PHYSICAL REVIEW C VOLUME 27, NUMBER 6 JUNE 1983

Test of isospin purity by measuring cross correlations in mirror channel reactions

K. Glasner, D. Bohle, G. Domogala, L. M. Ricken, J. A. Weismüller, and E. Kuhlmann
Institut für Experimentalphysik I, Ruhr Universität Bochum,
D-4630 Bochum, Federal Republic of Germany

(Received 19 January 1983)

Strong mirror channel correlations have been observed in the reactions $^{16}O(^{6}Li,p)^{21}Ne$ and $^{16}O(^{6}Li,n)^{21}Na$. The linear cross correlation coefficient r is found to be of the order of 0.6, indicating a high degree of isospin conservation. For the compound nucleus ^{22}Na the isospin mixing matrix element $\langle V_c \rangle$ is estimated to be about 1 keV at $E_x \cong 19$ MeV.

NUCLEAR REACTIONS $^{16}O(^{6}Li,p)^{21}Ne$, $^{16}O(^{6}Li,n\gamma)^{21}Na$; $E=4.0$–8.0 MeV; measured $\sigma(E,\theta)$. ^{22}Na deduced isospin mixing. Hauser-Feshbach calculations.

A powerful approach in probing isospin purity of compound nuclear reactions is the comparison of Ericson fluctuations in mirror decay channels.[1–3] In the limit of strict charge symmetry of the nuclear Hamiltonian the cross correlation coefficient of the two mirror channel excitation functions equals their respective autocorrelation values. Measurements which, so far, have been performed on mirror decays of the compound nuclei ^{22}Na (Ref. 1) and ^{26}Al (Ref. 2) revealed a reduced cross correlation, which might point to large isospin mixing effects. A trivial reason for a reduced cross correlation, however, is that, in general, different Q values for mirror channels are found, which naturally lead to an increased yield for one of the mirror decays. It has been proposed[4] that these extra contributions can be accounted for by assuming the amplitude f_2 for the reaction with the larger cross section to be written as the sum of two amplitudes f_1+g, the former being that of the mirror reaction channel, the latter being an independently varying random amplitude. In this approach a reduction of the cross correlation by a factor $\langle\sigma_1\rangle/\langle\sigma_2\rangle$ is obtained with $\langle\sigma_i\rangle$ denoting the energy averaged cross sections of the mirror decay channels. Of course, it is desirable to have a ratio close to 1 (or $g\approx 0$) to minimize the influence of the Q-value difference; for the measurements reported so far,[1,2] however, this ratio has been of the order of 0.5.

In this paper we present first measurements on the mirror reactions $^{16}O(^{6}Li,p)^{21}Ne$ and $^{16}O(^{6}Li,n)^{21}Na$, where the effect of different Q values is almost completely counterbalanced by the absence of the Coulomb barrier in the n channel, as extensive calculations in the framework of the Hauser-Feshbach (HF) formalism have shown.

Excitation functions of the reaction $^{16}O+^{6}Li$ have been measured in 100 keV steps for bombarding energies $4.0 \leq E_{Li} \leq 8.0$ MeV [$\hat{=} 17.4 \leq E_x(^{22}Na) \leq 20.3$ MeV]. A ^{6}Li beam of 100–200 particle nA was extracted from the Dynamitron tandem accelerator at the Ruhr Universität in Bochum. The direct registration of the decay neutrons was impossible due to the low yield in ^{6}Li beam as well as the small cross sections of the $(^{6}Li,n)$ reactions. Instead, secondary γ rays were recorded with a Ge(Li) detector set at a distance of 85 mm from the target and at 125° to minimize angular distribution effects. The target consisted of a 100 $\mu g/cm^2$ MoO_3 layer on a 0.1 mm thick Ta backing. Coulomb excitation on the Ta backing observed through its successive γ-ray decay eliminated uncertainties in the deduced cross sections with respect to beam current integration and absolute γ-ray efficiency of the Ge(Li) detector. Since in ^{21}Na the proton threshold is rather low (Fig. 1), γ-ray decay is to be expected of only a few bound levels, whereas higher lying states decay by proton emission. Thus, for instance, recording the $2.42 \rightarrow 0$ MeV, third excited state to ground state $(3\rightarrow 0)$, γ-ray transition (Fig. 1) yields a measure of the total neutron cross section for the reaction to that particular level, which is displayed in the lower part of Fig. 1 by the open circles. The solid points give the mirror p cross section obtained in the same way by simultaneously measuring the analog $2.80\rightarrow 0$ MeV $(4\rightarrow 0)$ transition in ^{21}Ne. A close similarity in the structures of the two excitation functions is observed. The larger cross section for ^{21}Ne is entirely accounted for by feeding processes from higher lying states, as could be shown by HF calculations. Elimination of these contributions is necessary and was attempted as given below.

