Massive neutrinos and nuclear structure

Fedor Šimkovic

Comenius University, Bratislava, Slovakia
and BLTP, JINR Dubna, Russia

The properties of the neutrinos have been the most important issue in particle physics, astro-physics and cosmology. About 70 years after discovery of neutrinos we do not know their basic properties, in particular absolute mass, CP properties, magnetic moment, nature (Dirac or Majorana), statistical properties, number of massive neutrinos etc. The nucleus is a laboratory, which allows us to measure and determine these properties or to establish useful limits on unknown parameters of particle physics side like neutrino masses.

1st Lecture "Massive neutrinos in nuclear processes": In this presentation the current status and perspective of the field of the single beta and double beta-decays is reviewed in the context of massive neutrinos. The problem of direct measurement of neutrino mass with help of the beta-decay of tritium (KATRIN), ^{187}Re (MARE) and the electron capture of ^{163}Ho (ECHo) is addressed. A connection of the neutrinoless double beta decay ($0\nu\beta\beta$-decay) to neutrino oscillations is analyzed. In view of recent measurements of the mixing angle θ_{13}, the possibility to determine the difference of two CP Majorana phases of the neutrino mixing matrix from the study of $0\nu\beta\beta$-decay is investigated. The claim of $0\nu\beta\beta$-decay in ^{76}Ge with recent negative results in ^{136}Xe and in other nuclei is compared, and with the lifetime ranges allowed or excluded at 90% C.L. are inferred. Further, the resonant neutrinoless double-electron capture in ^{152}Gd, ^{164}Er, and ^{180}W atoms, associated with the ground-state to ground-state nuclear transitions is subject of interest. The possibility of boson neutrino and partially boson neutrino is studied in light of the $2\nu\beta\beta$-decay data.

2nd Lecture "The mechanisms of the $0\nu\beta\beta$−decay": The recent progress in theoretical description of the $0\nu\beta\beta$-decay is reviewed. A novel mechanism of the $0\nu\beta\beta$-decay is presented. It is induced by lepton number violating 4-fermion neutral current interactions of neutrino with quarks from decaying nucleus. The net effect of these interactions results in generation of an effective in-medium Majorana neutrino mass, which influences the $0\nu\beta\beta$-decay rate. The light and sterile neutrino exchange mechanisms of the $0\nu\beta\beta$-decay are analyzed. The $0\nu\beta\beta$-decay with the inclusion of the right-handed leptonic and hadronic currents and by assuming small neutrino masses is revisited. Differential characteristics and phase-space integrals are calculated by using exact Dirac wave function with finite nuclear size and electron screening. The effective lepton number violating parameters are discussed in light of recent progress achieved by the GERDA, EXO and KamlandZen experiments. The possibility to discriminate between different pairs of CP non-conserving mechanisms inducing the $0\nu\beta\beta$-decay by using data on $0\nu\beta\beta$-decay half-lives of different nuclei is addressed.

3rd Lecture "Nuclear matrix elements for double beta decay": Nuclear physics is important for extracting useful information from the 0νββ-decay data. Interpreting existing results as a measurement of effective Majorana neutrino mass depends crucially on the knowledge of the corresponding nuclear matrix elements (NMEs) that govern the decay rate. The NMEs for 0νββ-decay must be evaluated using tools of nuclear structure theory. There are no observables that could be directly linked to the magnitude of 0νββ-decay NMEs and, thus, could be used to determine them in an essentially model independent way. The present-day results of the calculation of the 0νββ-decay NMEs are discussed, in particular those achieved recently within QRPA with partial restoration of the isospin symmetry. Subject of interest are the accuracy and reliability of calculated NMEs associated with different 0νββ-decay mechanisms. An impact of the quenching of the axial-vector coupling constant on double-beta decay processes is addressed. A connection between the 2νββ-decay and 0νββ-decay matrix elements is analyzed. The QRPA many-body theory is briefly introduced as well as the way of the calculation of double beta decay NMEs.