Clock Comparison Yields Clues to 'Constant' Change

Years of comparisons among the world's best atomic clocks—based on different atoms—have established the most precise limits ever achieved in the laboratory for detecting possible changes in so-called "constants" of nature. The comparisons at the National Institute of Standards and Technology may help scientists test the latest theories in physics and develop a more complete understanding of the history of the universe.

Some astronomical and geological studies suggest there might have been very small changes in the values of fundamental constants over billions of years, although the results have been inconsistent and controversial.

If fundamental constants are changing, the present-day rates of change are too small to be measured using conventional methods. However, a new comparison of NIST's cesium fountain and mercury ion clocks, scheduled to appear in this week's issue of *Physical Review Letters*, has narrowed the range in which one of them—the "fine-structure constant"— possibly could be changing by a factor of 20. Widely used in physical theory and experiments, the fine-structure constant, represents the strength of the interaction between electrons and photons.

Astronomers and geologists have attempted to detect changes in natural constants by examining phenomena dating back billions of years. The NIST experiments attained the same level of precision by comparing the relative drifts in the "ticks" of an experimental mercury ion clock, which operates at optical frequencies, and NIST-F1, the national standard cesium clock, which operates at lower microwave frequencies. These data can be plugged into equations to obtain upper limits for possible rates of change of the fine structure constant in recent times.

A second study, based on seven years of comparisons of cesium and hydrogen clocks at NIST and in Europe, achieved record limits on Local Position Invariance, the principle that two clocks based on natural frequencies of different atoms should undergo proportional frequency shifts when subjected to the same changes in gravitational field. The new experiments lowered the upper limit for a possible violation of LPI, by more than 20 times.

Changes in physical constants such as the fine structure constant or the gravitational constant would violate Albert Einstein's original theory of general relativity. Such violations are predicted in recent theories aimed at unifying gravitation and quantum mechanics. NIST scientists now plan an all-optical-frequency comparison of the mercury ion clock with an aluminum ion atomic clock, which could increase measurement precision further, offering a more stringent test of the theoretically predicted changes. Conducting such tests with many different types of atomic clocks offers the best chance of eliminating extraneous factors to clearly identify which, if any, of the fundamental "constants" are changing over time.

Citation:
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