GT MATRIX ELEMENTS FROM 0^o (p,n) CROSS SECTIONS

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New data from (p,n) reactions obtained at IUCF with the beam swinger facility show that the (p,n) reaction is a useful probe for studying structure relationships within A-chains of the type usually studied with beta decay. An advantage of the (p,n) reaction is that it is not restricted by beta-decay energetics. Therefore, the major part of the GT strength in medium weight and heavy nuclei which is inaccessible to beta decay can be located. This report concerns establishing the normalization between the (p,n) probe and the beta decay probe.

Beta decay is essentially a low momentum transfer process. The (p,n) reaction at high energy is capable of exploring low-q also. The minimum momentum transfer for a reaction involving a non-zero Q-value is, of course, also non-zero, but gets smaller as the bombarding energy increases. This minimum q occurs at zero degrees.

Although the general expression for the (p,n) differential cross section involves all of the isospin dependent components of the effective N-N force, in the low-q limit high multipoles, tensor, and spin-orbit terms become negligible and only the central monopole terms of the isospin and the spin-isospin components of the interaction are important. Then the zero degree cross section can be written as

$$\frac{d\sigma}{d\Omega}(0^o) = \left(\frac{\mu}{\pi\hbar^2}\right)^2 \frac{k_f}{k_i} \{N_\tau^D|J_\tau <F>|^2 + N_{\sigma\tau}^D|J_{\sigma\tau}<GT>|^2\} \qquad (1)$$

where J_τ and $J_{\sigma\tau}$ are the magnitudes of the volume integrals (q=0 components) of the spin-independent $(\tau_1 \cdot \tau_2)$ and spin-dependent $(\sigma_1 \cdot \sigma_2)(\tau_1 \cdot \tau_2)$ isovector central terms in v_{ip} including the contribution from knockout exchange. N_τ^D and $N_{\sigma\tau}^D$ are distortion factors that can be calculated, and <F> and <GT> are the Fermi and Gamow-Teller matrix elements given by[1]

$$<F> = \left(\frac{1}{2J_i+1}\right)^{1/2} <J_i|| T_- ||J_i> \qquad (2)$$

and

$$<GT> = \left(\frac{1}{2J_i+1}\right)^{1/2} <J_f|| \sum_k t_-(k)\, \bar{\sigma}(k) ||J_i> . \qquad (3)$$

The reduced matrix elements here are as defined in Ref. 1 and t_- and T_- are isospin lowering operators. The factors N_τ^D and $N_{\sigma\tau}^D$ are the factors by which the cross sections are reduced owing to the mismatch between the ingoing and outgoing distorted waves.

$$N^D = \frac{d\sigma/d\Omega\ (DW)}{d\sigma/d\Omega\ (PW)}\Big|_{\theta=0^o} \qquad (4)$$

