Isospin symmetry of M1 and GT transitions in the A=10 nuclei

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In our recent work [1, 2], we demonstrated the feasibility of getting high-resolution (n,p)-type spectra by using an intermediate energy triton beam produced with the breakup reaction ^{4}He$\rightarrow$t+p. Fig. 1 shows the (t,^{3}He) spectra obtained at 0° on targets of ^{9}Be, ^{10}B, ^{11}B, ^{12}C, and ^{13}C. The energy resolution obtained was $\sim$780 keV full-width-at-half-maximum (FWHM) for the ^{12}C target. The results from peak fitting are shown by the solid curves in the (t,^{3}He) spectra of Fig. 1. Gaussian line shapes were assumed for the peaks, and a quasi-free shape was assumed for the non-resonant background. The latter was successfully used in fitting (^{3}He,t) spectra with the semi-phenomenological function given in Ref. [3].

The transition from the 3^+ ground state of ^{10}B to the 0^+ ground states of ^{10}Be (not shown) was very weak as expected. The ^{3}He-particle energy spectrum for the ^{10}B(t,^{3}He)^{10}Be reaction, shown in Fig. 1(b), covers higher excitation energies. Three narrow peaks were seen at E_x = 3.37 MeV, 5.96 MeV, and 9.4 MeV; that at 5.96 MeV is the strongest. The peaks at 3.37 MeV and 5.96 MeV are GT transitions from the 3^+ ground state of ^{10}B to the 2_1^+ and 2_2^+ states in ^{10}Be. The spin-parity of the 9.4 MeV state is most likely 3_1^+, since shell-model calculations by Wang *et al.* [4] predict the presence of a strong GT transition to a 3_1^+ state at $\sim$9 MeV in the mirror nucleus ^{10}C and since two neutrons in the $p_{3/2}$ shell orbital can easily couple to $J^\pi=3_1^+$. A definite spin-parity assignment, however, is not yet given for the 9 MeV state, and the possibility of a 2^+ or 4^+ assignment cannot be excluded. The nature of the broad peak at $E_x\approx$12 MeV is not clear at present.

In Fig. 2, a new isobar diagram for T=1 mirror GT and M1 states is proposed for the A=10 system by taking into account the compilation of energy level data [5]. The 2_1^+ states at 3.37 MeV in ^{10}Be, at 5.16 MeV in ^{10}B, and at 3.35 MeV in ^{10}C are mirror states. The 2_2^+ states at 5.96 MeV in ^{10}Be, at 7.48 MeV in ^{10}B, and at 5.38 MeV in ^{10}C also constitute mirror states. These 2_2^+ states are excited with strong GT and M1 strengths. The M1 strength from the 3^+ to 2_2^+ states in ^{10}B is measured as B(M1)=1.745 μ_N^2 [6]. From this value, we can estimate the expected B(GT) values for the corresponding mirror states in ^{10}Be and ^{10}C by neglecting possible contributions from orbital excitations and from the isobar and meson exchange currents [7]. The value of B(GT)=B(M1)/2.64μ_N^2=0.66 agrees with the measured value B(GT$_-$)=0.68$\pm$0.02 obtained in the ^{10}B(p,n)^{10}C experiment [4]. On the other hand,

