New calculations on blackbody energy set the stage for clocks with unprecedented accuracy

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(PhysOrg.com) -- A team of physicists from the United States and Russia announced today that it has developed a means for computing, with unprecedented accuracy, a tiny, temperature-dependent source of error in atomic clocks. Although small, the correction could represent a big step towards atomic timekeepers' longstanding goal of a clock with a precision equivalent to one second of error every 32 billion years—longer than the age of the universe.

Precision timekeeping is one of the bedrock technologies of modern science and technology. It underpins precise navigation on Earth and in deep space, synchronization of broadband data streams, precision measurements of motion, forces and fields, and tests of the constancy of the laws of nature over time.

"Using our calculations, researchers can account for a subtle effect that is one of the largest contributors to error in modern atomic timekeeping," says lead author Marianna Safronova of the University of Delaware, the first author of the presentation. "We hope that our work will further improve upon what is already the most accurate measurement in science: the frequency of the aluminum quantum-logic clock," adds co-author Charles Clark, a physicist at the Joint Quantum Institute, a collaboration of the National Institute of Standards and Technology (NIST) and the University of Maryland.

The paper was presented today at the 2011 Conference on Lasers and Electro-Optics in Baltimore, Md.

The team studied an effect that is familiar to anyone who has basked in the warmth of a campfire: heat radiation. Any object at any temperature, whether the walls of a room, a person, the Sun or a hypothetical perfect radiant heat source known as a "black body," emits heat radiation. Even a completely isolated atom senses the temperature of its environment. Like heat swells the air in a hot-air balloon, so-called "blackbody radiation" (BBR) enlarges the size of the electron clouds within the atom, though to a much lesser degree—by one part in a hundred trillion, a size that poses a severe challenge to precision measurement.

This effect comes into play in the world's most precise atomic clock, recently built by NIST researchers. This quantum-logic clock, based on atomic energy levels in the aluminum ion, Al+, has an uncertainty of 1 second per 3.7 billion years, translating to 1 part in 8.6 x 10-18, due to a number of small effects that shift the actual tick rate of the clock.

To correct for the BBR shift, the team used the quantum theory of atomic structure to calculate the BBR shift of the atomic energy levels of the aluminum ion. To gain confidence in their method, they successfully reproduced the energy levels of the aluminum ion, and also compared their results against a predicted BBR shift in a strontium ion clock recently built in the United Kingdom. Their calculation reduces the relative uncertainty due to room-temperature BBR in the aluminum ion to 4 x 10-19 , or better than 18 decimal places, and a factor of 7 better than previous BBR calculations.

Current aluminum-ion clocks have larger sources of uncertainty than the BBR effect, but next-generation aluminum clocks are expected to greatly reduce those larger uncertainties and benefit substantially from better knowledge of the BBR shift.

More information: M. Safronova, M. Kozlov and C.W. Clark, "Precision Calculation of Blackbody Radiation Shifts for Metrology at the 18th Decimal Place." Paper CFC 3, presented on May 6,2011, at CLEO 2011, Baltimore, Md. Also presented on May 3, 2011, at the 2011 Joint Conference of the IEEE International Frequency Control Symposium & the European Frequency and Time Forum, San Francisco, Calif., Paper 7175.

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