Stabilizing Temperature in Vapor-Cell Atomic Clocks: The "Isoclinic-Point Thermometer"

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The Rb vapor cell atomic clock is (arguably) the workhouse of atomic timekeeping in space, finding applications on GPS, Galileo, Beidou, Milstar, and Advanced-EHF satellites. In the clock, the vapor of Rb atoms that creates the atomic clock signal is contained within a small glass cell (*i.e.,* the "resonance" cell), whose temperature needs to be carefully stabilized in order to achieve good long-term frequency stability. Specifically, not only must the *average* temperature of the vapor be stabile, fluctuations of the temperature *gradient* across the signal volume must also be minimized. Variations in the average temperature and the temperature gradient have been found to affect the long-term frequency stability of vapor-cell atomic clocks at the 10^{-13} to 10^{-14} level.

Routinely, temperature stability is achieved by placing a thermocouple or thermistor at the cold point of the resonance cell's exterior (*i.e.*, the region of the liquid Rb pool), as this location plays a primary role in defining the mean Rb vapor density. Then, through an electronic feedback loop, temperature fluctuations at that one location are compensated by varying the cell's heating elements. Unfortunately, there are at least two problems with this approach to resonance cell temperature stabilization: 1) the temperature of the vapor is not measured directly, only the temperature at a point on the exterior of the vapor's glass container is measured, and 2) changes in the temperature gradient across the signal volume may not be adequately detected or compensated. In this presentation, we discuss a novel approach to solving these problems by employing what we have come to call an "isoclinic-point thermometer."

It is well known that the absorption resonances, ω_{res}, of vapor-phase alkali atoms have fairly strong temperature dependences that arise from the effect of Doppler-broadening on the resonances' spectral overlap. However, in the absorption spectra of nuclear-spin 3/2 alkali atoms (*e.g.*, Rb) there is a spectral feature at ω_{iso}, the isoclinic point, which is insensitive to such temperature effects [1]. The isoclinic-point thermometer takes advantage of this spectral feature by calibrating the frequency difference Δ_{iso}, defined as $\omega_{res}-\omega_{iso}$, to temperature; and then using this frequency difference as a measure of signal volume temperature. Not only is Δ_{iso} a measure of the actual vapor temperature over the signal volume (as opposed to a point-measure of temperature on the resonance cell's exterior), it has the potential to be significantly more sensitive to fluctuations in the temperature gradient across the signal volume than any exterior probe.

In this presentation we review the spectroscopic nature of the isoclinic point, and we outline its use for the thermometry of vapor-phase systems. We will discuss two possible realizations of the isoclinic point thermometer, our calibration of these realizations to vapor temperature, and their potential sensitivity to vapor temperature variations.

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[1] N. P. Wells and J. C. Camparo, "^{87}Rb D_1 isoclinic point," Phys. Rev. A 82, 062505 (2010).