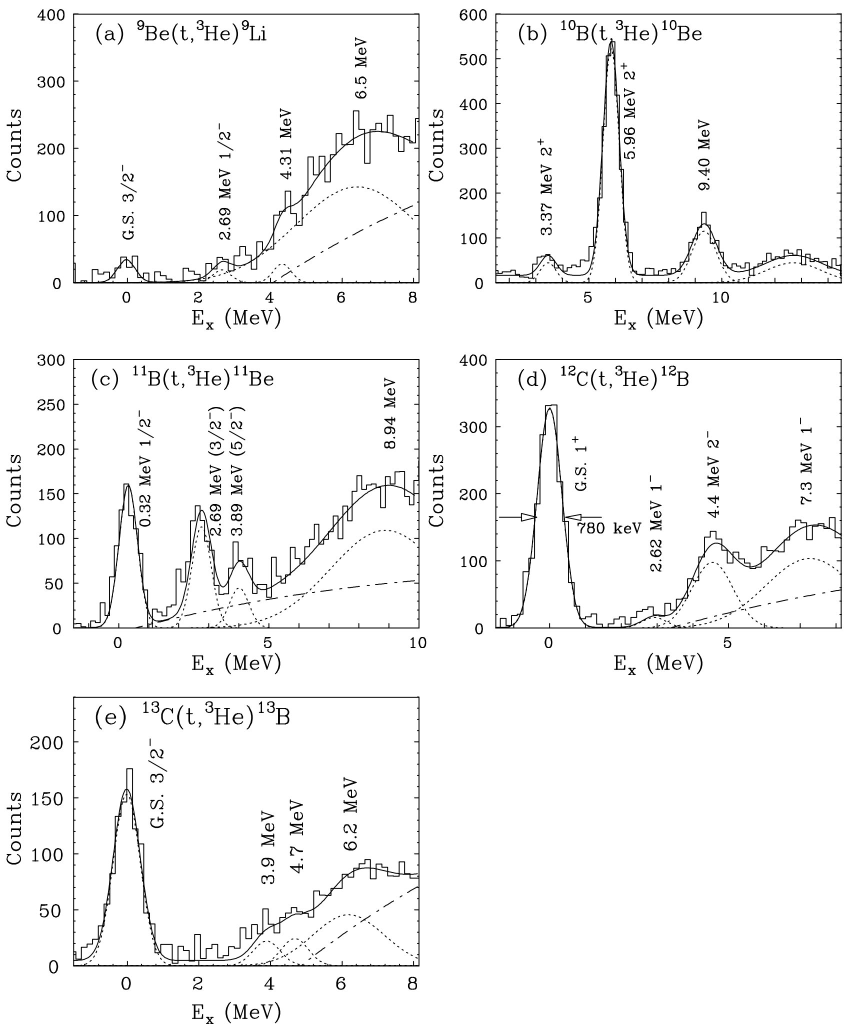

Figure 1: ^{3}He-particle energy spectra from the (t,^{3}He) reaction at 0° taken with a triton beam of 127 MeV/A. The dispersion matching method in charged-particle optics is applied to correct for the energy width of ~23 MeV of the initial triton beam from the (^{4}He,p+t) breakup reaction. The solid and dotted curves are the results of peak fitting. The dot-dashed curves represent the non-resonant quasi-free background. Experimental constant background was subtracted.

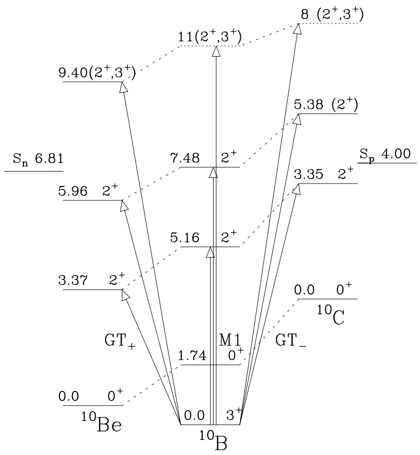

Figure 2: Isobar diagram for the A=10 system and states with GT_+, M1, and GT_- transitions from the ^{10}B ground state. The strong transitions into states in ^{10}Be, ^{10}B, and ^{10}C are indicated by the arrows. The mirror candidates for the 9.4 MeV state in ^{10}B have not been observed. They are estimated at 11 MeV in ^{10}B, and at 8 MeV in ^{10}C.

