bands and this provides evidence that all these superbands consist of two quasineutron $i_{13/2}$ bands coupled to the quasiparticle vacuum (ground state).

The authors wish to thank A. C. Kahler, R. D. Hichwa, and the ORIC Operations Staff for their help during these experiments, and I. Y. Lee for his helpful comments on the manuscript. This research was supported in part by the U. S. Energy Research and Development Administration, partially under contract with Union Carbide Corporation, and by the National Science Foundation and the Research Corporation.

[1]F. S. Stephens, Rev. Mod. Phys. 47, 43 (1975).
[2]I. Y. Lee, D. Cline, R. S. Simon, P. A. Butler, P. Colombani, M. W. Guidry, F. S. Stephens, R. M. Diamond, N. R. Johnson, and E. Eichler, Phys. Rev. Lett. 37, 420 (1976).
[3]F. S. Stephens and R. S. Simon, Nucl. Phys. A183, 257 (1972).
[4]C. Flaum and D. Cline, Phys. Rev. C14, 1224 (1976).
[5]T. L. Khoo, F. M. Bernthal, J. S. Boyno, and R. A. Warner, Phys. Rev. Lett. 31, 1146 (1973).
[6]H. R. Andrews, D. Ward, R. L. Graham, and J. S. Geiger, Nucl. Phys. A217, 141 (1974).
[7]M. V. Banaschik, C. Günther, H. Hübel, A. C. Rester, G. Nowicki, and J. J. Pinajian, Nucl. Phys. A222, 459 (1974).
[8]W. F. Davidson, R. M. Lieder, H. Beuscher, A. Neskakis, G. A. Varley, J. C. Wilmott, F. Kearns, and J. C. Lisle, J. Phys. G 3, 199 (1976).
[9]N. R. Johnson, S. W. Yates, R. M. Ronningen, R. D. Hichwa, L. L. Riedinger, and A. C. Kahler, Bull. Am. Phys. Soc. 21, 984 (1976).
[10]D. Cline, Bull. Am. Phys. Soc. 21, 962 (1976).
[11]L. K. Peker, private communication.

Isospin Impurity in the Compound Nucleus from a Comparison of Fluctuations in Mirror Reactions

J. J. Simpson and S. J. Wilson
Department of Physics, University of Guelph, Guelph, Ontario N1G 2W1, Canada

and

W. R. Dixon and R. S. Storey
Physics Division, National Research Council, Ottawa, Ontario K1A 0S1, Canada

and

J. A. Kuehner
Department of Physics, McMaster University, Hamilton, Ontario L8S 4K1, Canada
(Received 31 October 1977)

Ericson fluctuations of the triton and helium-3 decays of the compound nucleus ^{26}Al formed in the ^{14}N + ^{12}C reaction have been studied for excitation energies between 33 and 38 MeV. These mirror channels are only weakly correlated which is partly attributed to an isospin-nonconserving width of about 20 keV.

States of different isospin overlap in highly excited nuclei, where the average width Γ of the levels is much greater than the average level spacing. Where Γ is also much greater than the isospin-mixing width, isospin will be conserved.[1,2] Détraz *et al.*[3] examined Ericson fluctuations in the ^{7}Li and ^{7}Be mirror-channel decays of ^{22}Na near 53-MeV excitation and concluded from strong cross correlations of mirror channels that charge symmetry is preserved and that isospin is a good quantum number. We have studied fluctuations in the cross sections of the mirror reactions ^{12}C(^{14}N, t)^{23}Mg and ^{12}C(^{14}N, ^{3}He)^{23}Na at ^{26}Al excitation energies of 33 to 38 MeV to test charge symmetry at a lower excitation energy where Γ will be smaller than in their experiment. Briefly, we find a considerably reduced cross correlation between mirror channels which can be partly attributed to isospin mixing in the compound states.

