Atomic effects in antineutrino spectrum of ^{144}Pr

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Introduction

Prospective short-base neutrino experiments with intense radioactive sources aimed at sterile neutrino searches require precise knoweledge of the emitted (anti)neutrino spectrum. One of the most promising antineutrino sources for such experiments (probing $\bar{\nu}_e$ disappearance) is ^{144}Ce-^{144}Pr [1].
Antineutrinos are usually detected via inverse beta decay (IBD) process

$$\bar{\nu}_e + p \to n + e^+ \quad (1)$$

with a threshold $E_{thr} = 1806$ keV. The cross section of IBD could be calculated with 1% accuracy [2]. Since the effect of neutrino oscillations to sterile states is expected to be about several percent, the antineutrino spectrum has to be known with percent accuracy.
Let us now discuss the calculation of ^{144}Ce-^{144}Pr antineutrino spectra. Note that the actual antineutrino source is ^{144}Pr, because it has two decay branches with end-point energies greater than the IBD threshold E_{thr} (see figure 1). The first (dominant) branch is a non-unique first-forbidden Gamow–Teller transition $0^- \to 0^+$ with endpoint energy 2998 keV and 97.9% branching. The second one is a unique first-forbidden Gamow–Teller transition $0^- \to 2^+$ with endpoint energy 2301 keV and 1.04% branching. In our calculation, only the main decay transition (with the branching $I = 97.9\%$) of ^{144}Pr is considered.
Previously we analyzed the accuracy of antineutrino spectrum calculation and presented the influece of several types of effects on the spectrum [3]. In this work, we consider additional corrections related to atomic excitations and atomic exchange.

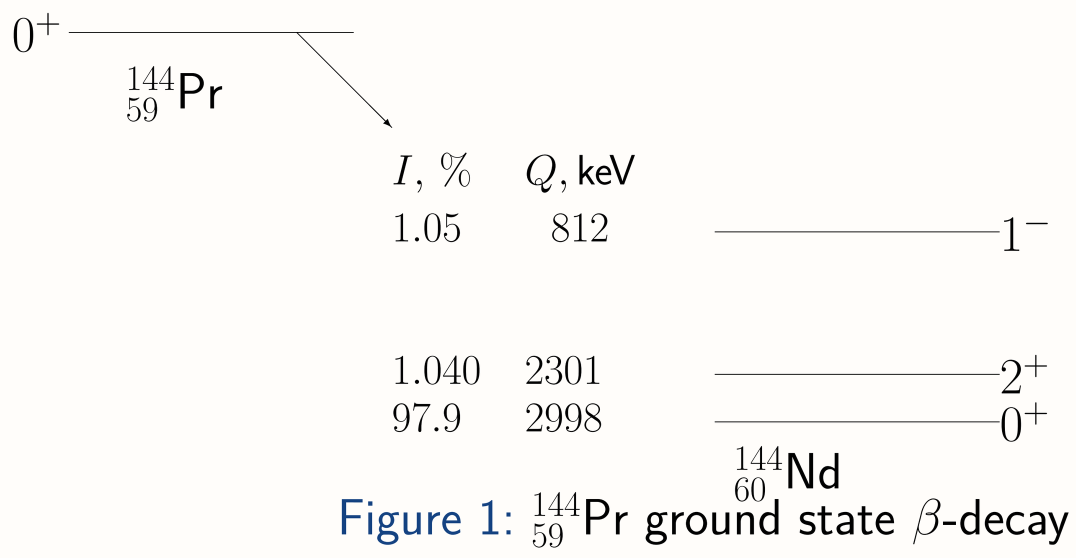

Figure 1: $^{144}_{59}$Pr ground state β-decay scheme.

Beta spectrum calculation

Let us write the electron spectrum in the following form:

$$N(E_e) = K p_e E_e (E_e - E_0)^2 F(Z, E_e) H(E_e) \times \\ \times C(Z, E_e) C_{excitation}(Z, E_e) C_{exchange}(Z, E_e)$$

Here E and E_0 are the total electron energy and the endpoint energy, p_e is the electron momentum, K is a normalization constant. The antineutrino spectrum is obtained by replacing E_e with $E_0 - E_e$.
The Fermi function $F(Z, E_e)$ describes the effect of nuclear Coulomb field on the outgoing electrons. In the case of forbidden decays one has to take into account the shape factor $H(E_e)$ depending on nuclear matrix elements. The factor $C(Z, E_e)$ includes electromagnetic and weak finite-size corrections, screening correction, radiative corrections, weak magnetism correction (see [3] for more detail). The corrections due to atomic exitations $C_{excitations}(Z, E_e)$ and atomic exchange $C_{exchange}(Z, E_e)$ are discussed below. The relative effects of corrections on antineutrino spectrum for ^{144}Pr branch with endpoint energy 2998 keV are shown on figure 2.

