Prediction of Observable Polarization–Analyzing-Power Differences in $^{11}B(p,n)^{11}C$

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Polarization–analyzing-power differences in $^{11}B(p,n)^{11}C$ are predicted to be observable at selected energies below $E_p \sim 10$ MeV at the level of $|P-A| \gtrsim 0.1$. This result is derived from recoil-corrected continuum shell-model calculations in the one-particle, one-hole approximation, using a realistic g-matrix interaction.

Following the pioneering work by Haight *et al.*[1] on $^3H(p,n)^3He$, polarization–analyzing-power comparisons have been made for several (p,n) reactions involving mirror nuclei.[2] In particular, experimental results have been obtained for $^3H(p,n)^3He$,[3,4] $^7Li(p,n)^7Be$,[5,6] $^9Be(p,n)^9Be$,[4,7] and $^{15}N(p,n)^{15}O$.[4,8] With the notable exception of $^{15}N(p,n)^{15}O$, the polarization (P) and the analyzing power (A) are found to be essentially indistinguishable[4] in each of these reactions at all energies and angles for which data are available. This Letter describes the results of a calculation which predicts observable differences between P and A for $^{11}B(p,n)^{11}C$.

On the theoretical side, it is known that a nonvanishing $P-A$ difference in these reactions requires the presence of both an isospin-symmetry-breaking component in the interactions responsible for the reaction[9] and a transverse spin-flip mechanism which yields a spin-flip asymmetry.[10] As a consequence of these requirements, Arnold[10] has suggested that an observed nonvanishing $P-A$ difference indicates the simultaneous presence of isospin mixing and configuration mixing in the states through which the reaction proceeds. It has also been suggested[11] that $P-A$ differences can, under suitable circumstances, provide information pertinent to the analysis of resonant states. Thus it is of interest to find and investigate examples of these reactions for which significant $P-A$ differences exist.

Conducting an experimental survey for differences between P and A in even one of these reactions is an extremely arduous procedure. The importance of theoretical guidance, if available, is therefore evident. However, the phenomena of interest occur in an energy region dominated by partially overlapping resonances where predictions which are both detailed and accurate are difficult to achieve. Some recent calculations[11] with the recoil-corrected continuum shell model[12,13] (RCCSM) have proven quite promising in this regard. Calculations for $^3H(p,n)^3He$ in the one-particle, one-hole (1p-1h) approximation have yielded polarizations and analyzing powers which are inexcellent agreement with the data. Similar calculations for $^{15}N(p,n)^{15}O$ have also resulted in good qualitative agreement with the large $P-A$ differences which are observed, although the detailed resonance structure of the reaction is not well reproduced.[14] Thus, one is encouraged to believe that the 1p-1h model already contains the major source of $P-A$ differences in these cases.

It is worth noting that the RCCSM is one of the simplest models which is capable of describing the various essential features of the problem. The model is microscopic so that the results directly relate to the nucleon-nucleon interaction itself. The multichannel capability allows target reorientations associated with the transverse spin-flip requirement to be properly taken into account. In addition, the model is able to handle noncentral interactions and isospin mixing, both of which are needed in order for significant $P-A$ differences to arise.[11] In these calculations, the isospin symmetry is broken only by a standard two-body Coulomb interaction. The transverse spin-flip requirement is met in large part by the noncentral components of the two-body interaction.

We have performed a dynamical calculation for the reaction $^{11}B(p,n)^{11}C$ based on the RCCSM in the 1p-1h approximation. The ^{12}C nucleus is taken to consist of closed shells of $1s_{1/2}$ and $1p_{3/2}$ orbits with oscillator parameter $\nu = m\omega/\hbar = 0.36$ fm^{-2}. The target and residual nuclei each have one hole in the $p_{3/2}$ shell. All interaction matrix elements are generated from a two-body interaction which, with small modifications, is taken to be the g-matrix interaction of Bertsch *et al.*[15] The modifications[14] consist of an increase by 15% of the strength of the central even and spin-orbit odd components of the interaction in order to improve agreement between calculated and observed thresholds in ^{12}B and ^{12}C. The qualitative conclusions suggested by the calculations are insensitive to these modifications.

