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Inelastic process observed in charge-exchange reactions of ^{56}Fe at 500 MeV/u

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Abstract. The inelastic (IE) component of the reaction product, which is produced through charge-exchange reactions at relativistic energies of $E \sim 1$ GeV/u, is one of the hopeful probes used to study the nuclear medium effect on Δ excitation. In the present study, the longitudinal-momentum (P_L) distribution of ^{56}Co, produced by bombarding C- and CH_2-target with a primary beam of ^{56}Fe at E=500 MeV/u, was observed by means of the spectrometer at HIMAC facility. The IE peak of ^{56}Co, produced from H and C targets, was successfully observed in energy transfer spectrum. The behaviors of the IE peaks are consistent with those observed in previous experiments. A remarkable reduction of the energy transfer for the IE process was also observed with C target compared with H target. The present results have shown the feasibility to investigate the energy transfer in charge-exchange reactions for heavy reaction system at the energy down to 500 MeV/u.

1 Introduction

In charge-exchange reactions at intermediate and relativistic energies, two reaction processes, quasielastic (QE) and inelastic (IE) processes, are included. It was indicated that the energy shift of the IE peak, which corresponds to Δ excitation, could be a good probe to study the nuclear medium effects by Udagawa et al.[1]. Systematic measurements performed at Saclay [2] have revealed behaviours of IE peaks found in longitudinal momentum (P_L) distributions of reaction products, produced from relativistic heavy ions (up to ^{40}Ar). The energy shift of the IE peak contains various contributions to be studied [1] and depends on incident energy as well as on reaction system. For instance, the IE peak was observed in the reaction ^{12}C(^{3}He, t) at the incident energy down to 500 MeV/u [3]. In the reaction, an amplitude of the IE peak decreases, whereas a peak position shows the downward energy shift with decreasing the incident energy. Recently, the IE peak was successfully

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observed in P_L distribution with a ^{208}Pb beam at 1A GeV by using the spectrometer FRS at GSI [4]. In order to confirm the feasibility to observe the energy shift for heavy reaction system at lower incident energy, P_L distributions of products in charge-exchange reactions at 500 MeV/u were observed at HIMAC facility with the relatively simple detection system in the present study.

2 Experimental

The measurement was performed at NIRS (National Institute of Radiological Sciences). ^{56}Co was produced through charge-exchange reactions by bombarding a 0.5-mm thick C-target and a 1-mm thick CH_2 target with a primary beam of ^{56}Fe at E = 500 MeV/u, provided by HIMAC synchrotron accelerator. The target thickness was selected to make the energy loss equivalent for C and CH_2 targets. Produced ^{56}Co was separated and identified with a high-energy transport system, SB2 [5], used as a doubly achromatic spectrometer. The momentum acceptance of the spectrometer was adjusted to $\Delta P/P$ =±0.05%. The angular acceptance was adjusted to ±13 mrad in both θ_x and θ_y. In order to observe the P_L distributions, the magnetic rigidity of the spectrometer was varied over a range of 98.8 ~ 100.1% with a step of 0.1% of that corresponding to the primary-beam velocity. The identification of reaction products was carried out by measuring the magnetic rigidity of SB2, and time-of-flight (TOF) and energy deposit (dE) of the reaction products. The detector system is rather simple compared with that used in [4]. Two plastic scintillation counters, installed at the dispersive focusing point F1 and the doubly achromatic focusing point F3, as shown in Figure 1, were used to measure TOF. Two silicon counters, installed at F3, were used to measure dE. A 17.6 mm thick wedge-shaped Al degrader was placed at F1 to reduce any contamination of ^{56}Co. In order to obtain the production rate, the counting rate of ^{56}Co was normalized by the primary-beam intensity and the thickness of the target, and was corrected by considering the momentum and angular acceptance defined by SB2. The primary-beam intensity was monitored as the count of charged particles scattered from a thin foil, which was inserted at an upstream position of the target. The typical value of the ambiguity in the calibration of the beam-intensity monitor was about ±5%. According to the charge-state distribution of the reaction products at 500 MeV/u evaluated by CHARGE code [6], the contributions of ^{56}Co, which were not fully stripped, were at most 0.04%, and negligible compared with other ambiguities.

