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Probing Nuclear Sizes through Precision Spectroscopy of Ultracold Bosonic and Fermionic Helium

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Precision measurements on calculable systems are commonly used for tests of highly involved quantum electrodynamics (QED) calculations and are sensitive probes for the discovery of new and unexplored areas of physics. In our experiment we apply laser cooling and trapping techniques on helium atoms, to perform a highly accurate measurement on the doubly forbidden 23S1 −21S0 transition at 1557 nm. From the isotope shift of this transition between the bosonic 4He and fermionic 3He isotope we extract the squared charge radius difference between the nuclei, which is used as a benchmark for tests of QED and comparison with muonic systems.

Our most recent experiment involves the measurement of this transition in a degenerate Fermi Gas of 3He, confined in a dipole trap at the 319.8 nm magic wavelength. In this configuration, the spectral lineshape is purely dominated by the Fermi-Dirac statistics of the gas, and showcases a remarkable sub-Doppler narrowing effect due to Pauli blockade of stimulated emission in the dense part of the cloud. Our modeling and tests of this unexpected effect confirm the first observation of Pauli blockade in a coherently driven system. [1]

The resulting accuracy of the 3He transition itself sets a solid benchmark for electronic structure calculations, as does a precise evaluation of the magic wavelength condition. We combine this newest result with our earlier measurement on a 4He Bose-Einstein condensate [2] to obtain the isotope shift. Together, this provides the most accurate determination of the nuclear charge radius difference between the alpha and helion particle, which defines a strong benchmark for tests of fundamental physics.

References

[1] R. Jannin, Y. van der Werf, K. Steinebach, H.L. Bethlem, and K.S.E. Eikema , Nat. Comm. 13, 6479 (2022)
[2] R.J. Rengelink, Y. van der Werf, R.P.M.J.W. Notermans, R. Jannin, K.S.E. Eikema, M.D. Hoogerland, and W. Vassen, Nat. Phys. 14, 1132-1137 (2018).

Author: VAN DER WERF, Yuri

Presenter: VAN DER WERF, Yuri

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