The calculated results are summarized in Fig. 1. The upper part of the figure shows the coefficients B_L of the expansion of the observable $k^2(d\sigma/d\Omega)(P-A)$ in associated Legendre polynomials, i.e.,

$$k^2(d\sigma/d\Omega)(P-A)=\sum\nolimits_L B_L P_L{}^1(\cos\theta).$$

The coefficients in this expansion have the general form[11]

$$B_L=\sum_{\alpha\beta J\alpha'\beta'J'} C(\alpha\beta J;\alpha'\beta'J';L)\,\mathrm{Im}(S_{\beta\alpha}{}^J A_{\beta'\alpha'}{}^{J'*}),$$

where αJ and βJ, etc., are proton or neutron channel labels, $C(\alpha\beta J;\alpha'\beta'J';L)$ is a geometrical coefficient, and

$$S_{\beta\alpha}{}^J=\tfrac{1}{2}(T_{\beta\alpha}{}^J+T_{\alpha\beta}{}^J),\quad A_{\beta\alpha}{}^J=\tfrac{1}{2}(T_{\beta\alpha}{}^J-T_{\alpha\beta}{}^J)$$

are linear combinations of T-matrix elements for the (p,n) reaction. The $A_{\beta\alpha}{}^J$ vanish identically unless the channel labels α and β are different and isospin symmetry is broken. Thus, they conveniently reflect the symmetry requirements enunciated by Arnold[10] and Conzett.[9] The nonvanishing $A_{\beta\alpha}{}^J$ are often relatively few in number and can be regarded as individual sources of "strength" for the generation of $P-A$ differences or "splittings." We will refer to the $A_{\beta\alpha}{}^J$ as "splitting strengths." In the case of ^{11}B$(p,n)^{11}$C, where the spin of the target or residual nucleus is $\frac{3}{2}$, there are more channels and correspondingly more strengths for each J^π in the compound nucleus than there are in ^{3}H$(p,n)^3$He or ^{15}N$(p,n)^{15}$O. The moduli of the more important of these strengths are shown in the center panel of Fig. 1, labeled with J^π and other appropriate channel quantum numbers. The lower part of the figure shows calculated contributions to the integrated (p,n) reaction cross section.

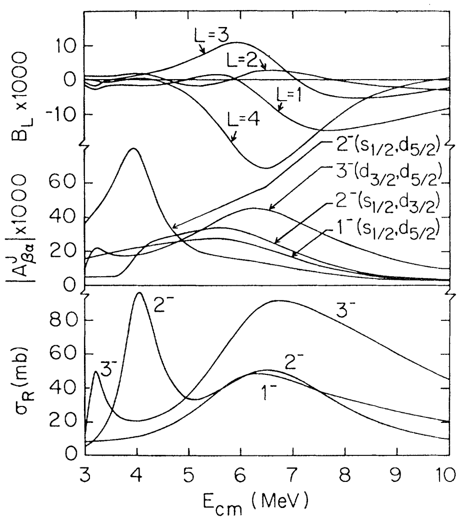

FIG. 1. Calculated results for the Legendre expansion coefficients, B_L, moduli of the largest splitting strengths, $|A_{\beta\alpha}{}^J|$, and contributions to the integrated (p,n) reaction cross section, σ_R, for ^{11}B$(p,n)^{11}$C as functions of c.m. bombarding energy.

The $1^-(s_{1/2},d_{5/2})$ and $3^-(d_{3/2},d_{5/2})$ splitting strengths are seen to exhibit broad resonances in rough correspondence with resonances appearing in σ_R. The $2^-(s_{1/2},d_{5/2})$ and $2^-(s_{1/2},d_{3/2})$ splitting strengths have completely different shapes from each other, but correspondences with resonances in σ_R can again be seen. Since the target and residual nuclei in ^{15}N$(p,n)^{15}$O have spin $\frac{1}{2}$, none of the important splitting strengths illustrated here are possible in that reaction.