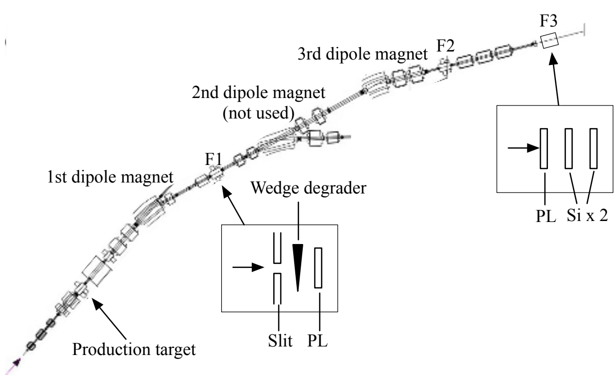

Figure 1 Secondary beam course, SB2, in the HIMAC facility. The detectors were installed at F1 and F3, as shown in the figure.

3 Results and discussion

A wedge-shaped Al degrader placed at F1 improved the predominance of ^{56}Co, as shown in Figure 2. Combining two dE signals, the tail part found in dE spectrum can be reduced to about 1%. It was experimentally confirmed that the angular acceptance of SB2 (±13 mrad both in θ_x and θ_y) covers most parts of the angular distribution of ^{56}Co. By normalizing the observed counting rate with the primary-beam intensity, the production rate of ^{56}Co as a function of the rigidity of SB2 was provided for each target, as shown in Figure 3. The difference in the observed momentum of ^{56}Fe ejecting from each target was small (~ 5 MeV/c), compared with the momentum acceptance of SB2 (~60 MeV/c). Therefore, the production rate of ^{56}Co with H target is provided as a simple subtraction of that with the C target from that with CH_2 target by adjusting the amount of C nuclei in each target. The P_L distributions of ^{56}Co produced from the H and C targets were obtained as shown in Figure 4. Considering the isotope-dependent energy loss in the target, the momentum shift of ^{56}Co from those corresponding to the primary beam is provided from the rigidity of SB2. In Figure 4, two peaks, that correspond to QE and IE processes, can be clearly seen at ΔP_L ~ -150 and -500 ~ -400 MeV/c, respectively.

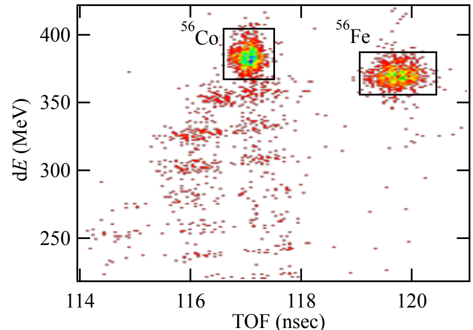

Figure 2 Particle identification in the dE‐TOF plane at Bρ = 99.8% with the C target.

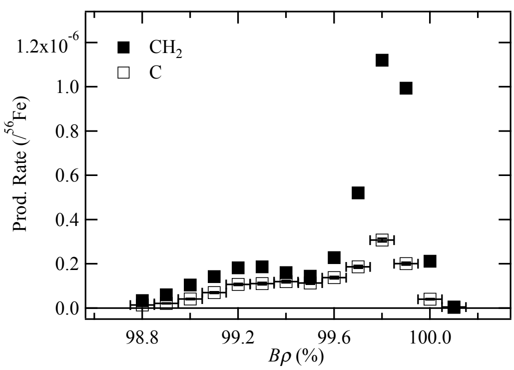

Figure 3 Production rate of ^{56}Co produced through the reaction with C and CH_2 targets at 500 MeV/u as a function of the relative rigidity (Bρ) of SB2.

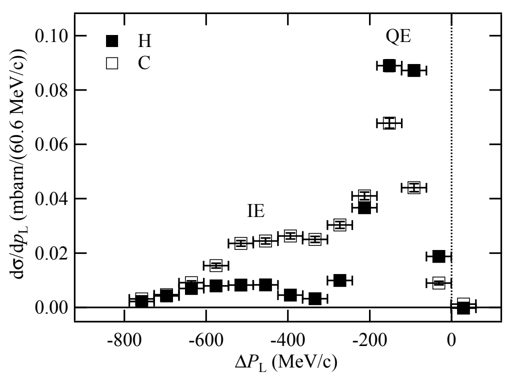

Figure 4 P_L distributions of ^{56}Co produced with H and C targets. ΔP_L denotes the momentum shift from that corresponding to the primary beam velocity.

