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Isospin Purity at High Excitation Energies as Evidenced by Cross Correlations of Mirror-Channel Fluctuations*

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The Ericson fluctuations of the mirror decays $^{15}O + ^7Li$ and $^{15}N + ^7Be$ of a ^{22}Na compound state near 53-MeV excitation energy are found to be correlated, providing evidence that isospin is a good quantum number at this high excitation energy.

For low-lying energy levels, isospin has been shown to be a good quantum number. With increasing excitation energy, though, the overlap of states with different T increases since the average width Γ of the levels becomes larger than their average separation distance D. The extent to which isospin is a good quantum number is accordingly predicted to deteriorate.[1] However, at still higher excitation energies, Γ becomes so large that it even exceeds the value of the isospin-mixing Coulomb matrix element $\langle H_c \rangle$. In other words, the half-life of the level becomes too short to let the Coulomb forces mix the isospin which should therefore again be a good quantum number.[1,2]

Experimental confirmation of good isospin purity of highly excited levels is rather limited. It consists largely of a trend for isospin-nonconserving nuclear reactions [such as $\Delta T = 1$ (d, α) reactions] to decrease in cross section with increasing bombarding energy.[3] However, the interpretation of these results in terms of isospin purity of an intermediate compound state is confused by the increasing role of direct mechanisms at higher bombarding energies. We wish to report what we think is experimental evidence of isospin purity for the overlapping levels of ^{22}Na near 53-MeV excitation energy.

In a study of the four-nucleon transfer reactions $^{19}F(^3He, ^7Li)^{15}O$ and $^{19}F(^3He, ^7Be)^{15}N$ near 40-MeV bombarding energy,[4] compound-nucleus effects were found to dominate at backward angles, as evidenced by a strong energy dependence of the cross sections. Figure 1 shows excitation

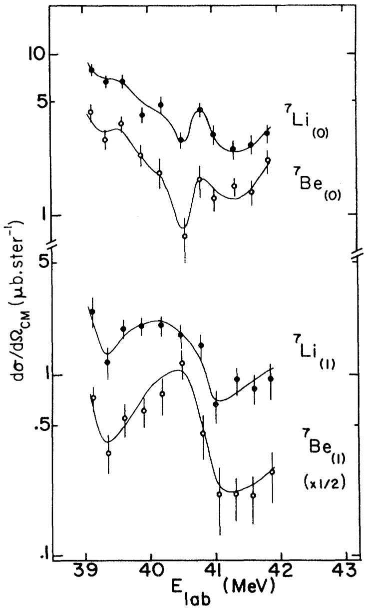

FIG. 1. Excitation functions at $\theta_{lab}=165°$ for the reactions ^{19}F(^{3}He, ^{7}Li$_{(0)}$)^{15}O(g.s.), ^{19}F(^{3}He, ^{7}Li$_{(1)}$)^{15}O(g.s.), ^{19}F(^{3}He, ^{7}Be$_{(0)}$)^{15}N(g.s.), and ^{19}F(^{3}He, ^{7}Be$_{(1)}$)^{15}N(g.s.) between E(^{3}He) = 39 and E(^{3}He) = 42 MeV.

functions at 165° for four decay channels. Two involve the ^{15}O ground state (g.s.), with ^{7}Li being in either its ground (0) or first-excited (1) state. The other two involve the mirror nuclear system, ^{15}N and ^{7}Be, either in its ground (0) or first-excited (1) state.

No cross correlation is evident between the ^{7}Li$_{(0)}$ and ^{7}Li$_{(1)}$, or between the ^{7}Be$_{(0)}$ and ^{7}Be$_{(1)}$ excitation functions. All of them also strongly differ from the excitation function of the reaction ^{19}F(^{3}He, ^{6}Li)^{16}O recorded simultaneously.[5] According to Ericson,[6] the fact that different decay-channel cross sections fluctuate independently is proof that these oscillations are of statistical origin. Only a very rough estimate of the coherence width Γ could be extracted from these data because of the short span of incident energies and the strong damping of oscillations at 165° due to the spins.[7] Our estimate for Γ is consistent with the value (~800 keV) which can be extracted from the compilation of Ref. 7 and the value (1.1 MeV) observed for ^{20}Ne at 37.5-MeV excitation energy.[8]

