論文の内容の要旨

Direct Measurement of the Hyperfine Transition of Positronium using High Power Sub-THz Radiation

(高強度サブテラヘルツ波を用いたポジトロニウムにおける超微細構造間遷移の直接測定)

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Positronium (Ps), the bound state of an electron and a positron, is a purely leptonic system and is a good target to study Quantum Electrodynamics (QED). The spin triplet state of Ps (ortho-positronium, o-Ps) has long lifetime of about 142 ns and mainly decays into three γ rays. On the other hand, the spin singlet state of Ps (para-positronium, p-Ps) mainly decays into two γ rays promptly. The energy level of the ground state o-Ps is higher than that of the ground state p-Ps because of the spin-spin interaction of the electron and the positron. The energy difference is called the hyperfine structure of the ground state of Ps (Ps-HFS). The Ps-HFS is significantly large about 203 GHz.

The precise measurement of the Ps-HFS gives the direct information on the bound state QED, but there is a large discrepancy (3.9 σ, 15 ppm) between the measured and the theoretical value. All previous measurements employed static magnetic field and the Ps-HFS has been measured indirectly using Zeeman effect, and the uniformity of the static magnetic field is the most significant systematic uncertainty of the previous measurements. Therefore, it is very important to measure the Ps-HFS again with a method totally different from the previous experiment.

The direct measurement using sub-THz radiation is free from systematic uncertainty of the static magnetic field, but it has never performed because it was impossible to prepare enough high power sub-THz radiation to cause the observable amount of the stimulated emission of the Ps-HFS. Therefore, even the hyperfine transition of the Ps-HFS itself has not yet been observed. However, the recent development of the gyrotron, which is a novel high power radiation source for sub-THz to THz region changes the situation. We developed a new optical system to accumulate sub-THz radiation of 11 kW (peak intensity of $I = 8.3 \times 10^7$ W/m^2, peak energy density of $\epsilon = 0.28\ J/m^3$) in a Fabry-Pérot resonant cavity and cause the hyperfine transition of the ground state of Ps. We have observed clear transition signals for the first time at the 5.4 σ level after 4.3 days of ON resonance data taking. The transition probability estimated from the data is consistent with the QED calculation and no excess was observed in OFF resonance data.