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Isospin Nonconservation in the Reaction $^{12}C(d, \alpha_2)^{10}B(1.74, T = 1)$†

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We question the recent conclusion that a simple compound-nucleus interpretation fails for this reaction.

Recently in this Journal von Ehrenstein *et al.*[1] reported six angular distributions of the isospin-forbidden α's from the reaction $^{12}C(d, \alpha_2)^{10}B(1.74, T = 1)$ and a few additional cross-section measurements at $\theta_{c.m.} \approx 160°$ for $16 < E_d < 17$ MeV. They concluded, "In the light of these new data, it is clearly not sufficient to interpret the reaction in terms of simple compound-nucleus formation." Apparently the evidence persuasive for this conclusion was that "the angular distributions··· show a pronounced enhancement (up to a factor 5) at forward angles within the incident deuteron energy interval $E_d = 12.0$ to 17.0 MeV."

We find the latter statement possibly misleading in the following respects: (1) The data for $12 < E_d < 14$ MeV are mainly from Smith[2] and consist of ~50 angular distributions which above $E_d = 13.5$ MeV show *backward* (not forward) enhancement. (2) Of the six new angular distributions for $E_d \geqslant 14$ MeV (see Fig. 1 of Ref. 1) only three show forward enhancement ($E_d = 14.4$, 14.8, and 15.4 MeV). The others show backward enhancement or are essentially isotropic.

Smith's complete data[2] consist of ≈150 angular distributions for $7.2 < E_d \leqslant 14.0$ MeV. Parametrizing these in terms of resonant partial waves shows nothing inconsistent with a simple compound-nucleus description.[2] Therefore, we are skeptical that the conclusion of Ref. 1 follows from the limited (but qualitatively similar) data for $E_d > 14$ MeV.

Before discussing the question further, let us review certain features of this particular reaction which we find many readers overlook:

(A) As Ref. 3 shows, the very simple spin-parity combination, $0^+1^+ \rightarrow 0^+0^+$, gives $d\sigma/d\Omega \propto |\sum_l \alpha_l dP_l/d\theta|^2$. Hence, the cross section must always vanish at 0° and 180°. Also, the $l = 0$ partial wave is forbidden and only compound states of natural parity are allowed, i.e., $J^{\pi} = l^{(-)^{l}}$.

(B) Since the reaction is also isospin forbidden, only those natural-parity states which have appreciable isospin impurity can contribute: namely, $T = 0$ states with $T = 1$ impurity and $T = 1$ states with $T = 0$ impurity. To have such mixing, $T = 0$ and $T = 1$ states of the same spin-parity combination must lie within a few hundred keV of each other since the Coulomb matrix elements, H_C, are ~100 keV. Also the states should belong to different configurations.[4] Although only a very few ^{14}N compound states will contribute, these states must lie close to another state of the same spin and parity. These nearby levels of the same spin and parity (but mixed isospin) will interfere with each other, and therefore the resonant shapes are not of simple Breit-Wigner form. Multilevel resonance formulas apply even for the simplest cases.[5]

As a consequence of (A) all partial waves with $l > 1$ give angular distributions with strong maxima at forward and/or backward angles *independent of the reaction mechanism* involved. For a single isolated resonance (or for any number of overlapping resonances with the same parity) the forward and backward peaks are of course symmetric about 90° c.m. For almost all other cases involving compound nuclear resonances, the opposite-parity partial waves by interference enhance (or diminish) the forward peak(s) relative to the backward peak(s). For our $0^+1^+ \rightarrow 0^+0^+$ system the result is that the angular distributions resemble direct reactions especially if $l \geqslant 3$ waves resonate, e.g., see Fig. 1. These pseudo-

