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# Systematic Study on Polarization of Reaction Products in ($^{13}C$, $^{12}B$) Reactions

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Single-proton transfer reactions ($^{13}C$, $^{12}B$) on seven target species have been studied systematically from the dependence of polarization of reaction products $^{12}B$ on the reaction Q-value at $\Theta_L$=20° using 91 MeV $^{13}C$ beams.

Polarization of reaction products is a subject from the infancy of nuclear physics studies. Not only do the polarization phenomena provide one with an important insight into the mechanism of reactions but also offer a possibility of spectroscopic studies of polarized unstable nuclei, if heavy-ion reactions are involved.

An elaborated clarification of polarization phenomena has been furnished recently for two-nucleon transfer reactions ($^{14}N$, $^{12}B$) [1-5] and the systematic behaviour of polarization has been envisaged.[5] The present experiment is a trial to see if a systematic behaviour prevails also in other types of reactions. Single nucleon transfer reactions are most accessible from the theory and the data will be reinterpreted in a more sophisticated microscopic models when they are completed.

The experimental method is similar to that used in the study of ($^{14}N$, $^{12}B$) reactions[1]. Use was made of the range method to establish the windows for the kinetic energy of reaction products $^{12}B$ and the asymmetry of beta-rays from the reaction products $^{12}B$ was observed to measure the polarization of beta-emitting nuclei $^{12}B(I^{\pi}=1^+$, $T_{1/2}$=20 ms and $E\beta_{max}$=13.37 MeV). A detailed description of the method is described elsewhere.[4]

Beams of 91 MeV $^{13}C$ ions were obtained from the 14 UD Pelletron of the Weizmann Institute of Science. The beam was pulsed at the low-energy end and the on- and off-beam times were 30 and 50 ms, respectively. Reaction products were implanted into a platinum stopper after being passed through the aluminium energy degrader. A static magnetic field of 1 kG was applied at the stopper along the reaction normal. Beta rays were detected by a pair of scintillation detector telescopes. An adiabatic-fact-passage NMR was applied to invert bodily the polarization of the implanted $^{12}B$ nuclei at every other beta-ray counting period and the measured polarization was free from the influence of instrumental symmetries.

Figure 1 shows the experimental results. In order to guide eyes, smooth curves were drawn as near as possible to the middle of the experimental points. The typical width of energy bins is 5 MeV and uncertainty in the measured polarization is 6 %. Six to seven experimental points reside on the kinetic energy axis. The sign of polarization is taken positive when $\vec{P}$ is parallel to $\vec{k}_f \times \vec{k}_i$.

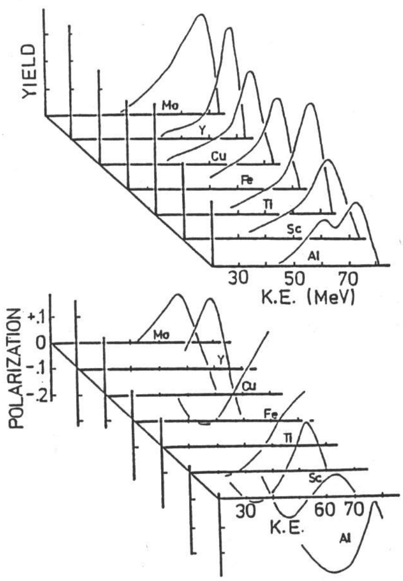


Fig. 1. Energy spectra (upper) and polarization (lower) of $^{12}B$ from the reactions ($^{13}C$, $^{12}B$) on various target nuclei as indicated.

The energy spectra have a single peak with a long tail towards smaller kinetic energy, except for the reaction $^{27}Al(^{13}C$, $^{12}B)$, where a small additional peak is seen on the tail. The rise to the maximum is abrupt on the side of larger kinetic energy. The tails extend to diminish at the energy corresponding to the Coulomb energy between the two-body reaction products at their closest contact.

The dependence of polarization on reaction Q-value shows a systematic beahviour. Polarization varies with changing reaction Q-value or kinetic energy of the reaction products. Polarization starts to deviate from zero as the reaction yield increase from zero at the smallest possible kinetic energy for $^{12}B$ nucleus. The sign of polarization exhibits a crossover as the kinetic energy of $^{12}B$ nucleus increases. The crossover of the sign of polarization takes place at kinetic energy corresponding to the maximum in the energy spectrum. The reactions on the three target nuclei, sustaining small atomic numbers, e.g., $^{nat}Ti$, $^{45}Sc$ and $^{27}A\ell$ produce a bouncing back of the sign of polarization and the sing of polarization is negative at the largest kinetic energies.

The sign of polarization shows a marked change at smaller kinetic energies than those at the maxima in the energy spectra for the reactions $^{nat}Mo(^{13}C, {}^{12}B)$ and $^{89}Y(^{13}C, {}^{12}B)$ the sign of polarization is positive, while it is negative for the $(^{13}C, {}^{12}B)$ reactions on the lighter targets than these, $^{nat}Cu$, $^{57}Fem$, $^{nat}Ti$, $^{45}Sc$ and $^{27}A\ell$. This supports an interpretation in terms of a macroscopic model. The reaction proceeds along a reaction trajectory. Those for the interaction of $^{13}C$ with a heavy target, e.g., $^{nat}Mo$ and $^{89}Y$ and of $^{12}B$ with the residual nucleus are deflected outwards from the target nucleus, owing to a strong Coulomb repulsion. The sign of the deflection angle is positive, so does the sign of polarization become positive. Such with a lighter target, e.g., $^{nat}Cu$, $^{57}Fe$, $^{nat}Ti$, $^{45}Sc$ and $^{27}A\ell$ is deflected inwards to the centre of the target nucleus owing to a strong inter-nuclear attraction when the kinetic energy of the product nucleus is small. The sign of the deflection angle is negative and that of polarization becomes negative.

At larger kinetic energy than the crossover point, polarization behaves differently for reactions on various target nuclei. Polarization decends abruptly from zeto at the cross-over point to negative values in the reactions on heavy target nuclei, $^{nat}Mo$ and $^{89}Y$. This is attributed to the direct process first observed in the polarization of $^{12}B$ from the reaction $^{100}Mo(^{14}N, {}^{12}B)$ at 90 MeV.[1,6,7] The sign of the deflection angle is positive. This means that the reaction trajectory keeps the positive deflection angle throughout the course of diminishing kinetic energy. The sign of polarization is positive for the medium target nuclei $^{nat}Cu$, $^{57}Fe$ and $^{nat}Ti$ in the range of kinetic energy above the crossover point. This reflects the larger contribution of positive deflection angle where the macroscopic description is still valid.

The lightest three target nuclei $^{nat}Ti$, $^{45}Sc$ and $^{27}A\ell$ shows a bouncing back of the sign of polarization towards the negative value at the highest kinetic energy. This is first observed for the light target nuclei. If this can be attributed to the direct process along an trajectory with the positive deflection angle, it can not be in accord with the fact that such is not observed in the reactions on $^{nat}Cu$ and $^{57}Fe$.

The systematic behaviour of polarization observed in the experiment can be interpreted in terms of the models which successfully explain the behaviour of polarization in the $(^{14}N, {}^{12}B)$ reactions. Such behaviour is considered to be a general feature in the heavy-ion transfer reactions, although small negative polarization at the làrgest end of kinetic energy axis for the lightest target nuclei is still to be clarified.

Possibility of using polarized nuclei from the heavy-ion transfer reactions is promising for studying spectroscopy of short-lived nuclei controlling the state of polarization.

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