Evolution of the Octupole collectivity in ^{152}Gd

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The search for physics beyond the Standard Model (SM) is presently a major issue. Despite its spectacular success, it is recognized that the SM could be incomplete and could eventually be incorporated into a more fundamental framework. As an example, the excess of matter over antimatter in the Universe indicates the presence of baryon-number-violating interactions and most likely of new sources of charge-parity (CP) violation. The existence of a finite permanent electric dipole moment (EDM) of a particle or an atom would violate time-reversal symmetry (T), and would also imply violation of the combined charge conjugation and parity symmetry (CP) through the CPT theorem [1,2,3]. EDMs are suppressed in the SM of particle physics, lying many orders of magnitude below current experimental sensitivity. Additional sources of CP violation are needed to account for baryogenesis and many theories beyond the SM, such as supersymmetry [4,5], predict EDMs within experimental reach.

Experimental searches for EDMs have so far yielded null results. The most significant limits have been set on the EDM of the neutron [6], the electron [7] and on the ^{199}Hg atom [8], leading to tight constraints on extensions of the SM [5]. The most sensitive EDM search to date is performed on the Hg nuclei providing for d (^{199}Hg) < (0.49 ±1.29stat±0.76syst) x10^{-29} *e* cm [8]. This value has been used to set new constrains on CP violation in physics beyond the standard model but an enhancement of about three orders of magnitude would be necessary to probe the prediction of the SM.

CP violation in atomic nuclei is conventionally parameterized by the Schiff moment S, the lowest order CP violating nuclear moment unscreened by the electron cloud. Schiff showed that any neutral system of electrically charged, point-like constituents interacting only electrostatically have no net EDM [9].

Nuclear structure can strongly amplify the sensitivity of nuclear EDM measurements. In particular, the occurrence of octupole deformation or octupole vibrations in nuclei lead to closely spaced parity doublets and considerably larger Schiff moments (proportional to the difference between the mean square radius of the nuclear dipole moment distribution and the nuclear charge distribution). The EDM of atoms is induced by the interaction of the electrons with the nuclear Schiff moment. Because a CP-violating Schiff moment induces a contribution to the atomic EDM, a large enhancement due to the octupole effects translates into an improved sensitivity to an atomic EDM when compared to atomic systems without this deformation. Enhancements factor of 10^2-10^3 have been calculated for nuclei with octupole deformation [10,11] or soft octupole vibrations [12].

Prior to the long-term program required for such (atomic) measurements, it is critical to identify the best possible candidates. In particular, the EDM of Pa is calculated to exceed the EDM of Ra by a factor 40 [13] and may become a prime candidate for an EDM measurement in the future. A particularly promising case is ^{229}Pa. Condition for that is the high octupole collectivity of the nucleus. Being an odd system the direct determination of the octupole strength is certainly difficult but an estimation can be obtained by the neighbour even-even nucleus ^{228}Th. Since ^{229}Pa can be seen as a proton coupled to the ^{228}Th core, the octupole collectivity of those two nuclei can be assumed to be similar. The octupole collectivity of ^{228}Th can be determined via a Coulomb excitation reaction through the B(E3) strength of the 0^+ to 3^- state of the octupole band and a letter of intent has been accepted at CERN ISOLDE on this measurement [14].

