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Thursday MORNING
24 May 1990 QTHH
NORTHWEST HALL

10:30 AM Laser Cooling: 1
Carl E. Wieman, *Joint Institute for Laboratory Astrophysics, Presider*

10:30 AM Invited paper
QTHH1 Advances in laser cooling of atoms

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As soon as the Doppler cooling limit was broken in 3-D optical molasses,[1-3] it was realized that polarization gradient cooling[4,5] would yield temperatures approaching the one-photon recoil energy. The corresponding temperature

$$\frac{\hbar^2 k^2}{m k_B}$$

is only 0.2 μK for cesium atoms laser cooled on the D_2 line. Here we present our attempts to approach this limit.

Using a time-of-flight (TOF) technique (the atoms fall in the earth gravity field), we get from the width of the TOF peak the initial velocity distribution in the molasses (Fig. 1). At present, our lowest measured temperature is

$$T = 5\ \mu\text{K}^{+2\ \mu\text{K}}_{-3\ \mu\text{K}}.$$

To our knowledge, this is the coldest gas ever observed.

In Fig. 2, we present the variation of the molasses temperature vs the parameter α = laser intensity/laser detuning. This variation is linear over a wide range of α, in good agreement with theoretical predictions.[4] Let us mention that we have been able to observe molasses for detunings as large as twenty-five natural widths.

A detailed comparison with the theory as well as possible uses for these ultracold cesium atoms are presented.

1. P. Lett, R. Watts, C. Westbrook, W. D. Phillips, P. Gould, and H. Metcalf, Phys. Rev. Lett. 61, 169 (1988).
2. J. Dalibard *et al.*, in *Proceedings, Eleventh Conference on Atomic Physics*, S. Haroche, J. C. Gay, and G. Grynberg, Eds. (World Scientific, Teaneck, NJ, 1989).
3. S. Chu, D. S. Weiss, Y. Shevy, and P. J. Ungar, in *Proceedings, Eleventh Conference on Atomic Physics*, S. Haroche, J. C. Gay, and G. Grynberg, Eds. (World Scientific, Teaneck, NJ, 1989).
4. J. Dalibard and C. Cohen-Tannoudji, J. Opt. Soc. Am. B 6, 2023 (1989).
5. P. J. Ungar, D. S. Weiss, E. Riis, and S. Chu, J. Opt. Soc. Am. B 6, 2058 (1989).

11:00 AM
QTHH2 Direct observation of the Doppleron resonances in the force on a neutral atom in an optical standing wave

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Theoretical extensions of Lamb's treatment[1] of a two-level atom in an intense optical standing wave revealed a series of multiphoton processes which have been named Dopplerons.[2] The effects of Doppleron resonances have been observed on the internal coordinates of CH_3F atoms in a gas cell.[3]

Physically, an n-photon Doppleron can be interpreted as the absorption of n photons from one traveling wave component of the standing wave and the stimulated emission of $(n-1)$ photons into the other counterpropagating traveling wave component. The net average change in momentum of the atom is $(2n-1)\hbar k$, where k is the magnitude of the wave vector of each traveling wave. In this picture the Doppleron resonance occurs for a detuning $\Delta = (2n-1)kv$, where v is the velocity of the atom. The Dopplerons can thereby give rise to a series of sharp resonance peaks in the force as a function of velocity for an atom in the standing wave field. An important conclusion is that the resulting acceleration (and hence force) can be orders of magnitude larger than purely spontaneous forces because of the large momentum change of the multiphoton process.

In our experiments we study the effect of Doppleron resonances on the velocity of sodium atoms in a nearly resonant optical standing wave. We observe a number of peaks in the velocity distribution which we attribute to slowing and cooling due to the Doppleron resonances. These results constitute the first direct observation of the effect of Dopplerons on the external coordinates of an atom. As predicted by a more rigorous continued fraction analysis, we observe that the position of these resonances does not occur at exactly $\Delta = nkv$, possibly due to the Stark shifts associated with the two traveling waves.[4]

For a more detailed comparison between the experimental data and theory, we performed numerical simulations based on a continued fraction[5] expansion of the force. Our data are in good agreement with numerical results. The fits of the velocity distribution correspond to a peak acceleration, which is a factor of 100 larger than the peak spontaneous acceleration of $\sim 10^6$ m/s^2.

