Precision Time Measurement and a Novel Two-Photon Clock Scheme

E. A. Alden†, K.R. Moore, and A. E. Leanhardt
Department of Physics, University of Michigan, Ann Arbor, Michigan 48109-1040, USA
†ealden@umich.edu

Abstract: We propose a novel two-photon excitation scheme for the $^1S_0 \rightarrow {}^3P_0$ optical clock transition that works in the absence of hyperfine structure and applied magnetic fields. Experimental progress in Hg is discussed.

OCIS Codes: (120.3940) Metrology; (270.4180) Multiphoton processes

The frontiers of precision time measurement in atomic clocks have been rapidly advancing in the last decade [1, 2, 3, 4, 5, 6]. Improvements in frequency standards advance metrology for everyday applications such as GPS and for tests of fundamental physics. Current optical-frequency atomic clocks based on the electric dipole $E1$ forbidden $^1S_0 \rightarrow {}^3P_0$ transition require either hyperfine structure or an applied magnetic field to induce mixing of the $^3P_0$ and $^3P_1$ levels. This reduces the lifetime of the $^3P_0$ level and thus the fundamental resolution of the clock. We propose an excitation scheme utilizing a two-photon excitation coupling the $^1S_0$ ground state to the $^3P_0$ clock state through an allowed $E1$ and $M1$ excitation sequence. Utilizing a two-photon transition with counter-propagating laser beams eliminates the first-order Doppler-broadening and thus permits the use of a hot vapor cell of Hg atoms. This largely increases the number of atoms addressed compared to ion frequency standards [1, 2, 3, 4] and introduces simpler initial state preparation compared to neutral frequency standards that employ an optical lattice [5, 6].

The transition rate using this two-photon excitation scheme is given by:

$$R_{2\gamma} = N\frac{4I^2}{\hbar^4 c^4 \epsilon_0^2}\frac{\langle {}^3P_0|\mu|{}^3P_1\rangle_{M1}^2 \langle {}^3P_1|d|{}^1S_0\rangle_{E1}^2}{\Gamma\Delta^2} \approx N\frac{I^2}{\Gamma}\times 10^{-10} \quad (1)$$

where N is the number of atoms sampled, I is the excitation laser intensity, $\langle {}^3P_0|\mu|{}^3P_1\rangle_{M1}$ is the magnetic dipole matrix element, $\langle {}^3P_1|d|{}^1S_0\rangle_{E1}$ is the electric dipole matrix element, Γ is the experimentally broadened linewidth of the transition, and Δ is the detuning of an excitation photon's energy from the intermediate $^3P_1$ level. It is experimentally feasible to achieve $I > 10^{10}[\frac{W}{m^2}]$, and $N > 10^8[\#]$. In the first phase of this experiment we anticipate $\Gamma \ll 10^8[Hz]$ and expect to detect transitions at a rate of a few Hertz.

To drive the $^1S_0 \rightarrow {}^3P_0$ transition in neutral Hg we have developed a high power, narrow linewidth laser system at 531 nm. A fiber amplified 1062nm laser has been doubled using a PPMgO:SLT crystal to produce CW powers of 5.5 W. Population in the metastable $^3P_0$ level can be detected using an NH_3 buffer gas which induces $^3P_0$ relaxation [7]. The presence of NH_3 broadens the transition linewidth but serves as an expedient tool to determine clock state population and demonstrate the viability of this clock scheme. An alternate, non-broadening detection scheme involves sampling the $E1$ allowed $^3P_0 \rightarrow {}^3S_1$ transition.

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