Deformed shell model study of event rates for WIMP-^{73}Ge inelastic scattering

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Introduction

There is overwhelming evidence for the existence of dark matter in the universe [1]. The existence of dark matter can be inferred from the rotation curves for spiral galaxies, gravitational lensing in clusters of galaxies, anisotropy in the cosmic microwave background radiation etc. Most of the dark matter is known to be cold. Up to now, the nature of this matter remains a mystery. Super symmetric theories of physics beyond the standard model provide the most promising nonbaryonic candidates for dark matter. In the simple picture, the dark matter in the galactic halo is assumed to be Weakly Interacting Massive Particles (WIMP). The most appealing WIMP candidate for nonbaryonic cold dark matter is the lightest super symmetric particle (LSP) which is expected to be a neutral Majorana fermion travelling with non-relativistic velocities.

Since the WIMP interacts very weakly with matter, its detection is quite difficult. One possibility to detect WIMP is through the recoil of the nucleus in WIMP-nucleus elastic scattering [2]. In WIMP-nucleus scattering, one should consider, in addition to the scalar interaction, the spin-spin interaction in which the WIMP couples to the spin of the nucleus. Exotic WIMPs can lead to large nucleon spin induced cross sections which in turn can lead to non-negligible probability for inelastic WIMP-nucleus scattering [3] provided the energy of the excited state is sufficiently low as in the $5/2^+$ and $7/2^+$ states of ^{73}Ge.

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We report here the first results for the detection rates for WIMP-^{73}Ge inelastic scattering using our Deformed Shell Model (DSM) based on Hartree-Fock states. Details of DSM can be found in ref. [4]. For experiments with ^{73}Ge, see[5].

Event rates for WIMP-nucleus scattering

The differential event rate per unit detector mass can be written as [1]

$$dR = N_t \, \phi \, \frac{d\sigma}{d \mid q \mid^2} f \, d^3v \, d \mid q \mid^2 \qquad (1)$$

In the above equation, N_t stands for the number of target nuclei per unit mass which is equal to $1/(Am_p)$, A being the mass number of the nucleus in the detector and m_p is the proton mass. ϕ is the dark matter flux which is equal to $\rho_0 v/m_\chi$. ρ_0 is the local WIMP density and m_χ is the WIMP mass. f takes into account the distribution of the WIMP velocity relative to the detector (or earth) and also the motion of the sun and earth. The distribution is assumed to be Maxwell-Boltzmann type. If we neglect the rotation of earth in its own axis, then $v = \mid \mathbf{v} \mid$ is the relative velocity of WIMP with respect to the detector. q represents the momentum transfer to the nuclear target. The evaluation of Eq. 1 involve spin structure functions $F_{\rho\rho'}(u)$ with ρ, ρ' = 0,1 defined as

$$F_{\rho\rho'}(u) = \sum_{\lambda,\kappa} \Omega_\rho^{(\lambda,\kappa)}(u) \Omega_{\rho'}^{(\lambda,\kappa)}(u) \; ;$$

$$\Omega_\rho^{(\lambda,\kappa)}(u) = \sqrt{\frac{4\pi}{2J_i+1}}$$

$$\times \langle J_f \| \sum_{j=1}^{A} \left[Y_\lambda(\Omega_j) \otimes \sigma(j) \right]_\kappa j_\lambda(\sqrt{u}\, r_j) \omega_\rho(j) \| J_i \rangle \qquad (2)$$

with $\omega_0(j) = 1$ and $\omega_1(j) = \tau(j)$; note that $\tau = +1$ for protons and -1 for neutrons. Here Ω_j is the solid angle for the position vector of the j-th nucleon and j_λ is the spherical Bessel function. The static spin matrix elements are defined as $\Omega_\rho(0) = \Omega_\rho^{(0,1)}(0)$. DSM is used to evaluate the spin structure functions $F_{\rho\rho'}$. The event rate is obtained by integrating Eq. 1 and is of the form $\langle R\rangle_{in} = (f_A^0)^2 E_1 + 2 f_A^0 f_A^1 E_2 + (f_A^1)^2 E_3$ where E_1, E_2 and E_3 are the three dimensional integrations and f_A^0 and f_A^1 represent isoscalar and isovector parts of the axial vector current.

Results and discussions

In DSM calculation, ^{56}Ni is taken as the inert core with the spherical orbits $1p_{3/2}$, $0f_{5/2}$, $1p_{1/2}$ and $0g_{9/2}$ forming the basis space. Modified Kuo interaction with single particle energies 0.0, 0.78, 1.08 and 4.90 MeV has been used in the calculation. We have generated three intrinsic states of positive parity and three intrinsic states of negative parity by particle-hole excitation over the lowest HF intrinsic state. Good angular momentum states are projected from each of these intrinsic states and then a band mixing calculation is performed. The calculated positive and negative parity energy levels agree quite well with experiment. The calculated magnetic moments for $9/2^+$ and $5/2^+$ also agree quite well with experiment.

The static spin matrix elements for the inelastic scattering to the $7/2^+$ state are $\Omega_0 = -0.167$ and $\Omega_1 = 0.142$. These values are about $6-7$ times smaller than the corresponding values in the elastic scattering case. However, these values are about 4 times larger than the values quoted for ^{83}Kr obtained within the full shell model with $jj44b$ effective interaction. Our values are almost as large as in ^{125}Te. Therefore the inelastic event rate should be competitive. The structure functions almost overlap with each other except for a small window lying between $0.7 \leq u \leq 4$. The nuclear structure coefficients E_1, E_2 and E_3 have been calculated. The inelastic nuclear structure coefficients do not depend on the detector threshold energy. Hence the event rate can be calculated by reading the values of E_i from the graph and using the nucleonic current parameters. Because of the large values of E_i, the inelastic scattering of WIMP from ^{73}Ge is a potential candidate for dark matter detection.

The first excited state for this nucleus is $5/2^+$ which is not connected to the ground state at small momentum transfer and $\lambda = 0$ or 1 and these are the dominant components for elastic scattering and $9/2^+ \rightarrow 7/2^+$ inelastic scattering. However, at finite momentum transfer and higher multipoles, there is contribution to this transition. We first calculate spin structure functions. We find that F_{01} is negative. The calculated nuclear structure functions E_1, E_2 and E_3 are smaller by two orders of magnitude compared to the transition $9/2^+ \rightarrow 7/2^+$. However, the nuclear structure factors exhibit much larger modulation, about 16%.

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