These experiments were performed using a standing wave laser field detuned by an amount Δ below the $3^2S_{1/2} \rightarrow 3^2P_{3/2}$ sodium transition (5890 Å). We present data for Δ ranging from −1.0 to −2.7 GHz. The standing wave intensity was 200 mW in a beam waist of $\sim$200 μm. Sodium atoms were loaded into the standing wave from a thermal sodium source at a temperature of $\sim$200°C.

1. W. E. Lamb, Jr., Phys. Rev. A 134, 1429 (1964).
2. E. Kyrola and S. Stenholm, Opt. Commun. 22, 123 (1977).
3. J. Reid and T. Oka, Phys. Rev. Lett. 38, 67 (1977).
4. P. R. Berman and J. Ziegler, Phys. Rev. A 15, 2042 (1977).
5. V. G. Minogin and O. T. Serimaa, Opt. Commun. 30, 373 (1979).

11:15 AM
QTHH3 Direct measurement of atomic velocity distribution in optical molasses

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Since the first optical molasses[1] came out, the temperature of the atomic vapor in the optical molasses, which was determined by measuring the time of flight (TOF), was found to be well below the Doppler cooling limit,[2] which is based on the assumption that a single frequency laser interacts with the two-energy-level atoms. The new theory[3] proposes that this lower temperature is due to the nonadiabatic motion of the atoms with Zeeman sublevels in the optical field with polarization gradients. A bimodal speed distribution in optical molasses was also observed.[4]

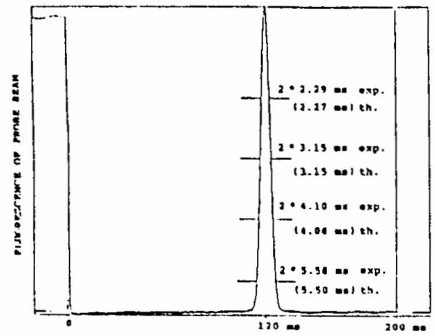
Using 285-nm UV light, which connects the 3^2S ground state to the 5^2P state in the sodium atom, we can measure directly the velocity distribution inside the optical molasses without the limitations of the TOF method. The resolution of our measurement is 13 cm/s, which is limited by the 450-kHz natural linewidth of the 5^2P state.

In our experimental setup, a JILA ring dye laser is used for both cooling and the optical molasses. The frequency of the dye laser is locked on an iodine line with a frequency offset supplied by an AOM so that the detuning of the optical molasses can be changed readily. The UV source for velocity probing includes a coherent 699 dye laser and nonlinear crystal for SHG. The frequency of the dye laser is locked on a reference cavity using the external frequency stabilizer to reduce the linewidth to 1 Hz.[5] A tunable sideband frequency generated by a traveling wave broadband EOM is used with a FM saturation spectrometer to lock the resonance frequency of the reference cavity to a nearby transition of iodine molecules with controllable frequency offset. This locking scheme provides both long term frequency stability and frequency tunability. An ADA crystal inside a buildup cavity for the fundamental frequency gives more than 10 mW of UV light at 285 nm.