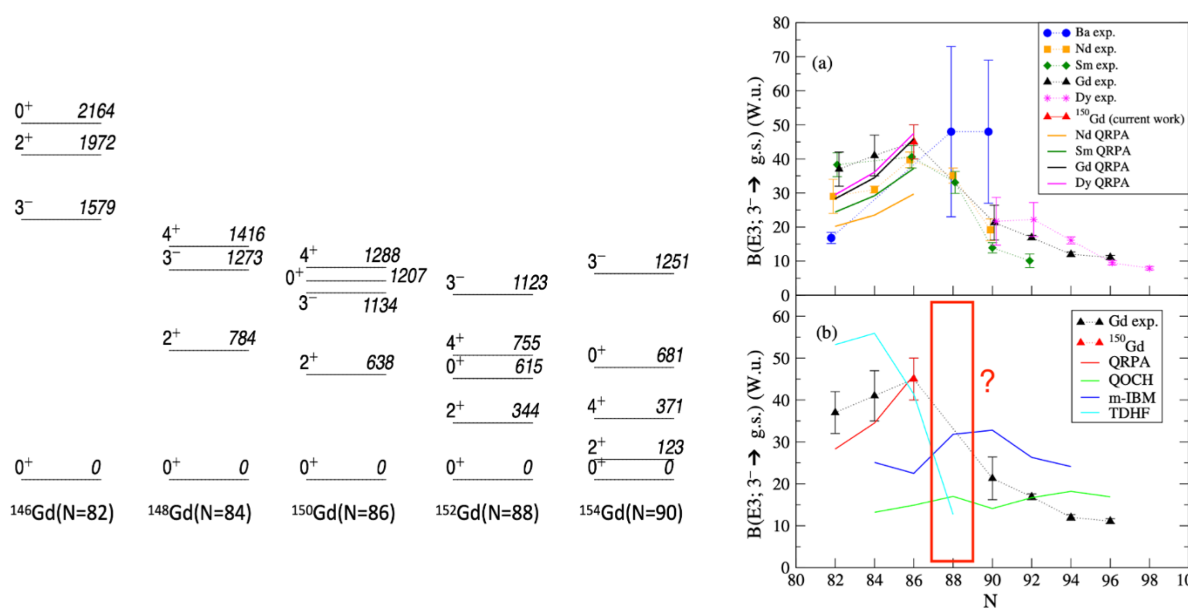

Figure 1. The evolution of 3^- states[2] and B(E3) value across the Z=64 Gd isotopic chain [15]. The B(E3) value of ^{152}Gd is missing.

The observation in the Lanthanides of low-lying states in nuclei with even Z, N having total angular momentum and parity $I^{\pi}=3^{-}$ is indicative of their undergoing octupole vibrations about a reflection-symmetric shape. Further evidence is provided by the sizeable value of the electric octupole (E3) moment for the transition to the ground state, indicating collective behaviour of the nucleons. Recently, the systematics of the E3 strength across the Gd isotopic chain has been studied and the results reveal that enhanced octupole collectivity is obtained for ^{150}Gd. The energy of 3-$^{-}$ state in ^{152}Gd is similar with ^{150}Gd. However, the B(E3) value is missing for ^{152}Gd, as is shown in Fig. 1. **The aim of this proposal is to achieve the direct determination of the octupole collectivity in ^{152}Gd by a Coulomb excitation measurement.**

Experimental setup: AGATA+SPIDER

Beam: ^{32}S with an energy of 110MeV

Target: ^{152}Gd, 1mg/cm2 onto a 2mg/cm2 Ta foil

Beam time: 7 days

Reference:

[1] I.P. Khriplovich and S.K. Lamoreaux, CP violation without strangeness (Springer, Berlin 1997).
[2] P.G.H. Sandars, Contemp. Phys. 42, 97 (2001)
[3] M. Pospelov and A. Ritz, Ann. Phys. (N.Y.) 318, 119 (2005)
[4] S.M. Barr, Int. J. Mod. Phys. A 8 209 (1993)
[5] K.A. Olive et al. Phys. Rev. D 72 075001 (2005)
[6] C.A. Backer et al., Phys. Rev. Lett. 97, 131801 (2006)
[7] B.C. Regan et al. Phys. Rev. Lett. 88, 071805 (2002)
[8] W.C. Griffith et al., Phys. Rev. Lett. 102, 101601 (2009)
[9] L.I. Schiff, Phys. Rev. 132, 2194 (1963)
[10] N. Auerbach et al., Phys. Rev. Lett. 76, 4316 (1996)
[11] V. Spevak, N. Auerbach, V.V. Flambaum, Phys. Rev. C 56, 1357 (1997)
[12] V.V. Flambaum and V.G. Zelevinsky Phys. Rev. C 68, 035502
[13] V.V. Flambaum Phys. Rev. A 77, 024501 (2008)
[14] G. de Angelis et al. Priv. Comm.
[15] S. Pascu, et. al. Phys. Rev. Lett. 134, 092501 (2025).
[16] https://www.nndc.bnl.gov/ensdf/.