Two pairs of excitation functions in Fig. 1 appear to be correlated. They correspond to the mirror ^{15}O + ^{7}Li$_{(0)}$ and ^{15}N + ^{7}Be$_{(0)}$ decay channels, and to the mirror ^{15}O + ^{7}Li$_{(1)}$ and ^{15}N + ^{7}Be$_{(1)}$ channels. A quantitative analysis of the cross correlations was performed to verify this qualitative indication. For the two sets of values (x_i) and (y_j), where x and y refer to the differential cross sections at 165°, and where i and j are used to label the different incident energies, we define $A(x,y)$ and $B(x,y)$ as

$$A(x,y)=\langle |x_i/\langle x_i\rangle - y_i/\langle y_i\rangle|\rangle$$

and

$$B(x,y)=\langle |x_i/\langle x_i\rangle - y_j/\langle y_j\rangle|\rangle, \quad i\neq j.$$

It is clear that if the two sets of values x_i and y_j tend to be linearly correlated, A will be smaller than B. The quantity $\alpha = 1 - A/B$ will be equal to 1 in the case of a perfectly linear correlation and approach 0 if the values x_i and y_j are random. All values of α in Table I are different from zero. This reflects the damping of the oscillations (two flat, structureless excitation functions would be perfectly correlated) as well as any possible direct-mechanism contribution to the cross section. However, the values of α for the two mirror pairs are markedly larger than all others and confirm the occurrence of a correlation between the mirror decay channels suggested by Fig. 1.

With the commonly used definition[9] of the linear-correlation coefficient,

$$\beta=\frac{N\sum x_i y_i - \sum x_i y_i}{[N\sum x_i^2-(\sum x_i)^2]^{1/2}[N\sum y_i^2-(\sum y_i)^2]^{1/2}},$$

where β, like α, increases from 0 to 1 with increasing correlation, we obtain the numerical values shown in Table II which essentially confirm the conclusion derived from Table I.

Ericson fluctuations result from the coherent

Table I. Values of the correlation coefficient α (defined in the text).

	^{7}Li$_{(0)}$ + ^{15}O	^{7}Li$_{(1)}$ + ^{15}O	^{7}Be$_{(0)}$ + ^{15}N	^{7}Be$_{(1)}$ + ^{15}N
^{7}Li$_{(0)}$ + ^{15}O	1	0.45 ± 0.13	0.64 ± 0.12[a]	0.29 ± 0.15
^{7}Li$_{(1)}$ + ^{15}O		1	0.32 ± 0.15	0.61 ± 0.16[a]
^{7}Be$_{(0)}$ + ^{15}N			1	0.14 ± 0.15
^{7}Be$_{(1)}$ + ^{15}N				1

[a] Correlations between mirror decays of the compound nucleus.

Table II. Values of the linear-correlation coefficient β (defined in the text).

	$^{7}\mathrm{Li}_{(0)}+{}^{15}\mathrm{O}$	$^{7}\mathrm{Li}_{(1)}+{}^{15}\mathrm{O}$	$^{7}\mathrm{Be}_{(0)}+{}^{15}\mathrm{N}$	$^{7}\mathrm{Be}_{(1)}+{}^{15}\mathrm{N}$
$^{7}\mathrm{Li}_{(0)}+{}^{15}\mathrm{O}$	1	0.66 ± 0.13	0.91 ± 0.05[a]	0.25 ± 0.16
$^{7}\mathrm{Li}_{(1)}+{}^{15}\mathrm{O}$		1	0.56 ± 0.16	0.77 ± 0.15[a]
$^{7}\mathrm{Be}_{(0)}+{}^{15}\mathrm{N}$			1	0.45 ± 0.18
$^{7}\mathrm{Be}_{(1)}+{}^{15}\mathrm{N}$				1

[a] Correlations between mirror decays of the compound nucleus.

sum of the many matrix elements, random in phase and amplitude, which correspond to the overlapping levels constituting the compound state. The fact that in the present work these fluctuations are correlated for mirror decay channels indicates that the mirror nuclear systems equally overlap with the wave functions of these levels. Therefore we conclude that charge symmetry is preserved and that isospin is a good quantum number. Furthermore, as the cross section results from a coherent summation, it is highly sensitive to the details of the wave functions of the overlapping levels, which makes the observed correlation all the more remarkable. The preserved purity of isospin also confirms that the isospin-mixing Coulomb matrix element $\langle H_c\rangle$ is much smaller than $\Gamma \sim 1$ MeV in the range of excitation energies investigated here. At low excitation energies, the values of $\langle H_c\rangle$ typically lie between 1 and 40 keV,[10] but larger core-excitation components of the wave functions of highly excited states would increase this value.

The extraction of a quantitative value of isospin purity from mirror-channel correlation coefficients would require a study of reactions with lower spins (to enhance the fluctuations) and higher yields.

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