Stopping Atoms with Diode Lasers*

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We have succeeded in stopping a beam of cesium atoms using frequency-chirped diode lasers. We scan over the Doppler profile of a 100°C thermal cesium beam to bring more than 10^{10} atoms/s to a temperature of 1°K, a limit imposed by the 30 MHz linewidth of our free-running lasers. These results are preliminary, and we expect that further work will provide substantial improvements in our final temperature and density. This is an extremely simple and inexpensive way to produce cold atoms.

Two techniques have been devised for using laser light to stop atoms. The NBS group in Gaithersburg [1] used a single frequency c.w. dye laser combined with a large tapered solenoid to achieve the necessary condition that the atomic transition and the laser frequency stay in resonance as the atoms slow. Hall and co-workers [2] used an alternative method, in which the frequency of the dye laser was swept (chirped) using state-of-the-art electro-optic modulators. While both of these approaches have been shown to work well, they involve large investments of money and equipment. We have found that the frequency chirp approach can be implemented using inexpensive diode lasers and simple electronics. The frequency of a diode laser can be smoothly and rapidly varied over many GHz simply by varying the injection current. Thus, by using an appropriate current ramp, we have stopped a beam of cesium atoms.

A schematic of the apparatus is shown in Fig. 1. Cesium atoms in a 100°C oven effuse from a 0.5 mm hole and are collimated to 8 mrad. At this oven temperature, the beam has a mean velocity of 2.7×10^4 cm/s, an intensity of 3×10^{11}/s and a Doppler FWHM of 400 MHz. The atoms are stopped by bombarding them with resonant counterpropagating $6s$-$6p_{3/2}$ photons at 8521 Å. Each atom-photon collision slows the atom by 0.35 cm/s. Thus, it takes approximately 76,000 photons to bring an atom to a halt. For an excited state lifetime of 30 ns, this process takes 5 ms and requires about 70 cm. Because cesium has two hyperfine ground states separated by 9192 MHz, two lasers are used. The primary cooling is done by one laser tuned to the $6s(F=4)$-$6p_{3/2}(F=5)$ transition. For circularly polarized light, this transition is a good approximation to a leakage-free two-level system. The other laser, tuned to the $6s(F=3)$-$6p_{3/2}$ transition, insures that the F=3 ground state is depleted. The F=4 laser has about 5 mW of power while the F=3 laser has 0.3 mW. Both lasers have a free-running linewidth of 30 MHz and are focused to match the atomic beam. Each injection current ramp sweeps the frequencies of the two lasers 1 GHz in 15 ms. The last 10 ms are spent sweeping the full Doppler profile of

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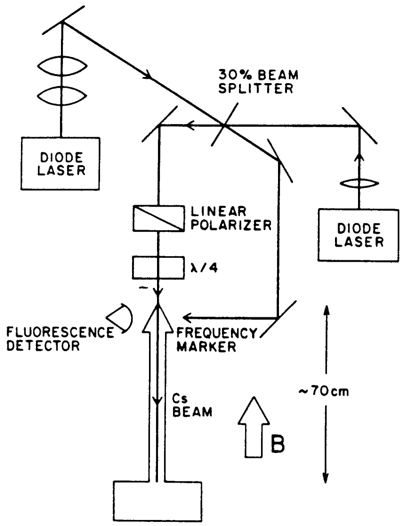

Fig. 1. Schematic of apparatus.

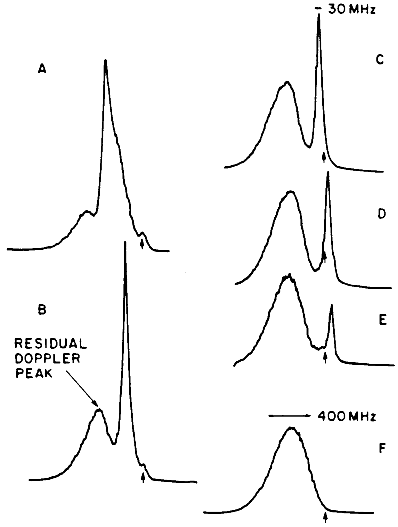

Fig. 2. Slowed atom scans. Curves A-E show various amounts of cooling. Curve F is the Doppler profile with no cooling. The arrows mark zero velocity.

the cesium beam. The end of the chirp may be adjusted to bring the atoms to any desired speed.

The same lasers are used to monitor the resulting velocity distribution. After each chirp, a portion of a much slower linear ramp (corresponding to a frequency change of 1.5 GHz in 6 s) is switched into the laser injection currents. At the same time, a detector is gated on to probe the slow atom fluorescence. This gate lasts for 250 μs, after which a new chirp is started. To give a zero velocity marker, a small fraction of the laser is sent in perpendicular to the atomic beam.

The results are shown in Fig. 2. The small bumps on A and B are the frequency marker peaks. As the figure shows, by adjusting the end of the frequency sweep to different points on the Doppler profile, we are able to slow, stop, or even reverse a portion of the atomic beam. The residual Doppler peak, which grows as more cooling is done, is due to uncooled atoms at the probe region. The linewidth of our lasers currently limits us to a 1°K temperature in the resulting stopped distribution.

References

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2. W. Ertmer, R. Blatt, J.L. Hall and M. Zhu, Phys. Rev. Lett. 54 (1985) 996.