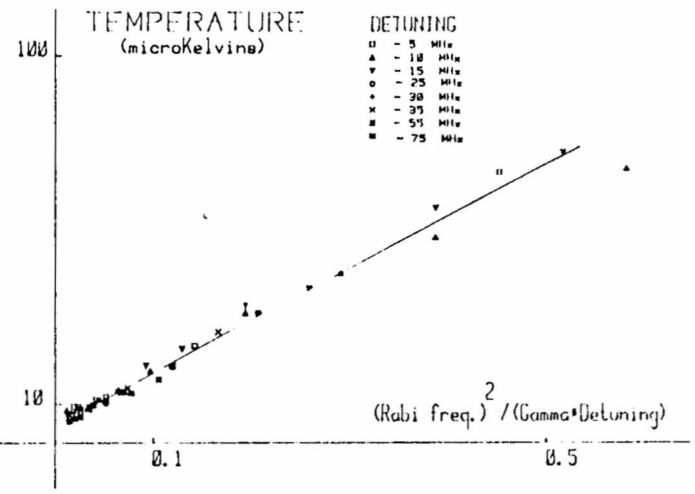
The laser cooled sodium atoms, which are prepared by the frequency chirping method, drift into the optical molasses region with a final velocity of $\sim$40 m/s. These slow atoms are caught by the optical molasses and decelerated further there. After loading the molasses the cooling beam is turned off first. The beams for molasses are turned off with a preset time delay. Then a UV AOM turns on the UV probing beam for the measurement. To reduce the background scattering light, the photomultiplier tube counts the fluorescence photons at 616 nm, which originate from the 5^2S to 3^2P decay channel.

A set of preliminary data is shown in Fig. 1, which involves the transition from $F = 2$ in the ground state $3^2S_{1/2}$ to the excited state $5^2P_{1/2}$. The two peaks in the figure are due to the hyperfine structure in the excited state. The systematic measurement is in process, and the latest results are reported.

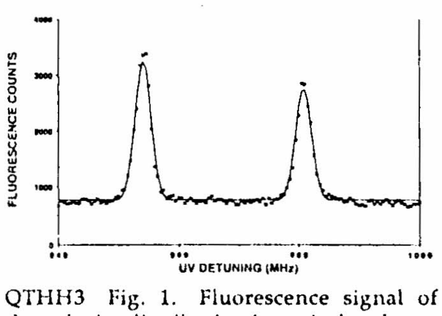
1. S. Chu, L. Hollberg, J. Bjorkholm, A. Cable, and A. Ashkin, Phys. Rev. Lett. 55, 48 (1985).



QTHH1 Fig. 1. Ultracold cesium atoms in optical molasses. Time-of-flight fluorescence signal of cesium atoms falling off from optical molasses. The molasses laser beams are 8.2 mm in diameter. The laser detuning is -3Γ, and the laser intensity is 0.5 mW/cm^2 in each arm. At $t = 0$, all laser beams are turned off except a horizontal probe beam located 70 mm below the molasses region. The probe beam is apertured to 2 mm in height $\times$ 6 mm in width. The mean arrival time is 120 ms. Assuming an initial distribution of atoms spatially uniform in the molasses and comparing the width of the TOF peak at various heights (0.1,0.3,0.5,0.7) with a theoretical TOF spectrum (numbers in parentheses) give the average quadratic velocity v_{rms} in the molasses. $v_{rms} = 1.8$ cm/s and corresponds to a temperature $T = (1/k_B)mv_{rms}^2 = 5\ \mu K^{+2\mu K}_{-3\mu K}$.



QTHH1 Fig. 2. Molasses temperature vs parameter α (square of the Rabi frequency divided by the laser detuning). The Rabi frequency is proportional to the square root of the laser power and is equal to the natural width $\Gamma(2\pi \times 5.3$ MHz) for a laser intensity of 2.25 mW/cm^2 (Clebsche-Gordan coefficient of 1). The laser intensity varies between 0 and 2.75 mW/cm^2 in each arm. The laser detuning varies between $-\Gamma$ and -14Γ. The temperature is deduced from the TOF peak full width at half-maximum. Contrary to Fig. 1, we take here for simplicity a δ-function for both the initial position distribution of atoms in the molasses and the probe beam height. At very small temperatures ($T \lesssim 10\ \mu$K), the position distribution becomes non-negligible in the TOF peak width, and consequently the plotted temperature is an upper limit to the actual temperature.



QTHH3 Fig. 1. Fluorescence signal of the velocity distribution in optical molasses with UV probing. The measured 2.9-MHz UV linewidth (FWHM) shows that the rms velocity is 32 cm/s. This specific set of data was taken when the detuning of the optical molasses was -25 MHz, and the intensity in each beam of the optical molasses was $\sim$10 mW/cm^2.

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