Excitation functions were measured at ^{14}N-beam energies of 39 to 50.2 MeV in energy steps of 200 or 400 keV. Targets were high-purity carbon 10 and 20 μg/cm^2 in thickness. Because of the rather low cross section for these reactions, we positioned a counter telescope to identify ^{3}He's and tritons at zero degrees, stopping the beam in a tantalum foil behind the target. This arrangement permitted a reasonably large solid angle (~35 msr) with a minimum of kinematic broadening. In addition, the choice of 0° is expected to

 © 1978 The American Physical Society

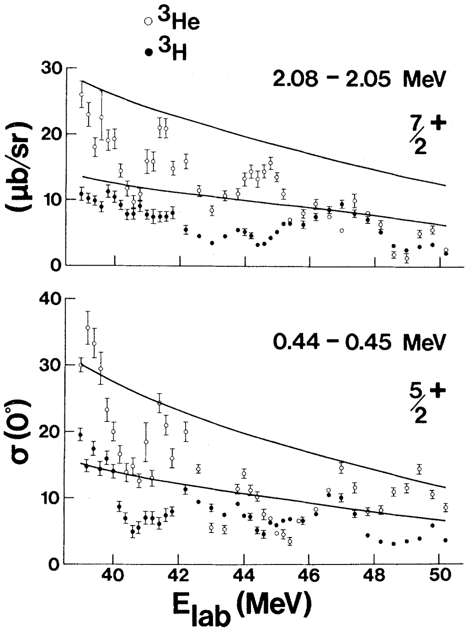

FIG. 1. Comparison of the fluctuations of the mirror reactions $^{12}C(^{14}N, ^{3}He)^{23}Na$ and $^{12}C(^{14}N, ^{3}H)^{23}Mg$. The energies of the mirror levels in the residual nuclei (that for ^{23}Na is given first) and their spin are given on the figure. Smooth curves are statistical-model calculations, the upper curve that for the ^{3}He reaction.

enhance fluctuations.

Figure 1 shows excitation functions for two of the six mirror channels studied. Also shown, as smooth curves, are statistical-model calculations of the zero-degree average differential cross section calculated with the code STATIS.[4] By use of the peak-counting method[5] or the auto-correlation function,[6]

$$C(\epsilon)=\frac{\langle \sigma(E+\epsilon)\sigma(E)\rangle}{\langle\sigma(E+\epsilon)\rangle\langle\sigma(E)\rangle}-1, \tag{1}$$

where $\langle\rangle$ stands for energy average, the average width Γ of the compound states is found to be about 350 keV. Fluctuations in the deuteron exit channel give a similar value for Γ.

It is evident from Fig. 1 that the cross correlation between mirror channels is not strong. In Table I are presented two quantitative measures of correlations between channels. One is the correlation function

$$C(1,2)=\frac{\langle\sigma_1(E)\sigma_2(E)\rangle}{\langle\sigma_1(E)\rangle\langle\sigma_2(E)\rangle}-1, \tag{2}$$

as conventionally defined in fluctuation analysis[6]; the other is the usual linear correlation coefficient, which is used by Détraz *et al.*[3] (their β),

$$r=C(1,2)/[C(1,1)C(2,2)]^{1/2}. \tag{3}$$

In both our work and that of Détraz *et al.* the random-correlation coefficient is large and positive. This undoubtedly arises from the fact that there is a general decrease in cross section with increasing energy. [Although two flat, constant excitation functions give $C(1,2)=0$, linearly sloping excitation functions give $C(1,2)\neq 0$, a positive sign indicating that they slope the same way.] This effect is demonstrated under columns (b) of Table I where the experimental cross section is divided by the statistical-model prediction before the correlation function is calculated. In the absence of direct reactions, the self-correlation function $C(0)$ equals $1/N$, where N is the effective number of incoherent contributions to the cross section.[7] The measured value of $C(0)$ determines N to be 5–6, after correction for the finite energy range of the data.[5] This value of N is consistent with that expected for a detector at 0° with the finite angular spread used in the experiment. This corroborates the conclusion of Olmer *et al.*[8] of a pure compound-nuclear reaction mechanism.

TABLE I. Values of the correlation coefficients C and r, defined in the text. Correlations of a cross section with itself, with its mirror counterpart, and with any other cross section are termed self-correlation, mirror correlation, and random correlation. The values are averages of all possible combinations for the category. Values under columns (b) have been corrected for the overall slope of the excitation functions (see text). Errors of the averages are enclosed in brackets.

