

Study of beta decay of ${}^8\text{He}$ with charged particle emission

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Abstract

This dissertation presents the results of β decay studies of ${}^8\text{He}$, the heaviest bound helium isotope, which is characterized by the largest neutron-to-proton ratio $N/Z=3$ among all known nuclei.

The experiment was performed at the Joint Institute for Nuclear Research in Dubna, Russia. The ${}^8\text{He}$ nuclei were produced in the fragmentation reaction of a 35 MeV/nucleon ${}^{18}\text{O}^{5+}$ beam impinging on a carbon target. The ACCULINNA separator was used to select and identify the nuclei of interest, which were stopped in the Optical Time Projection Chamber (OTPC). The OTPC detector is a gas detector working as a time-projection drift chamber. Charged particles are registered via detection of the light emitted from the primary-ionization charge-amplification structures. Each registered event contains a picture from the CCD camera, which represents the projection of the particle track on the anode plane, and the time distribution of the signal from the photomultiplier. The data collected from both photosensors enable the full 3-dimentional reconstruction of the particles trajectories and provide information on their energy and emission angle. In this thesis the procedure for the reconstruction of particle tracks is described. It is based on the comparison of the registered signals with the distributions generated by the code used to describe the energy-loss of ions in a gas. In the analysis, corrections taking into account the effects of diffusion and recombination of the primary charge have been included.

By using the OTPC detector, two decay channels of ${}^8\text{He}$ with charged particle emission were observed, analyzed and their branching ratios determined: (i) ${}^8\text{He} \rightarrow {}^8\text{Li} \rightarrow {}^8\text{Be}^* \rightarrow 2\alpha$ (ii) ${}^8\text{He} \rightarrow {}^8\text{Li}^* \rightarrow \alpha + t + n$. For the decay ${}^8\text{He} \rightarrow {}^8\text{Li} \rightarrow {}^8\text{Be}^* \rightarrow 2\alpha$ the energy spectrum of the emitted alpha particles was reconstructed and resulted in very good agreement with the energy spectrum determined in other experiments, thus validating the correctness of the calibrations performed and the reconstruction procedures of the OTPC data.

The most important part of the dissertation presented here is the analysis of the beta decay of ${}^8\text{He}$ with the emission of delayed triton nuclei. About 430 such decays were reconstructed, in each case the energy of triton, alpha particle and neutron, as well as the opening angle between the emitted alpha particle and triton, were determined and the energy spectra of the particles, as well the excitation–energy spectrum of ${}^8\text{Li}$ nuclei decaying into the $\alpha + t + n$ channel, were obtained. All distributions, except for the energy spectrum of tritons, were determined for the first time.

The full reconstruction of the kinematics of the ${}^8\text{Li}^* \rightarrow \alpha + t + n$ decay enabled to determine the decay mechanism of the highly excited 1^+ state in ${}^8\text{Li}$. It was found that 2/3 of the decays of ${}^8\text{He}$ proceed through a sequential decay with the formation of an intermediate ${}^5\text{He}$ resonance. In the remaining cases a direct democratic decay into the three–body $\alpha + t + n$ continuum occurs.

In this thesis, a theoretical model based on R-matrix theory and taking into account the sequential mechanism of ${}^8\text{He}$ decay was proposed. The model was used to calculate the energy spectra of the emitted particles as well as their angular correlations. Parameters describing the properties of the ${}^8\text{Li}$ 1^+ resonance state, i.e. its excitation energy, decay width and Gamow – Teller strength (B_{GT}), were treated as fitting parameters of the model. By fitting the model predictions to the experimentally–determined spectra, the position of the highly excited 1^+ state was determined to be 8.53–8.56 MeV, its width 1.25–1.47 MeV and the B_{GT} value in the range of 3.0 – 4.6. Such high B_{GT} value identifies the discussed 1^+ state as Gamow – Teller Giant Resonance (GTGR). The position of this state with respect to the Isobaric Analogue State of ${}^8\text{He}$ turns out to diverge significantly (approx. 5 MeV) from the prediction based on an extrapolation from a higher mass region. The energy of the GTGR is much better predicted by a schematic model with a separable Gamow – Teller interaction.

In the final conclusion of the thesis presented here, the need for new studies of the β – delayed neutron decay of ${}^8\text{He}$ is indicated. Also, the development of a theoretical model able to describe different mechanisms for ${}^8\text{He}$ decay and particle interactions in the final state is highly desirable.