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Improved Limits for Violations of Local Position and Local Lorentz Invariance from Atomic Clock Comparisons

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Searches for violations of Einstein's equivalence principle, such as tests of local Lorentz invariance and local position invariance, have become one of the leading applications of low-energy, high-precision experiments with laser-cooled atoms. In our laboratory, we operate atomic clocks based on the microwave ground state hyperfine splitting frequency of Caesium and optical clocks based on optical transitions of single trapped Ytterbium ions. The frequency ratio of an electric quadrupole and an electric octupole (E3) transition of Yb^+ has been determined with $3{\cdot}10^{-17}$ fractional uncertainty, improving upon previous measurements by an order of magnitude. Using two caesium fountain clocks, we measure the E3 transition frequency at 642 THz with 80 mHz uncertainty, the most accurate determination of an optical transition frequency to date. Repeated measurements of both quantities over several years are analyzed for potential violations of local position invariance [1]. We improve by factors of about 20 and 2 the limits for fractional temporal variations of the fine structure constant to $1.0(1.1) \cdot 10^{-18}$/yr and of the proton-to-electron mass ratio to $-8(36) \cdot 10^{-18}$/yr. Using the annual variation of the Sun's gravitational potential at Earth, we improve limits for a potential coupling of both constants to gravity. Operating the two optical clocks both on the E3 reference transition enables an even more accurate comparison and allows us to improve previous limits on a Lorentz symmetry violation for electrons by two orders of magnitude [2].

[1] R. Lange, N. Huntemann, J. M. Rahm, C. Sanner, H. Shao, B. Lipphardt, Chr. Tamm, S. Weyers, and E. Peik, Phys. Rev. Lett. 126, 011102 (2021).

[2] C. Sanner, N. Huntemann, R. Lange, Chr. Tamm, E. Peik, M.S. Safronova and S.G. Porsev Nature 567, 204 (2019).

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