Shell Effects in Neutron Capture on Pb

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In recent years it has been realized that the direct reaction mechanism (DC) can become the dominant process for (n,γ) reactions on intermediate and heavy nuclei near shell closures or for neutron rich isotopes when the level density becomes too low for the compound nucleus mechanism. In this work we want to investigate the impact of different microscopic descriptions on neutron capture on the even-even isotopes $^{210-228}$Pb. They are of importance in the r-process path going to very heavy elements.

For the computation of the DC cross section we used the direct capture code TEDCA [1]. For determining the nucleon-nucleus potential the folding procedure was employed, a method already successfully applied in the description of many systems.

The levels (and masses) needed as input for the DC calculation were taken from two different approaches. The first one was the relativistic mean field theory (RMFT), using the parameter set NLSH [2]. Also the density distributions needed for the determination of the folding potentials were derived from RMFT wave functions. The second method was the shell model developed by Möller et al. [3], utilizing folded-Yukawa potentials in the determination of the single-particle potentials, and employing the Lipkin-Nogami pairing model [3]. To be able to compare the predictions from both models the nuclei were considered to be spherically symmetric.

The strength parameter λ of the scattering potentials was determined by fitting experimental scattering data for ^{208}Pb+n at low energies. In the potentials for each of the other isotopes a factor λ was chosen giving the same volume integral as for the fitted ^{208}Pb-potential. For the bound state potentials λ is fixed by the requirement of correct reproduction of the binding energies. The spectroscopic factors were assumed to be unity for all transitions considered.

The results of our calculations are summarized in Fig. 1. The most striking feature is the sudden drop over several orders of magnitude in the cross sections calculated with the RMFT levels. This is due to the lack of low spin levels (J^π=1/2$^+$, 3/2$^+$) which are cut off by the decreasing neutron separation energy. Only after the 1i$_{11/2}$ shell (which forms the state at lowest energy in the RMFT) has been filled completely at ^{222}Pb the cross section is increasing because low spin states become available again.

If the r-process path crossed the Pb-isotopes in the mass range $A \approx$ 212–220, due to the comparatively long β-decay half lives the sudden drop in the neutron capture cross section would terminate the r-process and prevent the build-up of heavier elements. Since in some cases there are unbound low spin states close to the threshold a small shift in the level energies could already close the gap. However, note that the level spacing in the RMFT has the tendency to increase towards neutron rich nuclei [4], contrary to the Möller prediction (and contrary to a recent Hartree-Fock calculation [5], which will be included in an extension of this study).

Nevertheless, even if improved shell model descriptions and/or experiments have to clarify this point, the mechanism of cross section suppression due to the lack of low spin states could still be a possible restraint for the r-process path towards even more neutron rich isotopes and for nuclei beyond Pb. Because of the low level density the compound nucleus model would not be applicable in those cases.

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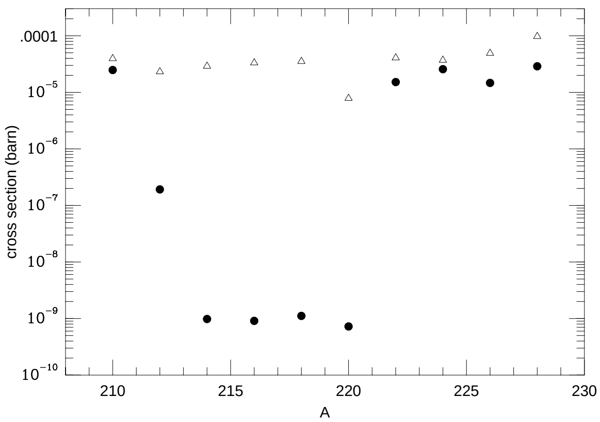

Figure 1: 30 keV cross sections for different Pb isotopes. Levels and masses are calculated with RMFT [2] (dots) and QRPA [3] (triangles).

References

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