Energy transfer spectra are obtained from observed P_L distributions as shown in Figure 5. The origin of the energy transfer is defined based on the center of the QE peak. In order to resolve the quantitative features of QE and IE peaks, the spectra are analyzed by double Gaussian functions. The contribution of momentum acceptance of SB2 ($\Delta P/P$ =±0.05%) was considered in the fitting function. As shown in the figure, obtained energy transfer spectra are well reproduced by the fitting. The fitting

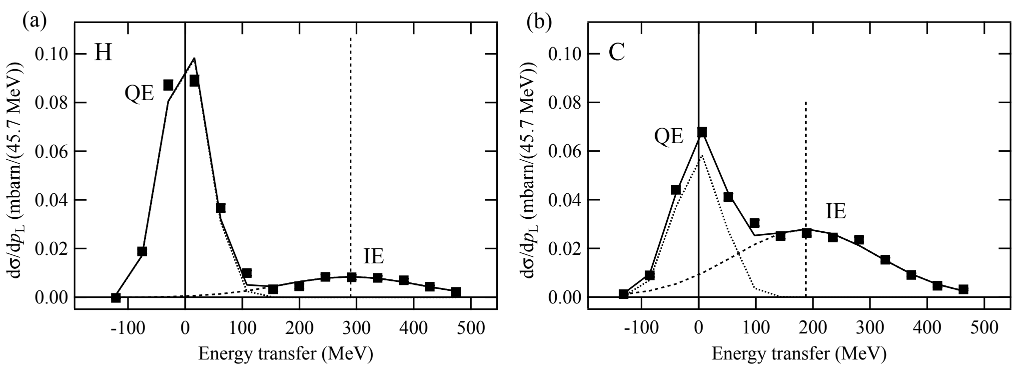

Figure 5 Energy transfer spectra for charge-exchange reactions with (a) H and (b) C targets. The solid line indicates a fitting result and dotted lines indicate QE and IE peaks. The vertical dotted line indicate the center of the IE peak.

parameters for each peak are summarized in Table 1. The width of the QE peak does not depend on the target. Also, the amplitude of the QE peak for C target decreases by about 40% compared with that for H target. The decreasing behaviour for the heavier target is consistent with that observed in [4]. Concerning the IE peak, the width, which does not depend on the target, is larger than that of the QE peak. Considering the narrow width of QE peak, the dominant part of that of the IE peak is evaluated as that is originated from the IE process. The center and amplitude of the IE peak shows a remarkable target dependence. The energy transfer for H target agrees with the previous results [1, 4]. The energy transfer for C target shows a remarkable reduction compared with H target. In contrast to the QE peak, the amplitude of the IE peak for C target increases by a factor 3.5.

Table 1. Fitting results of energy transfer spectra

	Amp. (mbarn/45.7 MeV)	Center (MeV)	Width (MeV)
H QE	0.408 ± 0.007	0	37.1 ± 0.5
IE	0.098 ± 0.006	289.4 ± 8.1	117.9 ± 8.7
C QE	0.238 ± 0.009	0	39.3 ± 1.3
IE	0.341 ± 0.010	187.4 ± 4.6	124.9 ± 3.1

4 Conclusion

Energy transfer spectra of ^{56}Co, produced through charge-exchange reactions with H and C targets at 500 MeV/u, were obtained from observed P_L distributions. The IE peaks, which correspond to Δ excitation in the nuclear medium, were successfully observed, and the behaviours of the peaks are consistent with the previous results. Especially, a remarkable reduction of the energy transfer was observed for C target compared with H target. In addition, the present results have shown the feasibility to investigate the energy transfer in charge-exchange reactions for heavy reaction system at the energy down to 500 MeV/u. And HIMAC facility is available for the experiment.

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