Correlating nuclear Schiff moment and magnetic moment of ^{129}Xe[†]

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The charge-parity (CP) violation within the standard model is not sufficient for describing the matter-antimatter asymmetry in the current universe. Permanent electric dipole moments (EDMs) of elementary and composite particles are promising probes of new sources of CP violation beyond the standard model. In particular, the EDMs of diamagnetic atoms including ^{129}Xe are induced by nuclear Schiff moment (NSM), which originates from the P and T (CP) violations in the hadronic sector. The current experimental limit on the atomic EDM of ^{129}Xe is $|d(^{129}\mathrm{Xe})| < 1.4 \times 10^{-27}$ e cm (95%C.L.).[1)]

The NSM of the neutron-odd nucleus ^{129}Xe is particularly sensitive to the neutron EDM. The NSM induced by the nucleon EDM is defined by[2)]

$$S_{2,k} = \frac{1}{6}\sum_{a=1}^{A} d_{a,k}\left(r_a^2 - \langle r^2\rangle_{\mathrm{ch}}\right) + \frac{2}{15}\sum_{a=1}^{A}\sum_{j} d_{a,j}\left(Q_{a,jk} - \langle Q_{jk}\rangle_{\mathrm{ch}}\right), \quad (1)$$

where σ_k is the spin Pauli matrix, $Q_{a,jk}$ is the nuclear quadrupole moment, and $\langle r^2\rangle_{\mathrm{ch}}$ is the root-mean-square charge radius. The nucleon EDM is represented by $d_{a,k} = d_p\sigma_k$ for proton and $d_{a,k} = d_n\sigma_k$ for neutron. The cartesian components are denoted by j and k.

We performed the large-scale shell model (LSSM) calculations of ^{129}Xe by using the SNV and SN100PN effective interactions to evaluate the NSM coefficients s_p, s_n, which are computed by using

$$S_2 = \langle\psi_{\mathrm{g.s.}}|S_{2,z}|\psi_{\mathrm{g.s.}}\rangle = \sum_{N=p,n} s_N d_N, \quad (2)$$

where $|\psi_{\mathrm{g.s.}}\rangle$ represents the nuclear ground state of definite parity. As shown in Fig. 1, our results are significantly different from the results of pair-truncated shell model (PTSM) calculations.

We found a apparent correlation between the NSM coefficient s_n and magnetic moment. This correlation can be helpful to reduce the theoretical uncertainty, and understood by a two-level model that describes the ground state as

$$|\psi_{\mathrm{g.s.}}\rangle = \alpha|\psi_1\rangle + \sqrt{1-\alpha^2}|\psi_2\rangle, \quad (3)$$

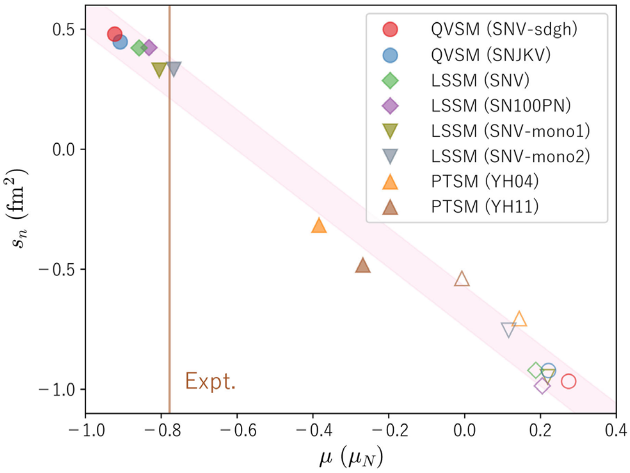

Fig. 1. Correlation between the magnetic moments μ and NSM coefficients s_n of ^{129}Xe. The filled and open symbols represent the ground state and the second lowest $1/2^+$ state, respectively. The light red band shows the 68% confidence interval.

where $|\psi_1\rangle$ and $|\psi_2\rangle$ denote the ideal ground state that reproduces the experimental value of the magnetic moment, and the ideal second lowest $1/2^+$ state, respectively. The strong quenching found in the PTSM can be explained by the contamination of $|\psi_2\rangle$. The results of the second lowest $1/2^+$ state are shown on the bottom right in Fig. 1, whereas our results of the ground state are close to the experimental value of the magnetic moment.

This correlation remains significant even if certain monopole interactions are changed. The results are shown as SNV-mono1 and SNV-mono2 in Fig. 1. We also performed the quasi-particle vacua shell-model (QVSM) calculations with including the $0g_{9/2}$ and $0h_{9/2}$ orbitals into the model space. These orbitals are strongly connected to the spin-orbit partners by the NSM and magnetic moment operators, but the influence is limited and the correlation is not disturbed.

In summary, we found the apparent correlation between the NSM coefficient s_n and the the magnetic moment of ^{129}Xe. Using this relation, we can reduce the theoretical discrepancy of s_n. Combining the 68% confidence interval of this relation and the experimental value of the magnetic moment, we obtained $s_n = 0.30 \pm 0.09$ fm^2, which supports our results of the LSSM and QVSM calculations.

References
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