Observation of a giant Gamow–Teller resonance in the reaction $^{90}Zr(^{6}Li, ^{6}He)^{90}Nb$

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The (^{6}Li, ^{6}He) reactions induced by 93-MeV ^{6}Li ions have been studied in the isotropes ^{13}C and ^{90}Zr in the angular interval 10°–14°. A giant Gamow–Teller resonance has been observed in the reaction (^{6}Li, ^{6}He) for the first time, at excitation energy $E_x \sim 8.7$ MeV. In addition, an $M1$ resonance may have been observed at an excitation energy of 13 MeV; this would be the analog of the $M1$ resonance of the ^{90}Zr nucleus.

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Immediately after the discovery of isobaric analog states, whose excitation in (p,n) reactions may be thought of as Fermi transitions, Ikeda *et al.*[1] predicted a giant Gamow–Teller resonance. It would be reasonable to expect this resonance to be excited well in charge-exchange, spin-flip reactions.

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Some interesting possibilities here are presented by the reaction (^{6}Li,^{6}He). Since its amplitude is determined primarily by the $(\sigma_1\sigma_2)(\tau_1\tau_2)$ interaction,[2,3] it may be advantageous to study this reaction instead of other charge-exchange reactions, e.g., (p,n) and (^{3}He,t), in which an interaction without spin flip is also important. It has not previously been possible to observe a Gamow–Teller resonance in the (^{6}Li,^{6}He) reaction, primarily because the energies of the ^{6}Li ion beams have been too low.

Our purpose in this study was to determine whether the reaction (^{6}Li,^{6}He) would in fact be useful for studying Gamow–Teller and other spin-flip excitations. This topic is of particular interest because observation of a Gamow–Teller resonance was recently reported[4] in the reaction (p,n) at 0°.

In the present experiments we studied the reaction (^{6}Li,^{6}He) in a beam of 93-MeV ^{6}Li ions. The targets were free-standing films of the isotopes ^{13}C and ^{90}Zr. The reaction products were measured with a $\Delta E_1 - \Delta E_2 - E$ counter telescope connected in a double system for two-dimensional analysis ($\Delta E_1 - E$ and $\Delta E_2 - E$), which worked on-line with an ES-1010 computer. A one-dimensional energy spectrum was recorded only if the events detected corresponded to certain ^{6}He positions in the two two-dimensional spectra (simultaneously). Devices in the ΔE and E systems reduced the background from pulse overlap.

The energy distributions of the ^{6}He nuclei were measured at several angles beginning at 10°. Figure 1 shows some of the spectra, for an angle of 12°. The excitation spectrum of the nucleus ^{13}N has a group of levels running up to an excitation energy ~20 MeV, but the most intense excitation is the doublet 3.51 ($3/2^-$)–3.55 ($5/2^+$)

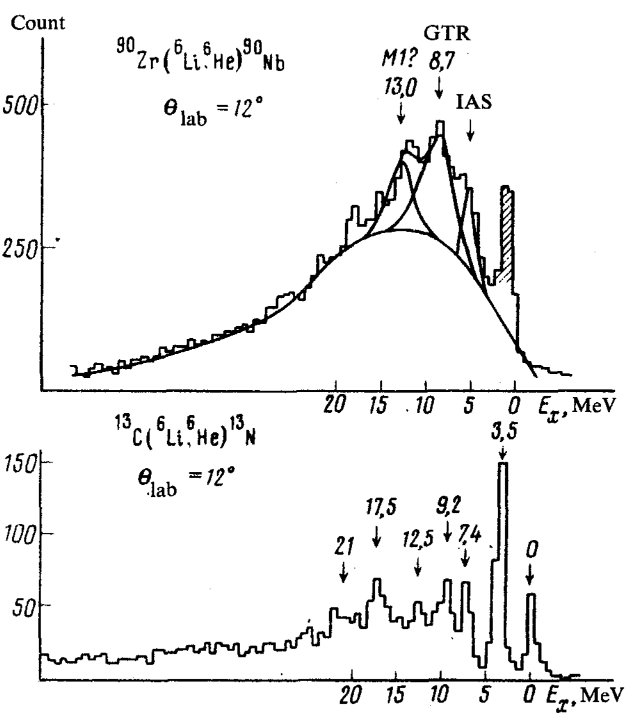

FIG. 1. Energy spectra of ^{6}He nuclei from the reactions ^{13}C(^{6}Li,^{6}He) and ^{90}Zr(^{6}Li,^{6}He)^{90}Nb at an angle of 12°. The hatched peak in the upper part of the figure corresponds to overlapping pulses from the elastic-scattering peak.

MeV, forbidden in our experiment; the $3/2^-$ state here corresponds to a Gamow–Teller transition. The reaction in the isotope ^{13}C was used for an energy calibration of the ^{90}Nb distributions as well as to illustrate the selectivity of the (^6Li,^6He) reaction with respect to the excitation of Gamow–Teller states.

In the energy spectrum of ^6He nuclei from the reaction $^{90}Zr(^6Li,^6He)$ we can clearly see a structure which can be approximated crudely by two Gaussian peaks with widths of 4.3 and 3 MeV, centered at excitation energies of 8.7 and 13 MeV, respectively. The errors in the positions and widths of the peaks, which are about 0.5 MeV, are determined primarily by the ambiguity in the decomposition of the observed structure. The most intense peak, at an excitation energy of 8.7 MeV, corresponds to the position of the giant Gamow–Teller resonance observed by Bainum *et al.*[4] The excitation energies found for the Gamow–Teller resonance in both these experiments agree well with the energy calculated by Gaponov and Lyutostanskiĭ[5] from the theory of finite Fermi systems. The peak at the excitation energy ~ 13 MeV, on the other hand, is probably an analog of the $M1$ resonance of ^{90}Zr $(1^+, T=5)$. This state is excited much more intensely in the reaction (^6Li,^6He) than in the (p,n) reaction. The origin of the group corresponding to the excitation energy of 5 MeV is not clear. There is an isobaric analog state 0^+, $T=5$ in this region; its excitation in the direct reaction (^6Li,^6He) is forbidden by the selection rules and could occur only by a stepwise mechanism. At low energies of the ^6Li ions (30 MeV) this mechanism makes some contribution to the reaction amplitude, but its role at higher energies requires special study.

In addition to the Gamow–Teller resonance and the $M1$ resonance in the reaction (^6Li,^6He), we can expect the excitation of other states with a significant Gamow–Teller matrix element. According to the calculations by Gaponov and Lyutostanskiĭ,[5] these states should lie well below the isobaric analog states in ^{90}Nb. It is possible that these states are masked by the peak from overlapping pulses of elastically scattered ^6Li nuclei, which span the excitation-energy interval 1–2 MeV.

The most important result of this study has been to demonstrate that the excitation of giant resonances associated with spin flip is observed in the reaction (^6Li,^6He), even at angles as large as 10°–14°, so that with smaller groups the selectivity of this reaction may prove much better than that in other charge-exchange reactions. By way of comparison, we note that the Gamow–Teller states can be observed reliably in the (p,n) reaction only at angles near 0°.

The (^6Li,^6He) reaction will be discussed in more detail in a separate paper; in particular, the angular distributions will be analyzed.

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