Gamma-ray excitation functions were also obtained

©1983 The American Physical Society

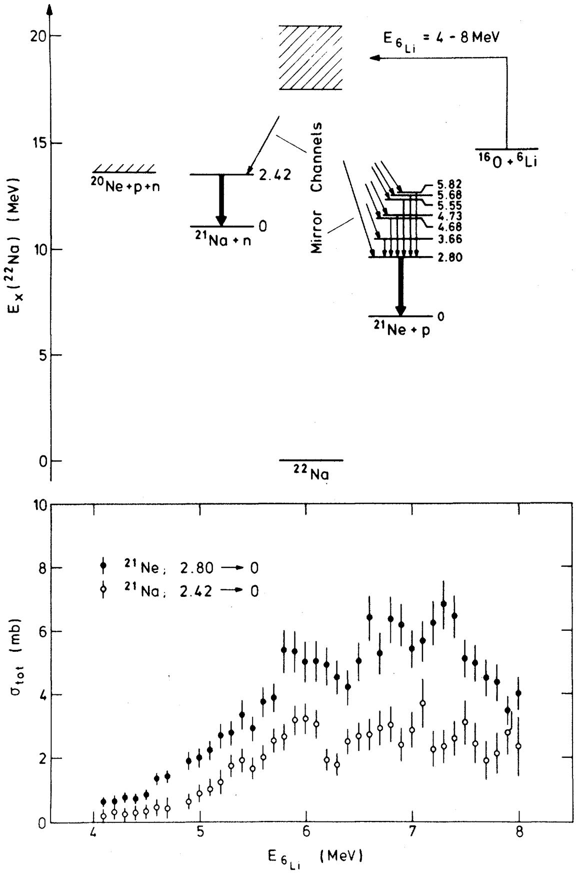

FIG. 1. Top: Q value and energy level diagram showing the close connection of particle decay channels and their respective successive γ-decay modes. Bottom: Mirror channel excitation functions as measured by use of the γ-ray technique (see text). The larger yield observed for ^{21}Ne is entirely due to feeding processes, as indicated in the top part of this figure.

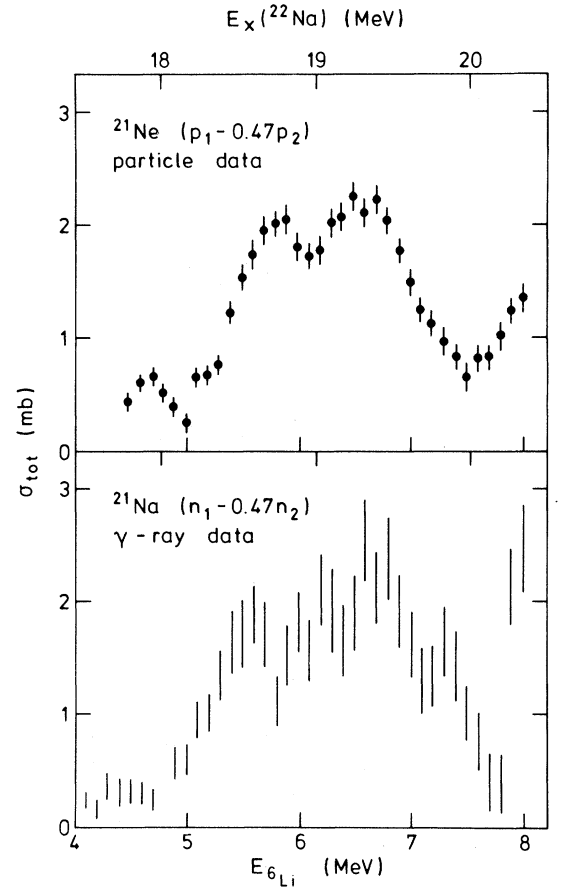

FIG. 2. Comparison of two composite mirror channel excitation functions measured through particle (top) and γ-ray spectroscopy (bottom). The relative weights (1, –0.47) have been determined, as given in the text.

