Elastic and Inelastic LSP-nucleus Scattering on Medium-heavy Nuclei

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Abstract. Elastic and inelastic scattering rates of the lightest supersymmetric particle (LSP) off nuclei are derived for the stable iodine, xenon and cesium detectors. The parameters of the supersymmetric theory are decoupled from the nuclear structure. The involved nuclear wave functions are calculated in the nuclear shell model by using a realistic effective two-nucleon interaction in a realistic valence space. By using fitted nuclear gyromagnetic factors we successfully reproduce the relevant spectroscopic data in the discussed nuclei.

1. Introduction
The dark-matter component of the Universe exhausts some 30% of the energy balance and is mostly in the form of cold dark matter (CDM). The CDM is believed to consist of non-relativistic heavy particles called WIMPs (weakly-interacting massive particles). The WIMPs are believed to constitute the major component of dark matter in our own galactic halo. To access the nature of dark matter a large number of direct detection experiments are looking for recoil signals of the nucleus on which the WIMP has scattered elastically or inelastically. Our obtained results for the stable iodine, xenon and cesium nuclei are of interest e.g. for the DAMA [1, 2] (129Xe and 127I), KIMS [3] (127I and 133Cs), NAIAD [4] and COUPP [5] (127I), ZEPLIN [6], XENON [7] and XMASS [8] (129Xe and 131Xe) experimental programs.

2. Nuclear-structure calculations
The large-scale shell-model calculations were performed in a valence space consisting of the single-particle orbitals 0g7/2, 1d5/2, 2s1/2, 1d3/2 and 0h11/2. This is the smallest realistic single-particle space to describe the physics of the 127I, 129Xe, 131Xe and 133Cs dark-matter detector nuclei. For the nucleon-nucleon two-body interaction we used an effective interaction based on Bonn-CD G-matrix [9]. For the reason of the CPU time consumption the number of neutron configurations had to be truncated as described in [10, 11]. The resulting energy spectra are in reasonable correspondence with the experimental data [11].

Contrary to our earlier calculations [12] we have renormalized the magnetic dipole operator by introducing effective spin and orbital angular-momentum gyromagnetic factors (g factors in short). The four optimal effective g factors were determined by a fit to 11 known magnetic moments of the nuclei 127I, 129Xe, 131Xe and 133Cs. The use of the fitted effective g factors improves the calculated magnetic moments substantially both for the ground states and for the lowest excited states of the nuclei considered [11]. The results are superior to those of the earlier
Figure 1. The $D_n$ factors of (1), in units of yr$^{-1}$kg$^{-1}$, plotted as functions of the LSP mass for three different threshold energies in the case of elastic scattering of the LSP off a $^{129}$Xe nucleus. Panel (a) shows $D_1$, panel (b) $-D_2$, panel (c) $D_3$, and panel (d) $D_4$. The thickness of the curves describes the annual modulation effect.

3. Elastic and inelastic LSP-nucleus scattering rates

The event rate of the LSP scattering off an Earth-bound detector can be written as

$$\langle R \rangle = \left[ \left( f_0^A \right)^2 D_1 + 2 f_0^A f_1^A D_2 + \left( f_1^A \right)^2 D_3 + A^2 \left( f_0^S - f_1^S \frac{A - 2Z}{A} \right)^2 D_4 \right] m_{\text{det}} \text{[kg]},$$

where $m_{\text{det}}$[kg] is the detector mass in units of kg, $A$ is the mass number of the target nucleus and the $f$ coefficients are specific to the chosen SUSY model [14]. The coefficients $D_n$ are folded with the symmetric Maxwell–Boltzmann velocity distribution of the LSPs and are given in detail in [11], both for the elastic and inelastic channels. It should be noted that the spin-independent coefficient $D_4$, containing the nuclear form factor, vanishes for inelastic scattering. Thus only the spin-dependent coefficients $D_1 - D_3$ are active for both scattering channels.

As an example of the computed results in Fig 1 we plot the $D_n$ in units of yr$^{-1}$kg$^{-1}$ and as functions of the LSP mass for the elastic scattering of the LSP off a $^{129}$Xe nucleus. Here the detector threshold, $Q_{\text{thr}}$, is the lowest recoil energy detectable by the measurement apparatus. In Fig 2 the corresponding factors are plotted for the inelastic LSP-$^{129}$Xe scattering for $Q_{\text{thr}} = 0$. 

calculation [13]. Because of this success, we introduce effective proton and neutron spin operators with the renormalization factors $r_p = 0.571$ for protons and $r_n = 0.881$ for neutrons. Below we use these effective spin operators to evaluate the observables of the LSP-nucleus scattering.
**Figure 2.** The $D_n$ factors of (1), in units of yr$^{-1}$kg$^{-1}$, plotted as functions of the LSP mass for the inelastic scattering of the LSP off a $^{129}$Xe nucleus. Panel (a) shows $D_1$, panel (b) $-D_2$, and panel (c) $D_3$. The thickness of the curves describes the annual modulation effect.

In [11] we have tabulated the $D_n$ coefficients for various LSP masses and detector thresholds to enable easy use in the context of different SUSY parametrizations.

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