	C (a)	C (b)	r Our work (a)	r Our work (b)	r Ref. 3
Self-correlation	0.25(0.03)	0.16(0.02)	1	1	1
Mirror correlation	0.16(0.03)	0.064(0.025)	0.65(0.03)	0.41(0.06)	0.90
Random correlation	0.11(0.01)	0.016(0.007)	0.46(0.03)	0.10(0.04)	0.48

TABLE II. Comparison of r with $\langle\sigma_t\rangle/\langle\sigma_{^3\mathrm{He}}\rangle$ for mirror channels. Errors on individual r values are statistical. The average r value and its error are calculated using Fisher's Z transformation for r when the true correlation is different from zero. The uncertainty in the weighted mean of $\langle\sigma_t\rangle/\langle\sigma_{^3\mathrm{He}}\rangle$ is calculated from the average variance.

Levels in residual nucleus (MeV) ^{23}Na	^{23}Mg	J^π	$\langle\sigma_t\rangle/\langle\sigma_{^3\mathrm{He}}\rangle$	r
0	0	3/2+	0.54	0.57(0.07)
0.44	0.45	5/2+	0.57	0.41(0.08)
2.08	2.05	7/2+	0.53	0.23(0.08)
2.70	2.72	9/2+	0.61	0.30(0.10)
2.98	2.91	3/2+	0.51	0.16(0.11)
5.53	5.45	11/2+	0.57	0.55(0.07)
Average			0.54(0.02)	$0.41^{+0.06}_{-0.07}$

Table I shows that the average cross correlation between mirror channels is considerably reduced from the average self-correlation. Much of this reduction can be attributed to the higher ^{3}He cross section. The Q value for the ^{3}He reaction is more positive, and for l values above about 9, ^{3}He transmission functions are larger than the triton ones, increasingly so for increasing l. If we describe this effect by postulating that, for each incoherent channel, the ^{3}He-reaction amplitude $f(^3\mathrm{He})$ is the sum of the triton-reaction amplitude $f(t)$ plus an independently varying random amplitude g,

$$f(^3\mathrm{He}) = f(t) + g \quad (f \text{ and } g \text{ complex}), \tag{4}$$

then one can show that the cross correlation between mirror channels is reduced from the value of the self-correlation function $C(0)$ by the ratio of the average triton cross section to average ^{3}He cross section[9]:

$$C(1,2) = C(0)\langle\sigma_t\rangle/\langle\sigma_{^3\mathrm{He}}\rangle \tag{5}$$

or

$$r = \langle\sigma_t\rangle/\langle\sigma_{^3\mathrm{He}}\rangle. \tag{6}$$

Table II compares the experimental ratio $\langle\sigma_t\rangle/\langle\sigma_{^3\mathrm{He}}\rangle$ to the value of r corrected for the slope of the excitation function as described above, for the six mirror channels studied. The values of r are generally what one expects from the ratio of cross sections, but are generally lower. We consider this reduction to be evidence for isospin mixing in the states of the compound nucleus. In a very simple model in which the states of the compound nucleus are primarily $T=0$ with some $T=1$ admixed and in which the mixing is the same in all the compound states contributing to the cross section, then $C(1,2)$ and r are reduced by a factor[9] $(1-2\beta^2)^2$ where β is the amplitude of $T=1$ in the compound states. The average value of r of 0.41 compared to the expected value of 0.54 leads to an average value of the $T=1$ amplitude β of 0.25. Crudely speaking then, the isospin-nonconserving width is $\simeq(0.25)^2\Gamma$, i.e., 20 keV. We also note that, because the random correlation is still positive, an empirical method of removing the energy dependence of the excitation function and reducing the random correlation to zero will also reduce the mirror correlation below 0.41. Furthermore, although the scatter in the values of r for different channels may reflect the finite energy range of data, it might also indicate a variation of the Coulomb mixing in different channels.