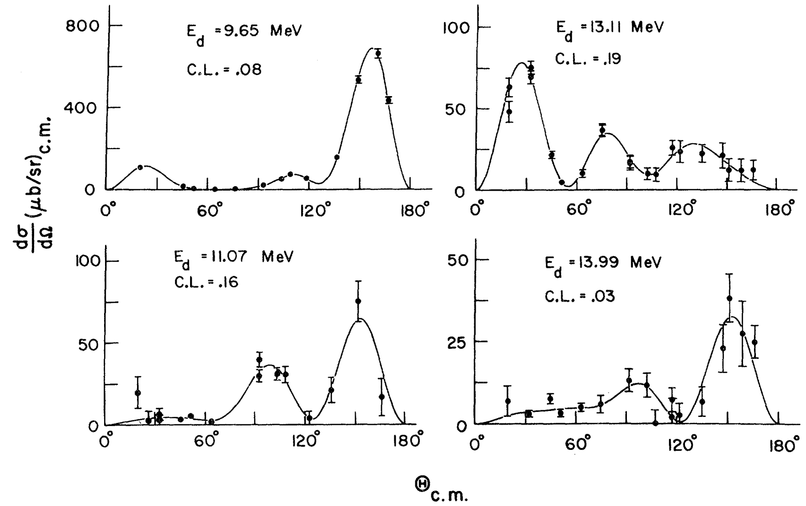

FIG. 1. Samples of the 150 angular distributions measured by Smith and parametrized in terms of the partial waves shown in Fig. 2. The "confidence level" (C.L.) of each fit is a function of χ^2 and the number of degrees of freedom. Confidence levels between 0.1 and 0.9 are acceptable. The forward (or backward) peaks superficially resemble direct reactions but here arise from a few interfering levels of the compound nucleus.

direct angular distributions often change rapidly as a function of bombarding energy. However, if only a few strong resonances dominate the cross section in the energy interval under consideration [as we expect from (B) above], these changes are slow since the interference effects involve amplitudes that drop off as $(E-E_\lambda)^{-1}$ rather than the $(E-E_\lambda)^{-2}$ cross-section dependence. The crucial question is then the number of strong levels and their widths.

This information is implicit in Smith's parametrization of his data below $E_d = 14$ MeV. Figure 2 shows his extracted partial-wave cross sections.[2,6] More explicitly, preliminary results[7] from a multilevel fitting of Fig. 2 indicate that each partial wave requires four or fewer levels (of the same J^π) for a reasonable fit.

The asymmetric angular distributions of Fig. 1, which individually often resemble direct reactions, result from interference between the odd and even partial waves shown in Fig. 2. Since each curve of Fig. 2 in turn arises from interference between a few ^{14}N states of the same spin and parity, we note that all the data for $E_d < 14$ MeV derive from a few compound-nuclear states of ^{14}N. We observe no unusual restrictions on level distribution or relative phase.

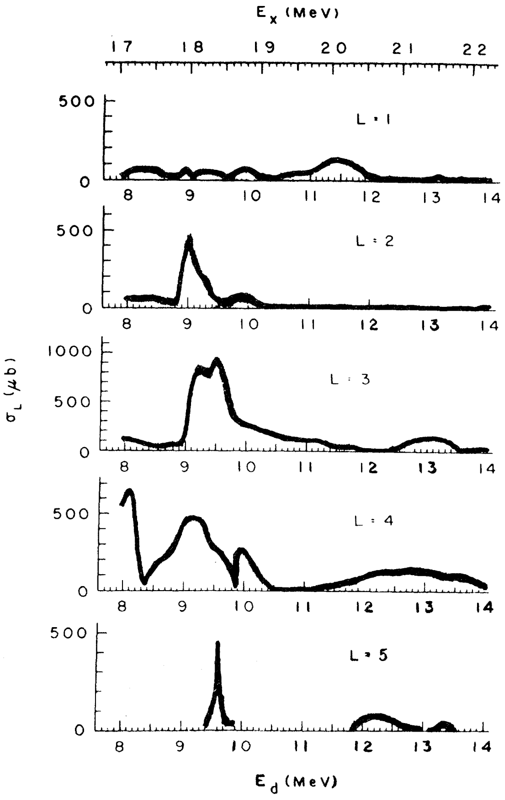

FIG. 2. Partial-wave parametrization of Smith's data (Ref. 2) for $8 < E_d < 14$ MeV. The ordinate is $\sigma_l = \frac{1}{8}\pi\lambda^2(2l+1)|S_l|^2$ (see Refs. 3 and 6). The upper abscissa scale E_x is the excitation energy of the compound nucleus ^{14}N. The maxima in a given partial wave arise from natural-parity ($J^\pi = l^{(-)^l}$) states in ^{14}N. These resonances are not simple Breit-Wigner shapes since interference with close-by states of the same spin-parity combination require a multilevel formula (Ref. 5). The curves are freehand smoothings of the extracted partial-wave cross sections, and most of the latter fall within the width of the smoothed curve.

