Invited talk

Laser cooling of positronium with a chirped laser pulse train

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Positronium is a bound pair of an electron and its antiparticle, a positron. It is the simplest atom, consisting of only two elementary particles, and provides an important physical system for the rigorous verification of quantum electrodynamics. The stringent test of quantum electrodynamics may provide an important foundation for the recent trend of research that explores physics beyond the Standard Model through precision spectroscopy of atoms and molecules. It may also be useful in investigations of matter-antimatter asymmetry and investigations of gravity acting on antimatter. A typical experimental measurement is for the 1S-2S transition frequency[1] with a natural width of 1.26 MHz.

Uncertainties regarding the 1S–2S transition frequency of positronium are approximately five times worse experimentally than theoretically at this time. The fundamental causes of the difficulty in improving the experimental uncertainties are the large velocity due to the lightweight nature of positronium, the lack of statistics due to the insufficient number of atoms, and the short self-decay lifetime. Therefore, the realization of rapid cooling of positronium is essentially critical in precision spectroscopy. Heat exchange with low-temperature materials is inefficient, and the realization of laser cooling has been long awaited since the theoretical study in 1988[2].

Laser cooling of positronium using the 1S–2P transition at a wavelength of 243 nm produces very large recoil velocities in a single cooling cycle, but the recoil-derived Doppler shift is on the order of several GHz. A special ultraviolet pulsed light source capable of maintaining the cooling cycle and accommodating a wide range of velocity distributions was needed. In this talk, we will present details of our demonstration of one-dimensional laser cooling of positronium[3]. The cooling is based on a pulse train that rapidly changes the central optical frequency during the lifetime of the positronium[4,5]: a portion of the dilute positronium gas at 600 K was cooled to approximately 1 K in 100 ns. This result marks the first laser cooling of positronium. It was demonstrated at the same time that the AE$\bar{\text{g}}$IS collaboration[6], which aims for highly efficient production of antihydrogen, performed positronium cooling with a broadband pulsed laser pulse. We will also discuss our ongoing extension to three-dimensional laser cooling and absolute measurement of 1S–2S transition frequency for slow positronium. We are also investigating highly efficient cooling using stimulated emission, which will also be the subject of this talk.

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