The results of Détraz *et al.* are probably consistent with the above considerations. Because of the sloping excitation function in the reactions they studied there is a large random correlation. If this is allowed for, their mirror correlation would reduce to something near 0.5, which appears to be about the ratio of their ^{7}Be to ^{7}Li cross sections. Their mirror correlation is insensitive to an isospin-mixing width of 20 keV because of the larger Γ (~800 keV) in their compound nucleus.

We have also examined the frequency distribution $f(R)$ of the ratio

$$R = [\sigma_{^3\mathrm{He}}(E) - \sigma_t(E)]/[\sigma_{\mathrm{He}}(E) + \sigma_t(E)].$$

In terms of the simple model discussed above,[9] $f(R)$ depends on N, β, and the relative amount of random amplitude in the ^{3}He cross section, $|g|/$

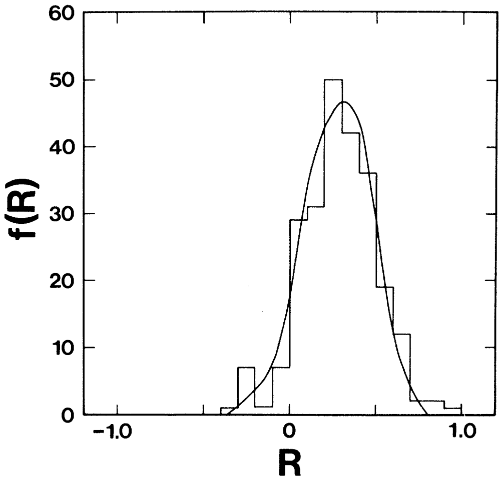

FIG. 2. The frequency distribution $f(R)$. The experimental histogram combines all six mirror reactions discussed in the text. The smooth curve is calculated by using normally distributed random numbers of mean zero for the real and imiginary parts of amplitudes, the curve shown being appropriate for $N = 6$, $\beta = 0.3$, and $|g|/|f(t)| = 0.96$, the last number giving a ratio $\langle\sigma_{^3\text{He}}\rangle / \langle\sigma_t\rangle$ in agreement with experiment.

$|f(t)|$. As Fig. 2 shows, a very good fit, as measured by comparing the mean and variance of the distribution, is obtained for values of the parameters determined by correlations. In fact, all reasonable values of N (4–6) and $|g|/|f(t)|$ (0.85 −1.02) require $\beta \gtrsim 0.15$ in the model.

In conclusion, we find that cross correlation between mirror-channel fluctuations is substantially reduced in the reactions $^{12}C(^{14}N, ^3He)^{23}Na$ and $^{12}C(^{14}N, t)^{23}Mg$. Although most of this reduction is a Q-value effect, there is a further reduction caused by isospin mixing in the compound states and an isospin-nonconserving width of ~20 keV. If one were to examine mirror reactions for decays of a compound nucleus at an excitation energy where Γ was also ~20 keV, one would expect a reduction in cross correlation considerably in excess of the Q-value effect.

The authors are extremely grateful to Dr. R. G. Stokstad for supplying them with a copy of his code STATIS and a copy of ABACUS. They also gratefully acknowledge financial assistance from the National Research Council of Canada.

[1] D. H. Wilkinson, Philos. Mag. 1, 379 (1956).

[2] A. M. Lane and R. G. Thomas, Rev. Mod. Phys. 30, 257 (1958).

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

[4] R. G. Stokstad, Wright Nuclear Structure Laboratory Internal Report No. 52, Yale University, 1972 (unpublished). We have not searched for best parameters, and have used the parametrized transmission functions of the code STATIS for the exit channels and optical-model transmission functions calculated by ABACUS (E. H. Auerbach) for the entrance channel.

[5] M. L. Halbert, F. E. Durham, and A. Van der Woude, Phys. Rev. 162, 899 (1967).

[6] I. Hall, Phys. Lett. 10, 199 (1964).

[7] T. Ericson and T. Mayer-Kuckuk, Annu. Rev. Nucl. Sci. 16, 183 (1966).

[8] C. Olmer, R. G. Stokstad, D. L. Hanson, K. A. Erb, M. W. Sachs, and D. A. Bromley, Phys. Rev. C 10, 1722 (1974).

[9] J. J. Simpson, to be published.