Optical lattice clocks and their applications

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Clocks are devices that allow us to share time by taking advantage of ubiquitous oscillatory phenomena in nature. We once relied on astronomical observations, and today we use far regular oscillations of cesium atoms to define the international system of unit (SI) for time, i.e., the SI second. Recent optical atomic clocks have achieved 100-fold improvement over cesium clocks [1]. This extreme precision, in turn, allows clocks to investigate the constancy of fundamental constants that they rely on and to measure clocks' altitudes using their gravitational-potential-dependent tick rates, i.e., chronometric leveling. Roles of the clocks are rapidly changing from those supposed previously.

An "optical lattice clock" proposed in 2001 [2] benefits from a low quantum-projection noise by simultaneously interrogating a large number of atoms trapped in optical lattices tuned to the "magic frequency" [3] that largely cancels the light shift perturbation of the lattice trap. About a thousand atoms enable such clocks to achieve 10^{-18} instability in a few hours of operation, which allows intensive investigation of systematic uncertainties and finding new applications.

We overview the progress of optical lattice clocks and address recent topics including 1) an "operational magic condition" [4, 5] to reduce the clock uncertainty to 10^{-19} by cancelling out the higher-order light shifts than that given by the electric-dipole interaction, 2) transportable Sr-based clocks that are being tested outside a laboratory targeting a cm-level chronometric levelling [6], and 3) a Cd-based clock to significantly reduce the blackbody radiation shift that is one of the major sources of uncertainties in Sr or Yb clocks.

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