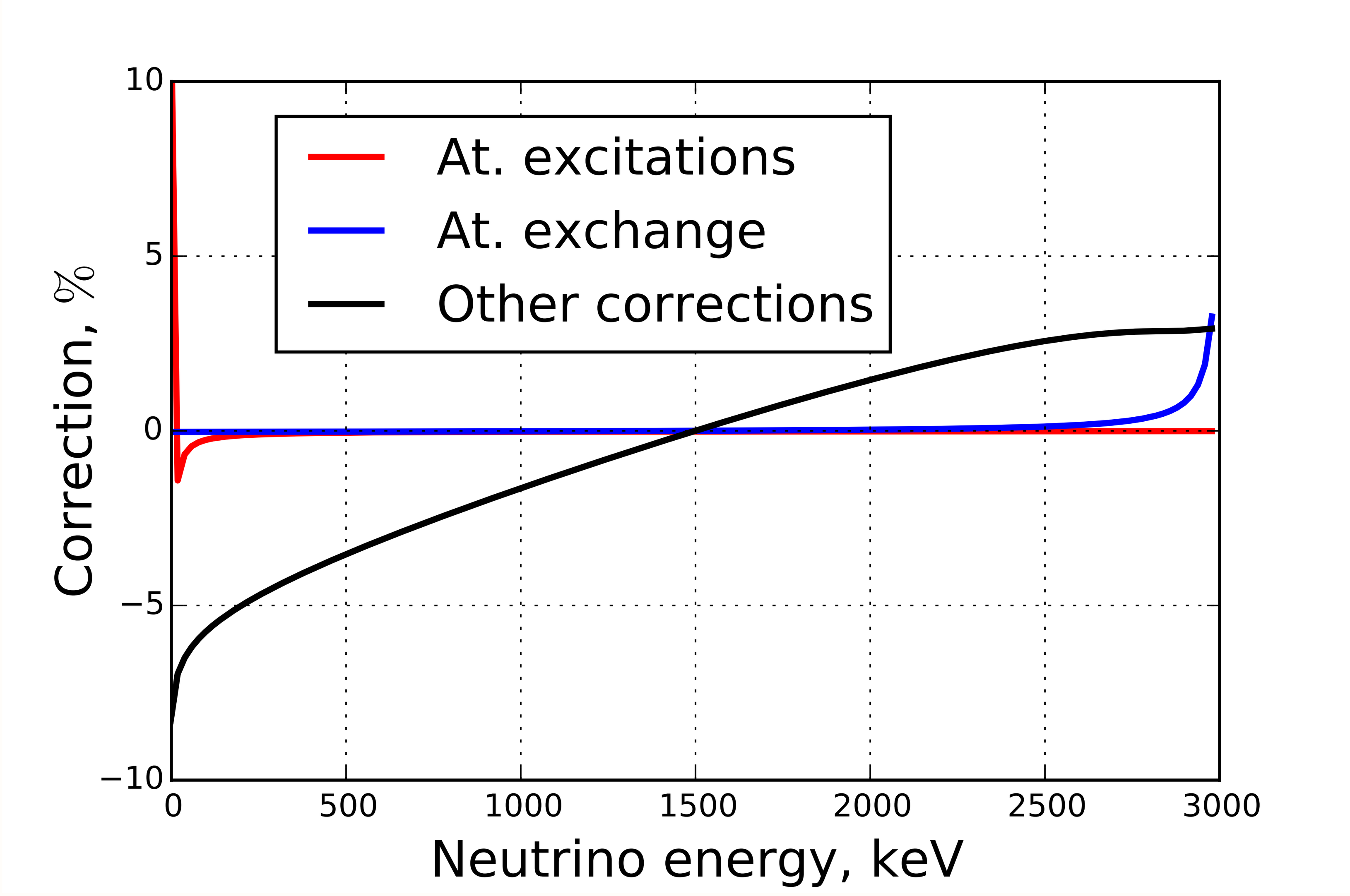

Figure 2: Relative effects of atomic excitations, atomic exchange and other corrections on antineutrino spectrum for ^{144}Pr branch with endpoint energy 2998 keV.

Atomic exitations

Imperfect overlap between atomic orbitals of the initial and final atom may cause transitions to excited states or into continuum. This effect, described by correction $C_{excitations}(Z, E_e)$, is relevant to electrons in a narrow energy range near the end-point and, thus, is not substantial for neutrino experiments. We used the formulas from [4] for computation.

Atomic exchange

The atomic exchange correction $C_{exchange}(Z, E_e)$ takes into account that the electron in β^--decay can be created not only in a continuous state, but also in a bound state on atomic orbital with a simultaneous transition of an atomic electron into continuum. For our calculations we use the results from [5]. The effect is significant for low-energy electrons ($E_e < 100$ keV) and, hence, for neutrinos with energies near the endpoint.

Conclusion

We showed the effects of atomic exchange and atomic excitations on ^{144}Pr beta spectrum and compared it to other corrections. The influence of atomic exchange can be significant for sterile neutrino searches with ^{144}Ce-^{144}Pr source. Note that there are various approaches to calculate the corrections to beta spectrum (see, e.g., the review [6]). Corrections are usually evaluated in separation from each other, and their mutual influence is often neglected. Thus, it is desirable to develop a more consistent computation method.

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