

(p,n) REACTIONS

THE $^{12}\text{C}(p,n)^{12}\text{N}$ REACTION AT 120, 160 AND 200 MeV

J. Rapaport and T. Taddeucci
Ohio University, Athens, Ohio 45701

C.D. Goodman and C.C. Foster
Indiana University Cyclotron Facility, Bloomington, Indiana 47405

C.A. Goulding
University of Texas, Austin, Texas 78712

E. Sugarbaker
Ohio State University, Columbus, Ohio 43210

D.E. Bainum
Emporia State University, Emporia, Kansas 66801

T.G. Masterson and D. Lind
University of Colorado, Boulder, Colorado 80309

C. Gaarde
Niels Bohr Institute, University of Copenhagen
Copenhagen, Denmark

D. Horen
Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830

Experimental studies of the (p,n) reaction at intermediate energies, currently being carried out at IUCF, are providing new information on isovector modes of excitation in nuclei.¹⁻⁴⁾ In particular the 0° (p,n) cross sections have been found to be proportional to the squares of the corresponding Fermi and Gamow-Teller (GT) matrix elements extracted from β -decay measurements.²⁾

Recently Petrovich, Love and McCarthy⁵⁾ have discussed the separation of current and spin contributions to isovector M1 excitations by means of the (e,e') and (p,n) reactions. They pointed out that the orbital and spin contributions can be obtained by combining information from inelastic electron scattering at small momentum transfer with (p,n) cross sections at forward angles. In particular they show that using the fact that the tensor interaction, the spin-orbit interaction and the L=2 transition densities are small near $q=0$, the cross section for the L=0 (p,n) transition can be written:

$$\frac{d\sigma}{d\Omega} \approx 8\pi \left\{ \frac{\mu}{2\pi\hbar^2} \right\}^2 \frac{k_f}{k_i} 3 |v^c(q) \rho^s(q)|^2$$

where μ and k denote the relativistic reduced energy (divided by c^2) and the wave number, $v^c(q)$ is the Bessel transform of the spin-dependent central component of the effective interaction and $\rho^s(q)$ is the spin transition density. Distortion and knockout-exchange effects are not included explicitly in this equation and thus $d\sigma/d\Omega$ represents the plane wave cross section (PW). The differential (p,n) cross sections are calculated including distortion and knockout exchange and are also calculated without distortion. The experimental cross section values are then divided by the ratio of the two calculations, $N(\theta)$, to yield the PW cross section values.

For allowed β -decay Gamow-Teller transitions, the GT matrix element gives a direct measure of $\rho^s(q=0)$. The essential relation is^{5,6)}

$$\langle \text{GT} \rangle^2 = 6\pi |\rho^s(q=0)|^2$$

and the GT matrix element can be obtained⁶⁾ from known log ft values. The $^{12}\text{N}(1^+) \rightarrow ^{12}\text{C}(0^+) \beta^+$ -rate⁷⁾ implies that for the $0^+ \rightarrow 1^+, T = 1$ transition in ^{12}C , $\rho^8(q=0) = 0.223$, an empirical value which agrees quite well with the value of 0.221 obtained from the Cohen and Kurath wave functions.⁵⁾ In this case as well as in others for which the GT matrix elements are empirically known from β -decay, it is possible to obtain the strength of the effective interaction at zero momentum transfer.²⁾ The effective interaction is both energy and momentum dependent. The empirical energy dependence of $v^c(q=0)$ is presented elsewhere.⁸⁾ It is well known⁹⁻¹²⁾ that at intermediate energies the effective nucleon-nucleon interaction may be replaced by the free nucleon-nucleon t-matrix. In particular the isovector spin-dependent component of the nucleon-nucleon (NN) force is shown to be almost independent of energy at zero momentum transfer.¹¹⁾ This is supported by the empirical evidence in ref. 8.

The present information on the $^{12}\text{C}(p,n)^{12}\text{N}$ reaction extends this study to higher momentum transfers. Absolute (p,n) cross sections were obtained using the techniques described in ref. 13. A sample time-of-flight spectrum at $\theta_L = 0^\circ$ and 160 MeV is shown in Fig. 1.

The angular distribution for the g.s. and 0.96 MeV transitions obtained at 120 MeV are shown in Fig. 2; we also present the data points obtained at $E_p = 122$ MeV (ref. 14) for the $^{12}\text{C}(p,p')^{12}\text{C}$ reaction leading to the $J^\pi = 1^+, T=1, E_x = 15.11$ MeV state, and to the $J^\pi = 2^+, T = 1, E_x = 16.11$ MeV state, isobaric analogs of the $^{12}\text{N}(\text{g.s.})$ and $^{12}\text{N}(0.96 \text{ MeV})$ states, respectively. The differential cross section for the g.s. transition at 160 MeV is presented in Fig. 3 together with the measured cross section at 200 MeV for the sum of the transitions to the g.s. and to the 0.96 MeV state.

