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Measurement of the double charge exchange reaction for the ^{20}Ne + ^{130}Te system at 306 MeV

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ABSTRACT

The ^{130}Te(^{20}Ne,^{20}O)^{130}Xe double charge exchange reaction was measured for the first time at very forward angles with the MAGNEX magnetic spectrometer at INFN-LNS. The study, performed at beam energy of 306 MeV, is part of a systematic exploration promoted by the NUMEN project. The last aims to measure specific reaction cross sections to provide experimentally driven information about nuclear matrix elements of interest in the context of neutrinoless double beta decay.

Neutrinos play an intriguing role in various areas of modern physics. Nowadays, neutrinoless double beta decay ($0\nu\beta\beta$) is among the "hot" phenomena under investigation [1,2]. This hypothetical decay, which was predicted almost 85 years ago [3,4] but never observed yet, is potentially the best resource to probe the Majorana or Dirac nature of neutrino and to extract its effective mass once the $\beta\beta$ decay nuclear matrix elements (NMEs) are accurately known. Moreover, if observed, $0\nu\beta\beta$ decay will signal that the total lepton number is not conserved in nature. In this context, the novel idea to use nuclear reactions induced by heavy-ion accelerated beams as tools towards the determination of the $\beta\beta$ decay NMEs is the basis of the NUMEN (NUclear Matrix Elements for Neutrinoless double beta decay) and NURE projects [5–8] at INFN-LNS. To this extent, the ^{20}Ne + ^{130}Te system was experimentally investigated in a global approach by measuring the complete net of reactions, including not only double charge exchange (DCE), but also elastic scattering [9], single charge exchange and transfer reactions, characterized by the same initial projectile and target nuclei. The interest in the ^{130}Te system is related to the fact that it is one of the candidates for $0\nu\beta\beta$, and the search for its decay is explored by different experiments presently taking data [10] or under construction [11]. The

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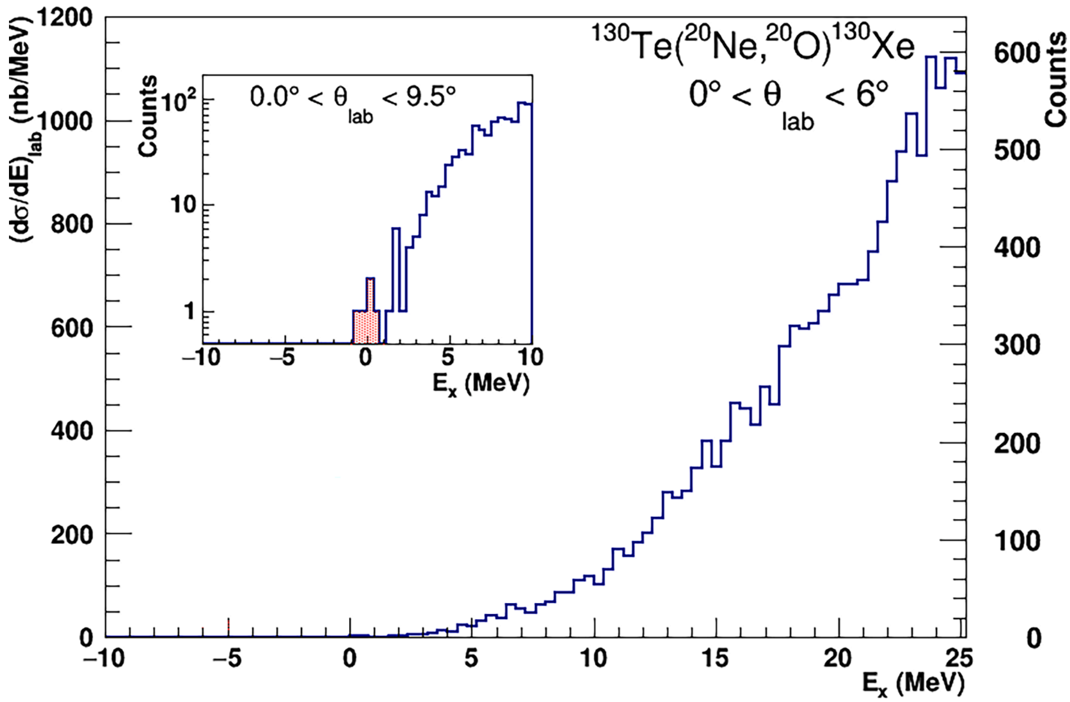

