Experiments with ultracold strontium atoms

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All-optical creation of quantum degenerate atomic gases has been one of the long-standing targets in laser cooling. We report on a novel approach towards this direction based on a narrow-line laser cooling for strontium atoms. By employing two transitions with markedly different dipole moments, *i.e.*, the allowed $^1S_0$-$^1P_1$ (λ = 461 nm, $\gamma = 2\pi$ x 32 MHz) and the spin-forbidden $^1S_0$-$^3P_1$ (λ = 689 nm, $\gamma = 2\pi$ x 7.6 kHz) transition, thermal strontium atoms were Doppler-cooled down to 400 nK, or the photon recoil temperature, in a magneto-optical trap (MOT). The use of a narrow spin-forbidden transition successfully reduced the radiation trapping effects at a high atom density over 10^{12}/cm^3, thus enabling us to attain the phase space density of 10^{-2} [1] in a MOT.

The cold atoms were then transferred into a far off-resonant optical dipole trap (FORT), in which the FORT laser wavelength was tuned to $\lambda \sim$ 800 nm to produce the same amount of light shifts in $^1S_0$ and $^3P_1$, as depicted by dotted lines in Fig. 1. Since the atomic resonance frequency is spatially unchanged in this FORT potential, Doppler-cooling can be applied simultaneously. Because of the efficient atom transfer into the FORT assisted by the Doppler-cooling, we achieved a hitherto high phase space density of 10^{-1} for a crossed-FORT configuration [2]. We have shown that the phase space density was severely limited by light-assisted inelastic collisions occurring in this optical cooling process.

To further increase the density, we are currently employing an evaporative cooling in a FORT with 1D-lattice configuration formed by a vertical standing wave. By reducing the FORT depth in a typical time constant of 0.5 s, we observed an increase in the phase space density as well as the significant drop in the atom temperature. Using time of flight technique, we measured highly anisotropic temperatures, 100 nK and 270 nK for the radial and axial direction respectively, indicating the vibrational ground-state occupation in the axial direction. In the talk, we will mention our experiments on cold collisions in the $^1S_0$ state, light assisted collisions in $^1S_0$-$^3P_1$ and energy pooling collisions in the $^3P_2$ state.

[1] H. Katori, T. Ido, Y. Isoya, and M. K-Gonokami, Phys. Rev. Lett. **82**, 1116 (1999).
[2] T. Ido, and Y. Isoya, and H. Katori, Phys. Rev. A **61** 061403(R).

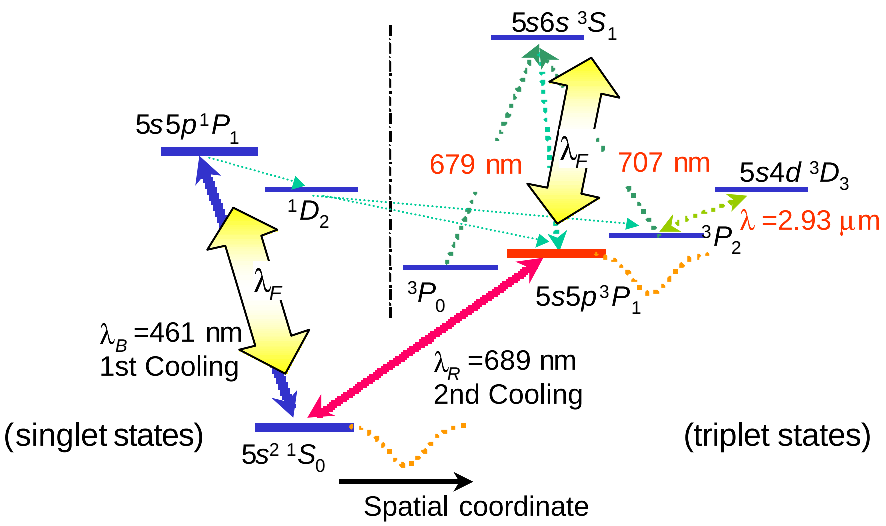

Figure 1: The energy levels of strontium atom.