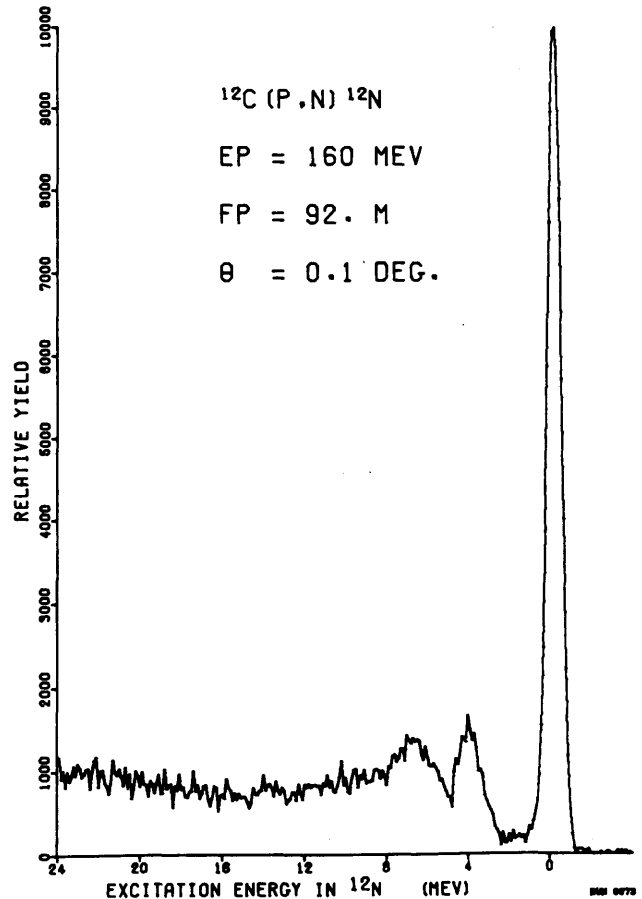


Figure 1. Neutron time-of-flight spectrum obtained at $\theta = 0^\circ$ for the $^{12}\text{C}(p,n)^{12}\text{N}$ reaction at 160 MeV.

The curves shown in the above figures are microscopic DWBA70 calculations obtained using transition densities from Cohen and Kurath¹⁵⁾ wave functions, and an effective interaction assumed to be the t-matrix for free nucleon-nucleon scattering as parameterized by Love and Franey.¹⁶⁾ The g.s. transition is reproduced quite well, but a normalization of 0.5 is needed for the 0.96 MeV transition.¹⁴⁾ Optical model parameters from ref. 14 and 17 were used.

Calculations were also done as above but with optical potential strengths equal to zero, which we denote as PW calculations. The ratio $N(\theta)$ between DW and PW results may be considered as a measure of

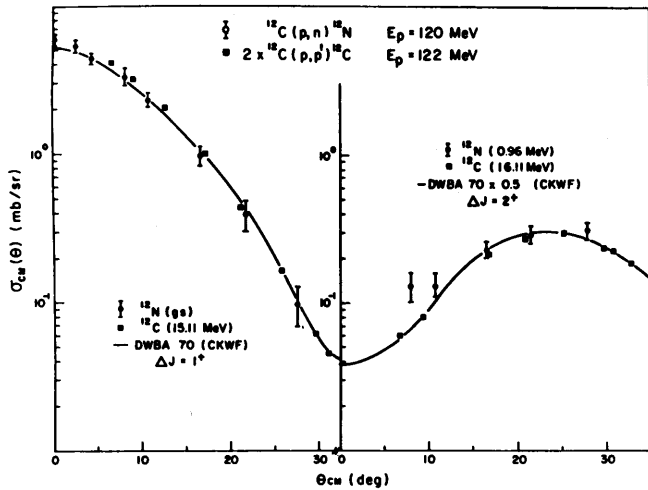


Figure 2. Angular distribution for the g.s. and 0.96 MeV transitions in the $^{12}\text{C}(p,n)^{12}\text{N}$ reaction at $E_p = 120$ MeV; the present data are compared to the $^{12}\text{C}(p,p')^{12}\text{C}$ results at $E_p = 122$ MeV from ref. 16. The latter values have been multiplied by 2 (see text). The solid lines are microscopic DWBA70 calculations.