Fig. 1. Excitation energy spectrum for the ^{130}Te(^{20}Ne,^{20}O)^{130}Xe DCE reaction at 306 MeV incident energy and $0^\circ < \theta_{lab} < 6^\circ$. Inset: zoomed view for $E_x < 10$ MeV and full angular range $0^\circ < \theta_{lab} < 9.5^\circ$ with the vertical axis in logarithmic scale. The $^{130}Te_{g.s.} \rightarrow {}^{130}Xe_{g.s.}$ region (-1 MeV $< E_x < 1$ MeV) is indicated with the red dotted area (see text for details). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

analysis of the DCE reaction channel in the ^{20}Ne + ^{130}Te collision gives the opportunity to extract the cross section for the $^{130}Te_{g.s.} \rightarrow {}^{130}Xe_{g.s.}$ transition which is a crucial ingredient for extracting information on the analogous $0\nu\beta\beta$ decay transition taking place between the same initial and final states [12–15]. A deeper investigation of this and other candidate systems for $0\nu\beta\beta$ is planned in the next phase of the NUMEN project after a challenging upgrade of both the K800 Superconducting Cyclotron and the MAGNEX magnetic spectrometer of INFN – LNS [16,17].

Here we present new experimental data for the ^{130}Te(^{20}Ne,^{20}O)^{130}Xe DCE reaction leading to the cross section for the $^{130}Te_{g.s.} \rightarrow {}^{130}Xe_{g.s.}$ transition. In our experiment a $^{20}Ne^{10+}$ beam was accelerated by the K800 Superconducting Cyclotron of INFN – LNS at 306 MeV total incident energy and impinged on a ~250 μg/cm^2 ^{130}Te target, evaporated onto a thin carbon foil with a thickness of ~40 μg/cm^2. An appropriate post – stripper foil (C_3H_6 or Carbon) was located downstream the target position in order to minimize the amount of unwanted $^{20}Ne^{8+}$ and $^{20}Ne^{9+}$ elastically scattered events reaching the focal plane [18]. The various ejectiles were momentum analyzed by the MAGNEX spectrometer [19] whose optical axis was set at $\theta_{opt} = -3^\circ$, allowing the measurement in the angular range of scattering angles $0^\circ \leq \theta_{lab} \leq 9.5^\circ$. The different ions were detected by the MAGNEX Focal Plane Detector (FPD) [20]. Adopting a particle identification technique as described in Ref. [21] and thanks to the excellent Z, mass and charge state resolution of MAGNEX, the $^{20}O^{8+}$ ions were appropriately selected. A software high – order trajectory reconstruction was applied to the data [22] and, the excitation energy ($E_x = Q_0 - Q$, where Q_0 is the g.s. to g.s. Q-value) spectra were obtained.

The excitation energy spectrum for the ^{130}Te(^{20}Ne,^{20}O)^{130}Xe DCE reaction is presented in Fig. 1 up to 25 MeV. Due to the finite angular and energy acceptance of MAGNEX [19], a measurement in the angular region $0^\circ < \theta_{lab} < 9.5^\circ$ was possible at excitation energy region up to 10 MeV while, an exploration up to 25 MeV requires the limited angular range $0^\circ < \theta_{lab} < 6^\circ$. The shape of the spectrum is rather structureless due to high density of the ^{130}Xe excited states [23] and the finite experimental energy resolution, which is typically 500 keV full width at half maximum in similar MAGNEX experiments [24,25]. In the ground state region, the counts are distributed in a peaked structure, which includes the transitions to the $^{20}O_{g.s.}(0^+)$ + $^{130}Xe_{g.s.}(0^+)$ and $^{20}O_{g.s.}(0^+)$ + $^{130}Xe_{0.536}(2^+)$ [23,26].

Only a few events were detected in the ground state region. The best estimate for the integrated cross section is 13 nb ([3,18] nb at 95% confidence level) in the angular range $0^\circ < \theta_{lab} < 9.5^\circ$ and in the energy range -1 MeV $< E_x < 1$ MeV. A contribution due to the first excited state of ^{130}Xe at 0.536 MeV may be expected in this region and therefore it may be included in the given cross section. No spurious events were observed in our measurement, as demonstrated by the fact that there are no counts at the negative excitation energy region while any background due to target or/and post – stripper contaminations (mainly carbon) is expected at $E_x > 33$ MeV due to kinematics. The present measurement provides, for the first time, the estimation of the order of magnitude of the extremely low DCE cross section for the transition under study. It should be highlighted that the upgrade of the Superconducting Cyclotron of INFN – LNS and the MAGNEX FPD are now in progress, therefore this reaction will be revisited with a much higher beam current allowing for a measurement with better statistics.

In summary, the ^{130}Te(^{20}Ne,^{20}O)^{130}Xe DCE reaction was measured for the first time in the MAGNEX magnetic spectrometer as a part of the NUMEN and NURE projects which aim at shedding light on the NMEs of the $0\nu\beta\beta$ decay. Our experimental results give an important input to the next phase of the NUMEN project in which a deeper investigation of many nuclei, candidates for $0\nu\beta\beta$ decay, is planned.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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