It is clear that the model predicts a number of resonances in the energy region shown and that there is a small but significant $P-A$ splitting over the entire region. Peaks in the modulus of the calculated $P-A$ splitting occur near 3.15 MeV and 140° (0.13) and near 6 MeV and 60° (0.1), where the numbers in parentheses are the maxima of $|P-A|$. It is perhaps surprising at first sight that one of these peaks occurs at an energy where the B_L coefficients are relatively small; but the value of $k^2(d\sigma/d\Omega)$ increases by a factor of 4 as one passes from the lower to the higher energy peak.

With the simple model it is not possible to reproduce the resonance structure observed[16] in the (p,n) reaction in detail. However, the coefficients A_L in the expansion of the differential cross section in Legendre polynomials have been compared[14] with experiment and generally follow the average behavior of the data. Indeed, the predictions for ^{11}B$(p,n)^{11}$C are better than those for ^{15}N$(p,n)^{15}$O in this regard. It is expected that the predicted differences between P and A which are obtained here may also represent smooth averages of the empirical quantities. Thus, the observed $P-A$ differences can be expected to fluctuate more rapidly with energy than those obtained here and may at certain energies considerably exceed the estimates given above. Even so, the splittings are unlikely to be as large as those observed in ^{15}N$(p,n)^{15}$O, $|P-A|_{\max}\approx 0.6$, and so it will be necessary to do careful experiments in order to discern the effect.

Earlier theoretical studies[11] suggest that the large qualitative difference between $P-A$ splittings observed in $^{3}\mathrm{H}(p,n)^{3}\mathrm{He}$ and $^{15}\mathrm{N}(p,n)^{15}\mathrm{O}$ can be understood in terms of the greater influence of the Coulomb interaction in the heavier system and differences in the extent to which the resonances which carry mixed isospin overlap. The reaction $^{11}\mathrm{B}(p,n)^{11}\mathrm{C}$ is similar to the reaction $^{15}\mathrm{N}(p,n)^{15}\mathrm{O}$ in that the splitting strengths are dominated by s- and d-wave resonances. However, the strengths are expected to be somewhat weaker in $^{11}\mathrm{B}(p,n)^{11}\mathrm{C}$ because the influence of the Coulomb interaction is less and the resonances are not as narrow. Perhaps the most surprising feature of the present results is that the $1^{-}(s_{1/2},d_{3/2})$ and $2^{-}(d_{3/2},d_{5/2})$ splitting strengths which dominate the reaction $^{15}\mathrm{N}(p,n)^{15}\mathrm{O}$ are found to be so much weaker in the reaction $^{11}\mathrm{B}(p,n)^{11}\mathrm{C}$. Indeed, the predicted $P-A$ differences in $^{11}\mathrm{B}(p,n)^{11}\mathrm{C}$ would be negligible if the spins of the target and residual nuclei were not $\frac{3}{2}$, thus permitting other strengths to contribute.

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Energy Dependence of Charged Pions Produced at 180° in 0.8–4.89-GeV Proton-Nucleus Collisions

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High-energy charged pions produced at 180° in 0.8–4.89-GeV proton-nucleus collisions have been studied. Both the slopes of the energy spectra and the π^{-}/π^{+} ratios increase rapidly with primary energy up to ~ 3–4 GeV, where limiting values appear to be reached. The dependence on target mass also changes over this energy range. Unlike forward pion-production results, backward pions at these energies do not obey the scaling law suggested by Schmidt and Blankenbecler.

We report on a systematic study of the energy dependence of charged pions produced at 180° in the collisions of 0.8–4.89-GeV protons with nuclei. A principal reason for studying production of energetic pions from nuclei in the backward direction is that in free nucleon-nucleon (N-N) collisions such production is kinematically restricted. Observation of pions beyond this kinematic limit may then be evidence for exotic production mechanisms such as production from clusters.[1-5] Early experiments by Baldin *et al.*[6] using 5.14- and 7.52-GeV protons observed