spin-orbit term, and the isovector central term. The shape of the angular distribution of the analyzing power for this transition is similar to that seen for the ^{28}Si($\vec{p}$,p')^{28}Si (6$^-$; T = 1; 14.35 MeV) reaction reported by Bacher et al.3) Our preliminary results are compared in Fig. 1 to a DWIA calculation with the effective interaction of Love4) at 140 MeV and optical model parameters from Comfort and Karp5) for 135 MeV protons on ^{12}C. The comparison between the experimental results and the calculations are similar also to the comparison reported by Bacher et al.3) for the transition to the 6$^-$, T = 1, stretched state in ^{28}Si; namely, the general shape of the angular distribution is reproduced, but the calculated analyzing powers are too small and cross through zero (near 60°) at too small an angle. This consistent discrepancy between measured analyzing powers and the predictions may indicate some problem with the strengths or phases of the interfering terms in the effective interaction, or with the distortion effects in the DWIA calculations for these transitions.

We are proceeding with the analysis of the analyzing power for the complete set of data for transitions to the 4$^-$ state and to other states in ^{16}F and for the ^{9}Be($\vec{p}$,n)^{9}B reaction.

1) R.S. Henderson, B.M. Spicer, I.D. Svalbe, V.C. Officer, G.G. Shute, D.W. Devins, D.L. Friesel, W.P. Jones, and A.C. Attard, Aust. J. Phys. 32, 411 (1979).

2) R.A. Lindgren, W.J. Gerace, A.D. Bacher, W.G. Love, and F. Petrovich, Phys. Rev. Lett. 42, 1524 (1979).

3) A.D. Bacher, G.T. Emery, W.P. Jones, D.W. Miller, C. Olmer, P. Schwandt, S. Yen, J.R. Sobie, T.E. Drake, W.G. Love, and F. Petrovich, IUCF Newsletter No. 27, 3 October 1980.

4) W.G. Love, in The (p,n) Reaction and the Nucleon-Nucleon Force, ed. C.D. Goodman et al. (Plenum, New York), p. 23 (1980).

5) J.R. Comfort and B.C. Karp, Phys. Rev. C21, 2162 (1980).

^{14}C(p,n)^{14}N AND THE QUESTION OF MISSING GAMOW-TELLER STRENGTH

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

D.E. Bainum
Emporia State University, Physical Science Department, Emporia, Kansas 66801

C. Gaarde and J. Larsen
Niels Bohr Institute, Copenhagen

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

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

T. Masterson
University of Colorado, Nuclear Physics Lab, Boulder, Colorado 80309

J. Rapaport and T.N. Taddeucci
Ohio University, Department of Physics, Athens, Ohio 43701

E. Sugarbaker
Ohio State University, Physics Department, Columbus, Ohio 43212

In previously reported work from the (p,n) program it was shown that the prominent peaks in 0° neutron spectra are interpretable as transitions to states of the final nucleus which are structurally related to the target ground state by the spin-isospin Gamow-Teller (GT) operator.1) Simple theoretical arguments indicate that the dominant component of the nucleon-nucleus interaction at low momentum transfer has the form of a spin-isospin operator. It was shown empirically and theoretically that there is a quantitative relationship between the (p,n) cross section and the GT matrix element connecting the initial and final states.

Neutron spectra from many targets have now been measured at IUCF. An examination of the 0° spectra shows that the GT strength in heavy nuclei is contained mostly in a broad resonance close in energy to the isobaric-analog state (IAS). In light nuclei the GT strength appears to be distributed among a few sharp states, and in intermediate nuclei one can usually see a split in strength between a broad resonance and a few sharp states.2)

For a nucleus with a neutron excess it can be shown that the total GT strength must be equal to or greater than a value proportional to the neutron excess. The physical reasoning is that a bound neutron can transform to a proton with the same number of degrees of freedom as a free neutron unless the transition is partially or wholly blocked by proton occupancy of the necessary final states. However, it is possible to block only as many transitions as there are protons available. A formal derivation of this sum rule may be made with the use of a commutator relationship between the β^+ and β^- transition operators,3) namely

$$\sum_f |\langle f|\sigma\tau_-|i\rangle|^2 - \sum_f |\langle f|\sigma\tau_+|i\rangle|^2 = 3(N - Z)$$

where σ and τ are the nucleon spin and isospin operators and summations over the nucleons and over the components of σ are implied.

We now define for a nucleus with a neutron excess

$$B(GT) = |\langle f|\sigma\tau_-|i\rangle|^2$$

It follows that the sum strength is

$$\sum B(GT) \geq 3\ (N - Z)$$

where the sum is over all possible final states. It was observed that for every case measured the total strength obtained by summing all spectral features that could resonably be attributed to GT strength is appreciably less than the minimum required by the sum rule, typically about 2/3. Any given individual case, however, does not provide convincing evidence for missing strength because of uncertainties in normalization of the cross sections and uncertainties in evaluating the underlying background. It is nevertheless true that no case has been measured which yields as much strength as the sum rule requires. Some possible explanations are: (1) the calculated relationship between the (p,n) cross section and $\langle|GT|\rangle^2$ is wrong; (2) part of the strength is so fragmented that it is not observed; or (3) the remaining strength lies above the 50 MeV range of excitation explored in the present experiments.

