# Tests of Fundamental Physics with Atomic Dysprosium


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While dysprosium (Dy) is among the most complex atoms in terms of spectroscopy, it has proven to be a useful system for testing fundamental physics. In Dy, there is a pair of long-lived, excited non-Rydberg opposite-parity states of the same total electronic angular momentum ($J$=10) that are separated in energy, depending on the isotope and hyperfine component, by anywhere between 3 MHz and a few GHz (with energies expressed in frequency units) in the absence of external fields. The near degeneracy allows measuring the difference in the energies of the levels directly by radio-frequency (rf) spectroscopy, enabling sensitive exotic-physics searches with relaxed requirements for the rf source in terms of its fractional frequency stability. Moreover, the separation of the levels can be easily tuned over a relatively large range of energies, for instance, applying a 1.4 G magnetic field brings certain sublevels to a crossing, so that one can work with a particularly "clean" realization of a quantum-mechanical two-level system.

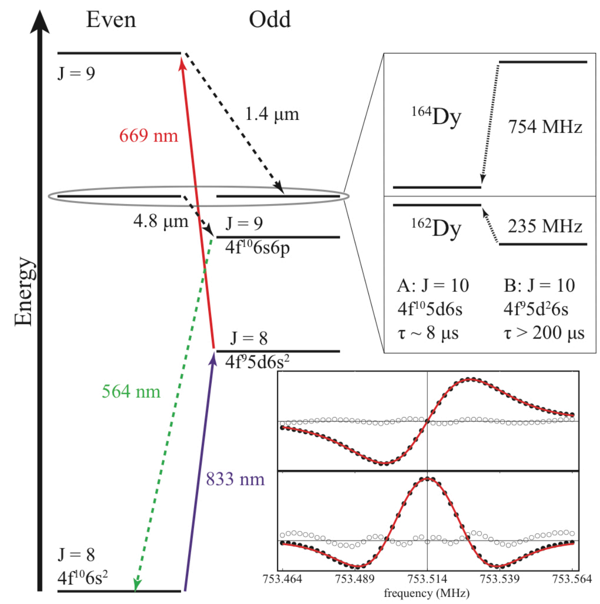


Fig. 1: Energy level diagram of Dy showing transitions for preparing atoms in state 'B', as well as spontaneous decay pathways from state 'A' that allow fluorescence detection of the rf transition, shown magnified for two isotopes of Dy. The bottom-right inset shows lineshapes for frequency-modulation spectroscopy of the transition in $^{164}$Dy, acquired with a lock-in amplifier at the first (top) and second (bottom) harmonics of the modulation frequency.

Over the years, Dy has been used to set stringent limits on physics beyond the standard model: a possible temporal variation of the fine-structure constant, α, variation in α induced by the changes of the gravitational potential of the Sun (exploiting the eccentricity of the Earth's orbit)[1], and certain types of violations of Lorentz invariance and the Einstein's Equivalence Principle[2]. Ongoing experiments with Dy aim at measuring atomic parity violation in a chain of isotopes and hyperfine components[3]; Dy may also prove to be a system of interest in searches for various exotic particles and fields permeating our galaxy, for instance, light scalar fields such as axions[4].

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[1] N. Leefer, *et. al.*, Phys. Rev. Lett.**111**(6), 060801 (2013)

[2] M.A. Hohensee, *et. al.*, Phys. Rev. Lett. **111**(5), 050401 (2013)

[3] A.-T. Nguyen, *et. al.*, Phys. Rev. A **56**(5), 3453-63 (1997)

[4] Y.V. Stadnick and V.V. Flambaum, arXiv:1312.6667 (2013)