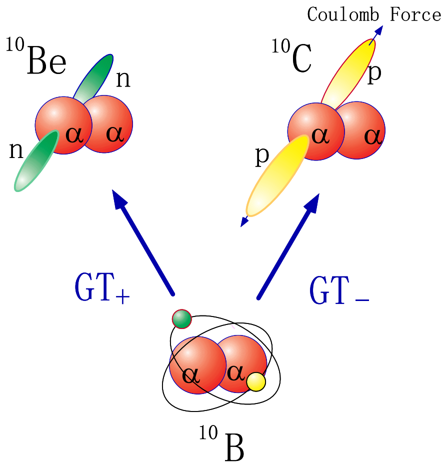

Figure 3: Schematic explanation of the Gamow-Teller transitions from ^{10}B. A simple alpha cluster model predicts that ^{10}C consists of two α particles surrounded by two valence protons in a (0,1,0) orbit in terms of harmonic-oscillator orbits (n_x, n_y, n_z). For details, see Ref. [8]. ^{10}Be is the isobaric mirror nucleus, in which two neutrons are in the (0,1,0) orbit without any effects from the Coulomb force.

the value measured in the present experiment of B(GT_+)=0.95±0.13 to the 2_2^+ mirror state at 5.9 MeV is larger.

This isospin symmetry violation would be possible if the nuclear structure differs between ^{10}C and ^{10}Be due to the presence of the Coulomb force. It would be interesting to determine whether or not the recent elaborate theories expressed in Ref. [8] can predict the observed difference although the mirror asymmetry in allowed Gamow-Teller β-decays in light nuclei is a long-standing problem [9].

The nuclei ^{10}Be, ^{10}B, and ^{10}C represent an isospin triplet. Therefore, the GT and M1 transitions in the A=10 system can be discussed by invoking mirror relations. The three states at 3.37 MeV, 5.96 MeV and 9.4 MeV are excited (see Fig. 1(b)) in the ^{10}B(t,^{3}He)^{10}Be reaction at θ=0°. We conclude that these three states in ^{10}Be are spin-isospin-flip GT excitations (ΔS=1, ΔT=1). In the DWBA analyses for the $2_{1,2}^+$ states (E_x = 3.35 and 5.3 MeV) in ^{10}C observed in the mirror reaction ^{10}B(p,n)^{10}C at E_p=186 MeV, Wang *et al.* [4] show that the corresponding transitions to these two states are dominated by $\Delta J^\pi=1^+$. Thus, one has to conclude that the two corresponding 2^+ mirror states in ^{10}Be at E_x=3.37 and 5.96 MeV are due to Gamow-Teller transitions and are the isobaric analog states of the $2_{1,2}^+$ states in ^{10}C.

The recent theoretical calculation [8] in the framework of the anti-symmetrized molecular dynamics (AMD) predicts that the ^{10}C nucleus consists of two alpha clusters and two valence protons (see Fig. 3). The mirror ^{10}Be nucleus consists of two alpha clusters and two valence neutrons. This concept has recently been discussed on the base of the nucleon transfer data by von Oertzen [10], and he claims that preliminary evidence for such states exists. The location of the excitation energy for the second 2^+ state in ^{10}Be is below the neutron separation energy (S_n=6.81 MeV), while that in ^{10}C is above the proton separation energy (S_p=4.00 MeV). As schematically shown in Fig. 3, the Coulomb repulsive force acts to separate two protons in the two-alpha core in ^{10}C, if the valence protons locate in a special (0,1,0) orbit as predicted in Ref. [8]. This special situation originated from the alpha cluster structures in the A=10 isobar nuclei may result in a large difference between the GT_+ and GT_- transition strengths from the ^{10}B ground state.

Another question which is not understood is the presence of the strong 3_1^+ (2^+ or 4^+) state at ~9 MeV in ^{10}Be, which is also predicted in a shell-model calculation [4]. Since there was no experimental evidence for corresponding 3^+ (2^+ or 4^+) states in both in ^{10}B and ^{10}C, high resolution studies of inelastic proton scattering and charge-exchange reactions on ^{10}B has been done, and we have already confirm a good isobar relation of M1 and GT excitations in the A=10 system.

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