$^{14}C(p,n)^{14}N$ is a valuable case to explore in this connection because model calculations can be made easily and existing calculations say that all the strength should be contained in just four 1^+ levels in ^{14}N, and almost all in two of the four.

We have measured $^{14}C(p,n)^{14}N$ with the beam-swinger facility at Ep=160 MeV. The target was made by pressing ^{14}C powder mixed with polystyrene as a binder. The pellet was then covered with polystyrene films for containment.

The measured 0° spectrum is shown in Fig. 1. It is seen that most of the strength is contained in the 3.95 MeV and 13.75 MeV states. The relative cross sections are listed in Table 1. The absolute target thickness is not known and, therefore, an absolute

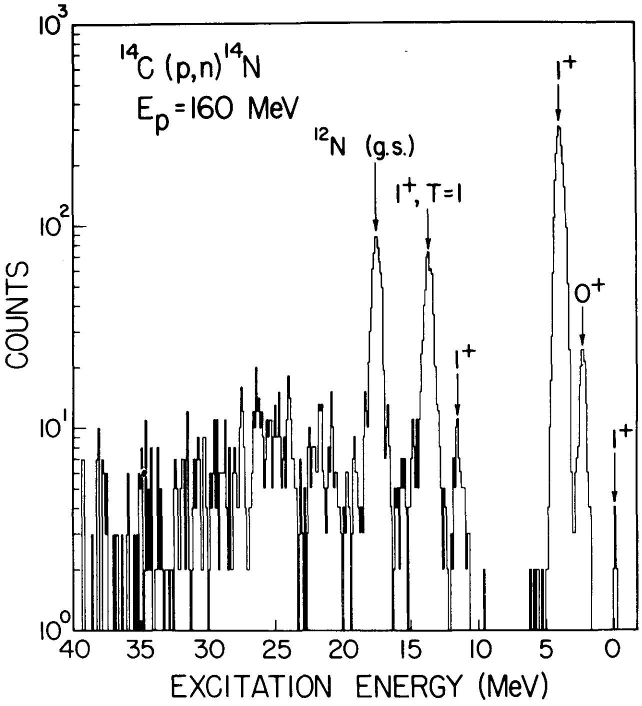

Figure 1. Neutron spectrum from $^{14}C(p,n)^{14}N$ at 0° and Ep=160 MeV. Most of the GT strength appears in the 3.95 and 13.75 MeV states. The state at 2.3 MeV is the isobaric-analog state.

cross section cannot be obtained directly. However, B(GT) values can be obtained by normalizing to beta-decay measurements of $^{14}O \rightarrow {}^{14}N(3.95)$. The values of B(GT) normalized in this way are also shown in Table 1. By this procedure we find $\sum B(GT) = 4.0 \pm 0.3$, compared to the sum rule value of 6. Results of model calculations are also given in Table 1 and the strength distribution agrees well with the measurements. The model sum, of course, is 6.

If, as the totality of the (p,n) data suggest, the strength deficit is a general feature of nuclear structure then the explanation must be given in terms of a general property of nuclear structure and not in terms of particular configurations. A leading contender for an explanation is the suggestion by Oset and Rho$^{6)}$ that Δ isobar-hole states couple to nucleon particle-hole states and that part of the strength is lifted to over 300 MeV excitation, beyond the scope of the present experiments. Prominent discussion of this possibility took place at a Workshop on Spin Excitations in Nuclei held at the Niels Bohr Institute in November 1980.$^{7)}$ The workshop was organized to discuss the implications of the recent IUCF (p,n) results and several members of the (p,n) group took part.

We thank Bill Lozowski for successfully undertaking the difficult task of fabricating the ^{14}C target. We also thank Dieter Kurath for providing us with calculations and discussions of GT matrix elements for p-shell nuclei, including those shown in Table 1.

Table 1. Gamow-Teller strengths for mass-14 $0^+(T=1)$ to $1^+(T=0,1)$ transitions.

Final State in ^{14}N (J,T, excitation in MeV)		B(GT)		
		Calculation	Beta Decay	(p,n)
1,0	0.0	0.02	3×10^{-6}	0.03
1,0	3.95	4.84	3.0±0.2	3.0 (normalized)
1,0	11.5 (exper.)			0.07
1,1	13.75	1.13		0.77
1,0	~15 (theory)	0.01		

1) C.D. Goodman, C.A. Goulding, M.B. Greenfield, J. Rapaport, D.E. Bainum, C.C. Foster, W.G. Love, and F. Petrovich, Phys. Rev. Lett. 44, 1755 (1980).

2) See "General Features at Gamow-Teller Resonances", contribution to this report.

3) C. Gaarde, J.S. Larsen, M.N. Harakeh, S.Y. van der Wert, M. Igarashi, and A. Muller-Arnke, Nucl. Phys. A334, 248 (1980).

4) D. Kurath, private communication.

5) H.S. Wilson, R.W. Kavanagh, and F.M. Mann, Phys. Rev. C22, 1696 (1980).

6) E. Oset and M. Rho, Phys. Rev. Lett. 42, 47 (1979).

7) Workshop on Spin Excitations in Nuclei, Niels Bohr Institute, Copenhagen, November 5-6, 1980.