controlled MOT. In Figure 1(a) we show detected fluorescence as a function of time. When feedback is off, the fluorescence exhibits clear steps as the stochastic loading and loss events result in a random walk in trap occupation number. When feedback is on, however, the fluorescence remains clamped at the single-atom level with only occasional drops to the zero-atom level followed by immediate reloading of single atoms. Figures 1(b) and 1(c) show histograms of the data in Fig. 1 (a). As expected, the feedback-off histogram resembles a Poisson distribution in atom number. In sharp contrast, the feedback-on histogram contains only a single peak, under which 98% of the measurements lie.

We have conducted studies of the behavior of our feedback-controlled MOT as a function of load rate and MOT lifetime, and have also investigated how rapidly atoms can be ejected from the trap while still maintaining a high probability of ejecting a single atom. This latter study showed that with the present configuration, ejection rates up to 10 Hz are possible while maintaining a 90% single atom probability. We have also modeled the behavior with Monte Carlo simulations, which reproduced the experimental results faithfully. These calculations predict that with complete optimization of the feedback, ejection rates of 400 Hz or higher are possible with 99% single atom probability.

1. C. C. Bradley, J. J. McClelland, W. R. Anderson, and R. J. Celotta, "Magneto-Optical Trapping of Chromium Atoms," Phys. Rev.A **61,** 053407 (1999).

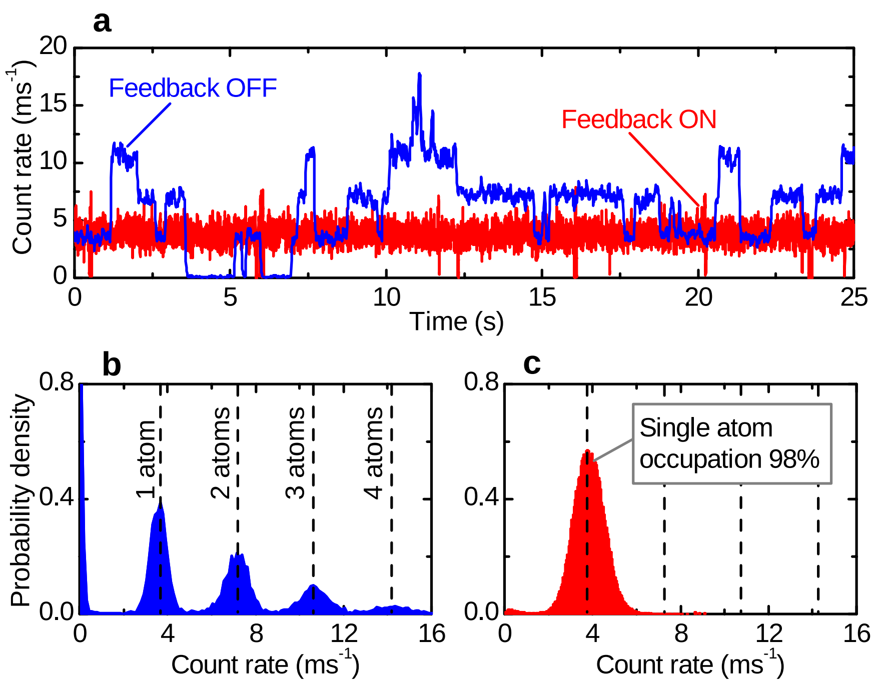


**Figure 1.** Fluorescence from a feedback-controlled single-atom magneto-optical trap. (a) Time series of feedback-off data showing random single atoms jumps, and feedback-on data showing constant, single-atom fluorescence. (b) Histogram of feedback-off data in 1(a). (c) Histogram of feedback-on data in 1(a). Note that the feedback-off data were collected with a much smaller load rate and longer detection time constant than feedback-on data.