for the $1 \rightarrow 0$ and $2 \rightarrow 1$ transitions in ^{21}Na and ^{21}Ne; in all of these, feeding does occur. In fact, the large number of bound states in ^{21}Ne causes the registration of secondary γ rays to be a poor measure of p cross sections. It will only be employed for the $2.80 \rightarrow 0$ MeV transition where feeding through a still limited number of just six higher lying states had to be considered (Fig. 1). Instead, total p cross sections were determined by directly detecting protons by use of Si surface barrier detectors. Eleven-point angular distributions were taken for bombarding energies $4.5 \leq E_{Li} \leq 8.0$ MeV in steps of 100 keV. Self-supporting SiO_2 targets (≈ 35 $\mu g/cm^2$) were used; only proton groups from the decay to the ground (0), first (1), and second (2) excited states in ^{21}Ne could be analyzed due to the finite resolution of the detectors.

The contributions of various neutron groups to the transitions $1 \rightarrow 0$ $(2 \rightarrow 1)$ in ^{21}Na are evaluated by use of known γ-ray branching ratios[5] and are found to be $1n_1 + 0.93n_2 + 0.96n_5$ $(1n_2 + 0.63n_5)$, respectively. By suitably combining the γ-ray excitation functions one can eliminate some of the feeding contributions. Multiplying the yield curve of the $2 \rightarrow 1$ transition by $(0.96/0.63)$ and subtracting it from the one of the $1 \rightarrow 0$ transition yields an excitation function shown in the lower part of Fig. 2. In the top part of this figure the corresponding proton yield curve is given as obtained by appropriately combining the p_1 and p_2 data. The similarity in the absolute cross section as well as in the structures is striking.

Before proceeding with the further analysis we state that (i) the bombarding energy is rather low, (ii) the measured cross sections are well reproduced by HF calculations, and (iii) no strong forward peaking of the particle angular distributions is found. Hence we assume that the $^{16}O + ^6Li$ reaction is mainly of a compound nuclear type and thus can be subjected to a correlation analysis.

TABLE I. Values of the linear cross correlation coefficient r and ratios of energy averaged cross sections for different proton and neutron excitation functions. Values in column A (B) have been deduced from the original (corrected) data, respectively (see text).

	r		
Mirror channels	A	B	$\frac{\langle\sigma(n)\rangle}{\langle\sigma(p)\rangle}$
$n_1-0.47n_2/p_1-0.47p_2$	0.57 ±0.19	0.63 ±0.22	1.05
$n_1+0.33n_5/p_1$	0.47 ±0.16	0.35 ±0.12	1.31
$n_3/p_4+\sum_k w_kp_k$[a]	0.42 ±0.14	0.47 ±0.16	0.51
Average	0.49 ±0.10	0.49 ±0.09	
Random correlation[b]	0.24 ±0.08	0.21 ±0.08	

[a] Feeding term $\sum_k w_kp_k$ contains a sum of six contributions with w_k ranging from 0.04 up to 0.53.

[b] Linear random correlation coefficient was obtained by additionally using γ-ray data originating from α-decay channels.

The linear correlation coefficient r, defined as[2]

$$r=C(1,2)/[C(1,1)C(2,2)]^{1/2} ,$$

was calculated for various sets of mirror channel excitation functions (Table I), where $C(1,2)$ [$C(1,1)$ and $C(2,2)$] are the respective cross- [auto-] correlation coefficients. The results listed in column A were directly derived from the experimental cross section data, whereas those in column B were corrected for the overall slope in the excitation functions by using reduced data $\sigma/\sigma_{\mathrm{HF}}$. No large differences are found for the two sets of r coefficients, revealing only a minor influence of the slow energy variation of the individual yield curves. The size of the errors is mainly due to finite range of data corrections[6] which, in turn, were necessary because of the small sample size $n\approx 25$.