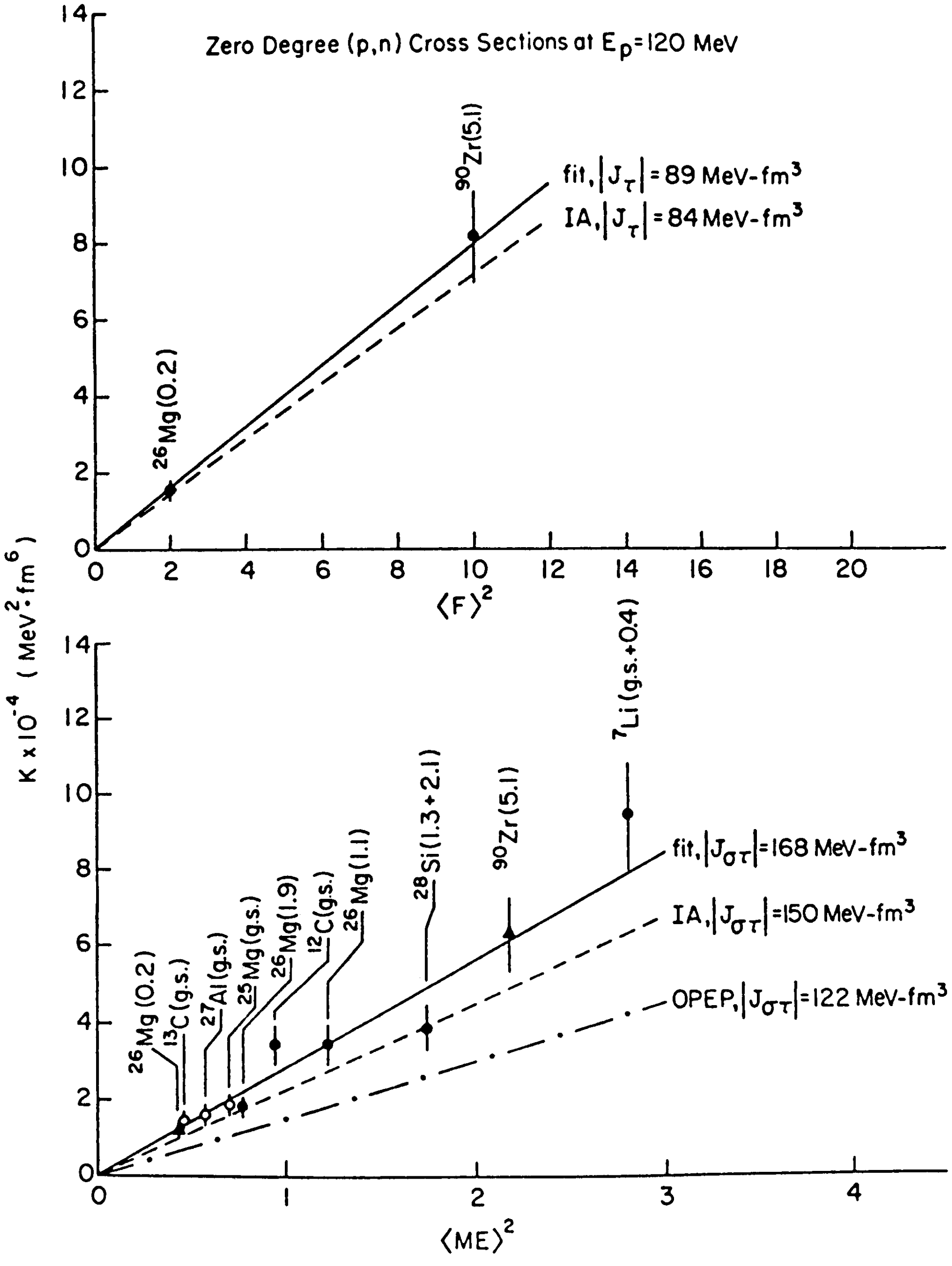
The plane wave cross sections are computed with the proper k_f/k_i weighting but with Q=0 so that $\theta=0^o$ corresponds to q=0. N^D exhibits a smooth exponential A-dependence and is only moderately sensitive to the reaction Q-values and the model nuclear wave functions.

Some sensitivity of N^D to the interaction components was found with the N^D_τ values being smaller than $N^D_{\sigma\tau}$ values. This can be understood in terms of the shapes of the isovector central terms in the t-matrix interaction of Ref. 2. The $t_{\sigma\tau}$ component has a long range characteristic of OPEP, while t_τ has a much shorter range characteristic of multiple pion exchange.[2,3,4] When t_τ acts the projectile must penetrate more of the absorbing potential to "see" the interaction than when $t_{\sigma\tau}$ acts. The beta decay rate is given by

$$^1/_{ft} = G_V{}^2\langle F\rangle^2 + G_A{}^2\langle GT\rangle^2 \qquad (5)$$

Equations (1) and (5) provide the basis for comparison between (p,n) and beta decay.

Figure 1 shows a plot representing this comparison. A reduced cross section,



<u>Figure 1</u>. Graphs of K, defined in Eq. (6) and deduced from the measured 0^o (p,n) cross sections, versus $<F>^2$ and $<ME>^2$. The top graph contains only the pure Fermi transitions while the lower graph contains the complete data set. Error bars on K reflect uncertainties in measured cross sections only. The points are labeled by target nucleus and the excitation energy in the final nucleus in parentheses. The solid curves represent the best fit strengths, the dashed curves, the impulse approximation strengths, and the dot-dashed curve the OPEP strength.

$$K = \frac{d\sigma}{d\Omega}(0^o)/[(\frac{\mu}{\pi\hbar^2})^2 \frac{k_f}{k_i} N^D] \qquad (6)$$

is plotted vs. an effective matrix element,

$$<ME>^2 = <GT>^2 + \frac{N^D_\tau}{N^D_{\sigma\tau}} \left(\frac{J_\tau}{J_{\sigma\tau}}\right)^2 <F>^2 . \qquad (7)$$

A linear relationship is apparent. Values for J_τ^2 and $J^2_{\sigma\tau}$ can be obtained from the data. OPEP alone does not account for all of the cross section for the GT transitions. The line labelled IA is an impulse approximation calculation from Ref. 3.