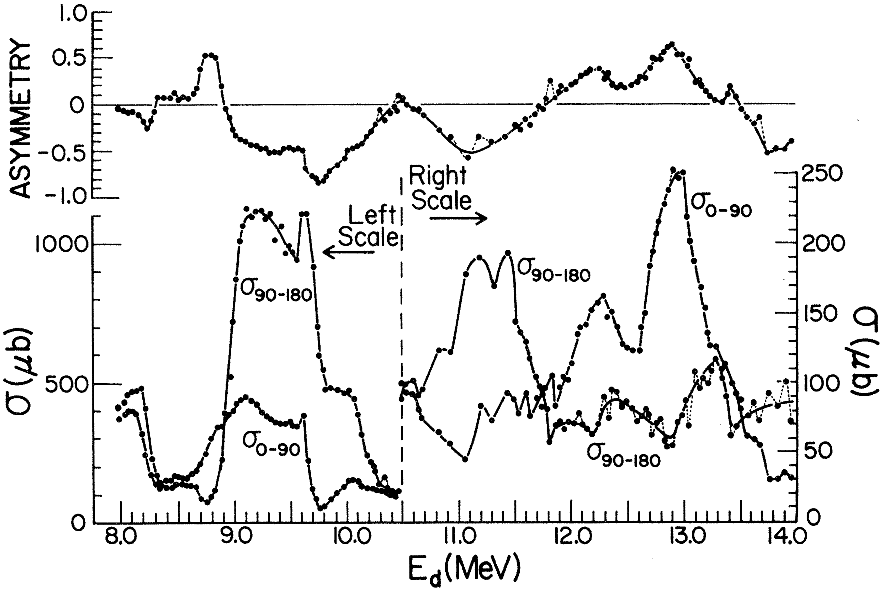

FIG. 3. Asymmetry of the isospin-forbidden reaction. The lower plots are Smith's fitted differential cross sections integrated separately over the forward angles (0°–90°) and backward angles (90°–180°). The asymmetry plotted in the upper curve is $(\sigma_{0°\text{-}90°} - \sigma_{90°\text{-}180°})/\sigma_{\text{total}}$. Note the long energy intervals where there is a net forward or backward asymmetry.

Reference 1 finds it difficult to reconcile the forward enhancement of their angular distributions at $E_d = 14.4$, 14.8, and 15.4 MeV with a simple compound-nucleus description. However, Smith finds such forward (or backward) enhancement extending over even wider energy intervals below $E_d = 14$ MeV, and these data require only a few compound levels for a quantitative description. Figure 3 summarizes the forward-angle cross sections (0–90°) and the back-angle cross sections (90°–180°) calculated from his partial-wave fits. Also plotted is the asymmetry $= [\sigma(0°\text{–}90°) - \sigma(90°\text{–}180°)]/\sigma_{\text{total}}$. Note the strong backward asymmetry over most of the region $9 < E_d < 11.8$ MeV and the strong forward asymmetry for $11.8 < E_d < 13.5$ MeV. Of interest also is the backward asymmetry above $E_d > 13.5$ MeV which is the region immediately below the data of Ref. 1.

Since the data of Ref. 1 for $E_d > 14$ MeV are not qualitatively different from Smith's fitted data below $E_d = 14$ MeV, we suggest that an extraction of partial-wave cross sections and an examination of these in terms of specific ^{14}N levels would show that the Ref. 1 data are compatible with the simple compound-nucleus description.

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