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Francis M. Pipkin Award Talk: Molecular lattice clock with long vibrational coherence

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Atomic clocks are at the forefront of fundamental physics tests, detection of general relativistic effects, and studies of many-body systems. On the other hand, molecular structure offers a wide range of distinct energy scales that are at the heart of new protocols in precision measurement and quantum information science. Here we describe a fundamentally new type of lattice clock that is based on vibrations in diatomic strontium molecules, and present coherent Rabi oscillations between weakly and deeply bound molecules that persist for tens of milliseconds. This is made possible by a careful control of molecular quantum states, and by a state-insensitive magic lattice trap that weakly couples to molecular vibronic resonances and enhances the coherence time between molecules and light by several orders of magnitude, resulting in a quality factor of nearly a trillion. Our technique of extended coherence across the entire molecular potential depth is applicable to long-term storage of quantum information in qubits based on ultracold polar molecules, while the vibrational clock enables precise probes of interatomic forces, tests of Newtonian gravitation at ultrashort range, and model-independent searches for electron-to-proton mass ratio variations.