By comparison with the random correlation coefficient (Table I) a significant mirror correlation is observed with an average value of $\bar{r}=0.49\pm0.10$. Also given in Table I is the ratio $\langle\sigma(n)\rangle/\langle\sigma(p)\rangle$ which is close to 1 for the top pair of excitation functions, but differs strongly from unity where additional feeding processes occur in either channel. Such additional contributions yield a reduced cross correlation in much the same way as was mentioned above for the case of strongly different Q values.[4] Hence we regard the one result to be more realistic, where a ratio of approximately 1 for the two mirror cross sections is observed and tentatively give a linear cross correlation coefficient r of the order of 0.6. For a better comparison with results from other experiments[7,8] which also aimed at probing isospin purity, we additionally give the isospin mixing parameter f defined as $r=[(1-f)/(1+f)]^2$ in the limit $\langle\sigma(n)\rangle/\langle\sigma(p)\rangle=1$. A rather small mixing parameter $f=0.13\pm0.08$ is found. This result corroborates the findings of a recent study[9,10] on the ^{6}Li-induced reaction $^{12}\mathrm{C}(^6\mathrm{Li},\alpha)^{14}\mathrm{N}$. There, a strong reduction of up to a factor of 100 was observed for the isospin forbidden α transition to the first excited $T=1$ state in ^{14}N indicating a high degree of isospin purity in the compound nucleus ^{18}F.

In a final step the isospin mixing matrix element $\langle V_c\rangle$, given as[7]

$$\langle V_c\rangle^2=\frac{1}{2\pi}\,\frac{f\Gamma^{\uparrow}_{>}D_{<}}{1-f(N_>/N_<+1)} ,$$

will be evaluated. The unknown decay width $\Gamma^{\uparrow}_{>}$ around 19 MeV can be connected to the mean coherence width $\Gamma=100$ keV deduced from our correlation analysis. Due to the $T=0$ entrance channel isospin, $T=T_<=0$ levels are predominantly excited. Furthermore, for self-conjugate nuclei one has the relation $\Gamma^{\uparrow}_{>}\lesssim\Gamma^{\uparrow}_{<}$. Hence we estimate $\Gamma^{\uparrow}_{>}\lesssim\Gamma^{\uparrow}_{<}\approx\Gamma=100$ keV. The average level spacing of $T_<$ levels $D_<\approx 0.5$ keV is obtained from HF calculations. To compute the ratio $N_>/N_<$ (N being the number of levels of either isospin) we apply the HF level density formula to ^{22}Na ($T_z=0$) at $U=19$ MeV, which yields $N_<$, and to, e.g., ^{22}Ne ($|T_z|=1$) at U corrected for the pairing energy and the energy of the first excited $T=1$ state in ^{22}Na. We find $N_>/N_<=0.13$, which, together with the other data, gives $\langle V_c\rangle\approx 1$ keV. It should be emphasized that this result is only an order of magnitude estimate and should not be taken too seriously, since it depends strongly on the assumed values for $\Gamma^{\uparrow}_{>}$ and $D_<$. The main goal of the present analysis lies in the application of the isospin mixing formalism to an "ideal" reaction, where the average mirror channel cross sections are identical. Its essential result is a linear cross correlation coefficient of order 0.6 which indicates a high degree of isospin conservation.

This work was supported in part by the Deutsche Forschungsgemeinschaft.

---

[1] C. Detraz, C. E. Moss, L. D. Zafiratos, and C. S. Zaidins, Phys. Rev. Lett. 26, 448 (1971).

[2] J. J. Simpson, S. J. Wilson, W. R. Dixon, R. S. Storey, and J. A. Kuehner, Phys. Rev. Lett. 40, 154 (1978).

[3] H. A. Weidenmüller, A. Richter, and H. L. Harney, Phys. Rev. C 18, 1953 (1978).

[4] J. J. Simpson and S. J. Wilson, Phys. Rev. C 19, 272 (1979).

[5] P. M. Endt and C. Van der Leun, Nucl. Phys. A310, 1 (1978).

[6] A. Richter, in *Nuclear Spectroscopy and Reactions B,* edited by J. Cerny (Academic, New York, 1974), p. 374.

[7] H. L. Harney, H. A. Weidenmüller, and A. Richter, Phys. Rev. C 16, 1774 (1977).

[8] C. R. Lux, N. T. Porile, and S. H. Grimes, Phys. Rev. C 15, 1308 (1977).

[9] J. Schwenzel, K. Glasner, P. Niermann, and E. Kuhlmann, Nucl. Phys. A367, 145 (1981).

[10] J. P. Sokol and C. P. Browne, Phys. Rev. C 17, 388 (1978).