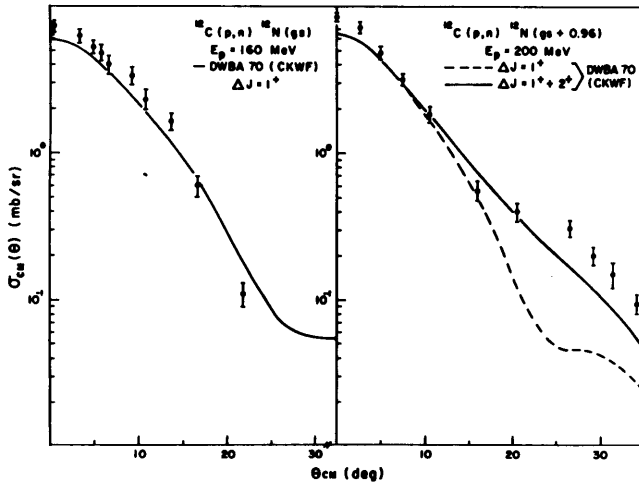


Figure 3. Angular distribution for the g.s. transition in the $^{12}\text{C}(p,n)^{12}\text{N}$ reaction at 160 MeV and for the g.s. and 0.96 MeV transitions at 200 MeV. The solid lines are microscopic DWBA70 calculations.

distortion effects and are both angle and energy dependent. Values for $N(\theta)$ were calculated at 120, 160 and 200 MeV. The measured (p,n) cross-section values $\sigma(\theta)$ were divided by $N(\theta)$ to obtain $\sigma_{PW}(q)$ which are presented in Fig. 4 plotted versus momentum transfer q .

The data points at 120, 160 and 200 MeV cluster

about a smooth curve. Both the g.s. and 0.96 MeV transitions depend on the spin dependent isospin term of the effective interaction. The fact that a single smooth curve describes all the data points at 120, 160 and 200 MeV indicates that the effective interaction describing these transitions is almost energy independent in this energy region.

A relation similar to eq. (1) may be obtained for larger values of q ; then the (p,n) PW cross section values could be used to obtain empirical quantities related to functions of $v^c(q)$ and $\rho^s(q)$ which combined with electron scattering results yield values which may be used to separate the orbital current and spin contributions to isovector M1 transitions.

The $\sigma_{PW}(q)$ values shown in Fig. 4 are energy independent in the energy region 100–200 MeV. This fact has a clear and important practical consequence: values of the efficiency for neutron detectors in the indicated energy range may be calculated by normalization to the above results.

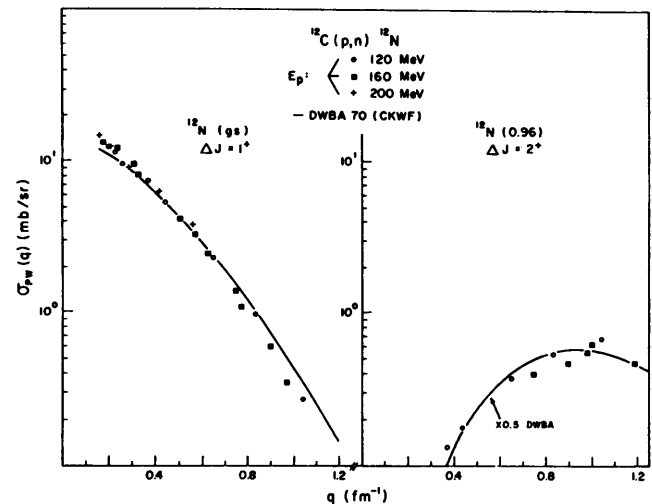


Figure 4. Plane wave cross sections for the $^{12}\text{C}(p,n)^{12}\text{N}(g.s.)$ and $^{12}\text{C}(p,n)^{12}\text{N}(0.96 \text{ MeV})$ transitions calculated from the measured cross sections at 120, 160 and 200 MeV. The solid lines represent DWBA70 plane wave calculations. The $\Delta J = 2$ DWBA calculation has been multiplied by 0.5 (see text).

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MEASUREMENT OF ASYMMETRIES IN THE $^{12,13,14}\text{C}(\vec{p},n)$ REACTIONS

C.A. Goulding

University of Texas, Austin, Texas 78712

C.D. Goodman and C.C. Foster

Indiana University Cyclotron Facility, Bloomington, Indiana 47405

T. Taddeucci and J. Rapaport

Ohio University, Athens, Ohio 43701

D. Horen

Oak Ridge National Lab, Oak Ridge, Tennessee 37830

T. Masterson

University of Colorado, Boulder, Colorado 80309

D. Bainum

Emporia State University, Emporia, Kansas 66801

E. Sugarbaker

Ohio State University, Columbus, Ohio 43212

A measurement of the (\vec{p},n) asymmetries for three carbon isotopes in the angular region of 0° to 50° has been completed. The energy resolution of the measurement was less than 800 keV for $0-25^\circ$ and less than 1.5 MeV for $25-50^\circ$.

A preliminary analysis of the $^{12}\text{C}(\vec{p},n)$ data has been completed and is shown in Fig. 1. In general, the spin-flip asymmetries are much larger than the predictions of either the Love-Franey¹⁾ or Picklesimer-Walker²⁾ effective interactions. Analysis