Electric Dipole Transitions in mirror nuclei

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Abstract

The strength of electric dipole E1 transitions in mirror nuclei offer a unique possibility to verify fundamental symmetries, identify and quantify isospin mixing mechanisms. Since E1 transitions are purely isovector in nature, under isospin conservation, E1 transitions in mirror nuclei should have equal strength. Partial theoretical explanation has been advanced for the experimentally observed violations to this selection rule. Because only sparse experimental data exist, to develop a deeper understanding of the phenomena, more measurements are needed.

The mirror nuclei with mass 19 offer a unique opportunity to address such study on the violation of isospin symmetry because it is the only case where a $1/2^-$ to $1/2^+$, having a **pure E1 transition**. This is a unique opportunity of testing isospin mixing with high precision because in this case mixing with E2 transition is not possible. Only one measurement was performed of this E1 transition. We propose to obtain a second more precise measurement.

Scientific Motivation

Isospin is a powerful concept because the nuclear interaction is approximately charge-symmetric and charge-independent, meaning rotation symmetry in the isospin space. The charge symmetry requires that the proton-proton interaction (V_{pp}) is equal to the neutron-neutron interaction (V_{nn}), while charge independence requires (V_{pp} + V_{nn})/2 = V_{np}. However, these symmetries are known to be slightly broken and the origin of the isospin symmetry breaking is an object of study that can reveal details about the nuclear interaction. The nuclei located near the N = Z line are particularly suitable to study isospin-symmetry breaking effects. The case of mirror nuclei, with the number of protons and neutrons interchanged, is even more special. As the number of *pp* interactions in one nucleus equals the number of *nn* interactions in the other, it is possible to directly study the charge symmetry of the nuclear interaction.

In the hypothesis of isospin symmetry, the energy spectra of mirror nuclei are expected to be identical. Differences are introduced by the Coulomb interaction and the residual isospin non conserving part of the nuclear interaction. Mirror energy differences (MED), have been extensively used to investigate isospin symmetry breaking effects [1]. Interestingly, the MED provide also information on the evolution of the nuclear structure as a function of excitation energy and spin [1]. Recently, it has been shown, for nuclei of the *sd* shell, that the nuclear skin can be deduced from the measured MED [2].

While these studies, that rely on the isospin purity of the states, have become a mature research field, there is a lack of information on the isospin mixing induced by broken- symmetry effects. Indeed, a crucial next phase in the study of Isospin Symmetry Breaking (ISB) physics is the precise measurement of the properties of the wave functions. This can be performed by measuring the transition probabilities that should verify specific selection rules.
The electric dipole, *E1*, operator, for example, has a pure isovector character when considering the long-wavelength limit [3]. Consequently E1 transitions are forbidden between states with the same isospin in N = Z nuclei and analog *E1* transitions in mirror nuclei are predicted to have the same strength. Deviations from these rules can be used to study isospin symmetry breaking [3]. Large differences in *E1* transition strengths have been found in pairs of mirror nuclei, namely ^{67}As-^{67}Se [4], and, more recently, ^{31}P-^{31}S [5]. For the former case, Bizzeti and collaborators [3] proposed that the large isoscalar component, driving the observed asymmetry in the *E1* transition strengths, is a combined effect of the level mixing induced by the isovector part of the Coulomb interaction, and of the coherent mixing with higher-lying states involving the Giant Isovector Monopole Resonance. Similar explanations were given recently to the observed the discrepancy in *E1* transition strengths in the A = 31 mirror pair [5] based on mean-field calculations. The authors in Ref. [3] agree to the fact that shell model calculations involving two or more main shells, allowing for particle-hole excitations across those shells, would be the ideal method for describing *E1* transition strengths.

The lifetime of the $1/2^-$ state in ^{19}Ne was measured to be 61(3) ps [6] using an inverse kinematics (^{3}He, ^{4}He) reaction. The measurement made use of only one 15 cc Ge(Li) detector. Despite the small uncertainty claimed by the authors the result was obtained with a plunger based on an extended gas target and, by construction, it heavily depends on the modelization of the target itself. The measurement made use of 2 target thicknesses: 1.66 and 7.66 mm. The gas target for recoil distance method that was used for such measurement is described in ref [7].

With the experiment here proposed we wish to measure again the lifetime of the 1/2- state. ***This aims to be the most precise direct measurement of isospin purity in nuclei that are being use for the calculation of V_{UD} element of the CKM matrix***. In case the previous measurement is disproven an isospin mixing will be quantified with impact in the unitarity of the

CKM matrix. In case the B(E1) obtained for ^{19}Ne will be compatible with that of its mirror ^{19}F, this will be the best experimental constrain to isospin mixing setting a stringent upper limit.

Experimental details

The ^{19}Ne nucleus will be populated in (d,t) reaction with a ^{20}Ne beam at 200 MeV impinging on a titanium deuterated target of 0.5 mg/cm^2 in a plunger configuration with a gold stopper. Trace will be used for the identification of the tritons. AGATA will be used at backward angles to maximize the Doppler shift.

It will be important to study the feeding to the 1/2- state. The 5/2- state at 1508 keV is the slowest state above the 1/2- and it is estimated to have a lifetime of 1.6(2) ps and thus it will have a limited impact on the precision of the measurement.

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