The measured 0° cross sections and the matrix elements deduced from beta decay rates are given in Table I.

Table I. Differential cross sections at 0° for transitions observed in the (p,n) reaction at 120 MeV and the squares of the matrix elements for corresponding β-decay transitions.

Target	J_i^π → J_f^π	E_x [a] (MeV)	$\frac{d\sigma}{d\Omega}(0^o)$ [b] (mb/sr)	$<F>^2$ [c]	$<GT>^2$ [d]
^{7}Li	$3/2^- \to 3/2^-$	0.00	31 ± 5	1	1.40[f]
	$3/2^- \to 1/2^-$	0.43		-	1.19[f]
^{12}C	$0^+ \to 1^+$	0.00	7.0 ± 1.1	-	.942 ± .006[g]
^{13}C	$1/2^- \to 1/2^-$	0.00	4.5 ± .7	1	.274 ± .002[h]
^{25}Mg	$5/2^+ \to 5/2^+$	0.00	4.2 ± .6	1	0.45 ± .03[i]
^{26}Mg	$0^+ \to 0^+$	0.23	2.7 ± .4	2	-
	$0^+ \to 1^+$	1.06	7.8 ±1.2	-	1.21 ± .05[j]
	$0^+ \to 1^+$	1.85[e]	4.1 ± .6	-	0.64 ± .04[j]
	$0^+ \to 1^+$	2.07			0.14 ± .03[j]
^{27}Al	$5/2^+ \to 5/2^+$	0.00	3.6 ± .5	1	0.34 ± .05[k]
^{28}Si	$0^+ \to 1^+$	1.31[e]	7.4 ± 1.1	-	0.37[l]
	$0^+ \to 1^+$	2.10		-	1.39[l]
^{90}Zr	$0^+ \to 0^+$	5.10	6.3 ± .9	10	-

a) Excitation energy in final nucleus reached in the (p,n) reaction.
b) For origin of quoted errors see text.
c) These values are deduced from the usual isospin assumptions.
d) Quoted errors are based on uncertainties in measured ft values and the small uncertainties in the parameters in eq. (5) are not included.
e) Unresolved in (p,n) measurements.
f) Ref. 5 p. 64.
g) Ref. 5, p. 94.
h) Ref. 5, p. 41.
i) Ref. 6, p. 131.
j) Ref. 6, p. 161.
k) Ref. 6, p. 187.
l) Deduced from study of M1 and 62 MeV (p,n) data reported in Ref. 7.

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GAMOW-TELLER RESONANCES OBSERVED IN ^{90,92,94}Zr(p,n) at 120 and 160 MeV

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Because the β-decay and nucleon charge exchange operators are identical in the spin isospin space of the target (decaying) nucleus, strong Gamow-Teller transitions should be seen strongly in charge exchange reactions. Searches with the (p,n) reaction at E_p= 45 MeV indicate that Gamow-Teller strength is concentrated just above the isobaric analog state (IAS).[1] But the enhancement in the continuum is relatively weak, making quantitative conclusions uncertain. The situation at E_p= 120 MeV is much less ambiguous because of the dominance of the spin-flip part of the effective two-nucleon interaction above 100 MeV.[2]

The ^{90,92,94}Zr(p,n) spectra shown in Fig. 1 were obtained with the beam swinger time of flight system at Indiana University. The IAS (0^+, T=5) and the states labelled 1^+ all have strongly forward peaked angular distributions characteristic of L=0. Since the transition to the IAS exhausts the non-spin-flip L=0 strength, the 1^+ identification follows. The stronger 1^+ state is assigned T=4 and the weaker T=5 based on intensity ratios expected from the isospin geometry. Finally, the state labelled 1^- has been so assigned because of its L=1 angular distribution.

Two qualitative conclusions follow immediately from this data. First, a substantial fraction of the Gamow-Teller strength has been seen. The relative areas of the 1^+ and IAS states, combined with a knowledge of the ratio of spin-flip to non-spin-flip strengths for the effective interaction leads to the conclusion that the Gamow-Teller matrix element for the 1^+ transition is comparable to the Fermi matrix element for the IAS transition. And second, the Gamow-Teller strength moves toward the IAS as N increases. The width of the 1^+ strength remains about constant at ∿ 4.5 MeV