THE GAMOW-TELLER STRENGTH FUNCTION FOR ^{37}Cl → ^{37}Ar

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The Gamow-Teller strength function for ^{37}Cl → ^{37}Ar is of unusual interest because ^{37}Cl is used as the neutrino detector in the Homestake Mine experiment that first reported the so-called "solar neutrino problem." An IUCF measurement of $^{37}\mathrm{Cl(p,n)}^{37}\mathrm{Ar}$ was published in 1981.[1] Prior to that, some information concerning the GT strength function was obtained from a measurement of the decay of ^{37}Ca → ^{37}K.[2] This is the isospin mirror of ^{37}Cl → ^{37}Ar. The actual measurement was of the spectrum of protons emitted from ^{37}K following beta decay. The energy level emitting the proton was inferred from the proton energy.

The GT strength functions from the (p,n) and the delayed proton experiments did not agree very well, and the discrepancies led Haxton and Adelberger[3] to hypothesize that the differences might arise from false identifications of the proton emitting states if protons feed excited states in ^{36}Ar. This idea motivated a new experiment on the decay of ^{37}Ca in which proton-gamma coincidences were measured.[4] The new experiment resolved some of the discrepancies but uncovered new ones. The new comparison of (p,n) and delayed proton measurements aroused considerable controversy[5–8] which motivated the new (p,n) experiment reported here. Preliminary results were reported in previous IUCF annual reports.

The data were taken with the IUCF Beam Swinger time-of-flight facility with a flight path of 130 m and proton energies of 100 and 160 MeV. The neutrons were detected with 12 scintillator bars, each 10 × 15 × 100 cm. Each bar had photomultipliers at both ends, which allowed for determination of the position of the scintillation to about 3 cm from the time difference of the signals from the two ends. The bars were placed with the long dimension parallel to the flight path.

Fitting of the data proved difficult because of the presence of a long tail on the low energy side of each peak due to neutrons scattered from the ground below the neutron detector hut. Fitting with a standard gaussian fitting program using skewed gaussians

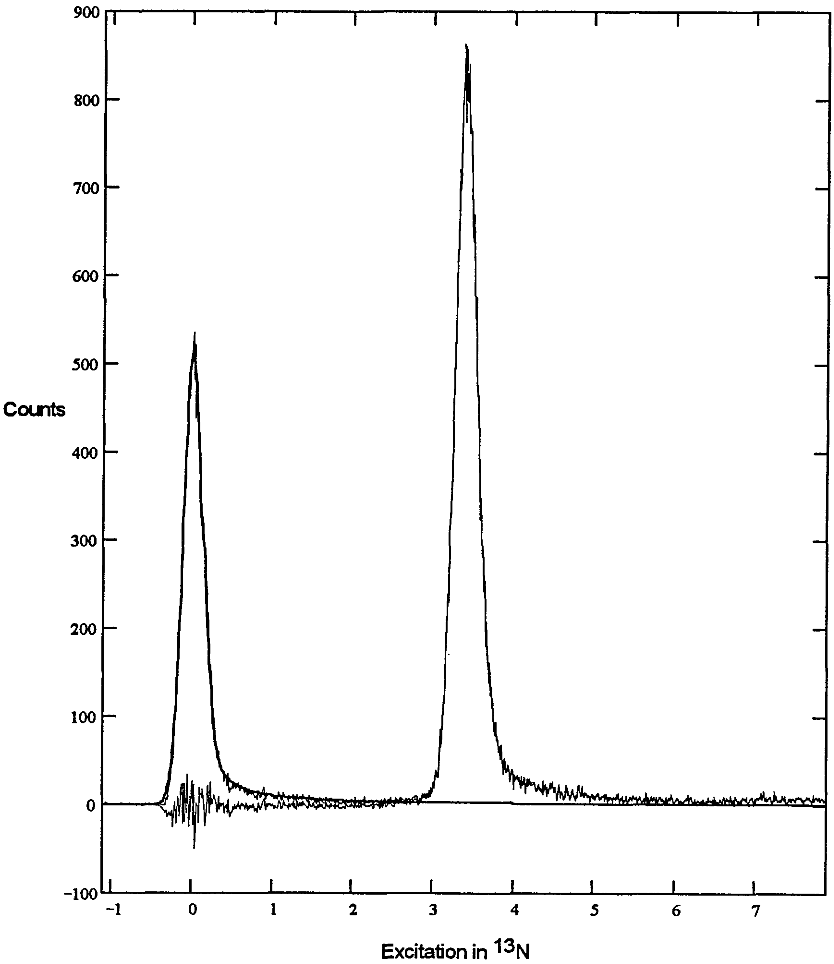
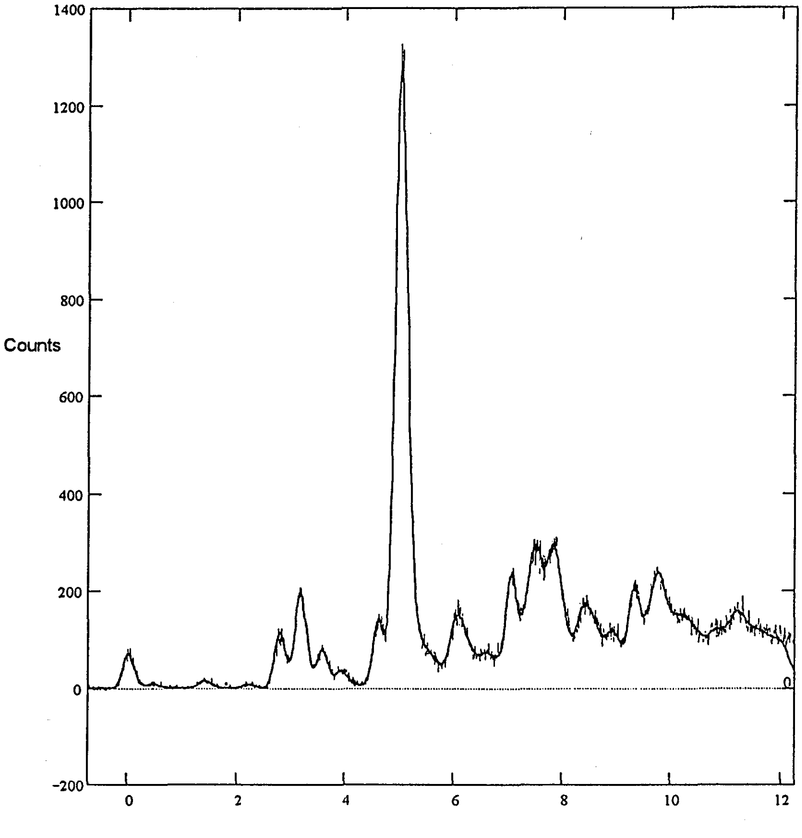


Figure 1. Mathcad printout showing fit to the ground state transition for $^{13}\mathrm{C(p,n)}$.

proved unsuccessful. Instead, we stripped the spectra using an empirical peak shape that included the long tail. We used Mathcad 4.0 (Ref. 9) for the processing. The functional form of the peak shape is a gaussian with a tail attached on the low energy side of the peak. The tail is defined analytically as the sum of three terms, $C_1/(x+b)$, $C_2/(x^2+b)$, and $C_3/(x^3+b)$, where x is the distance from the centroid of the gaussian. C_1 and C_2 are adjustable parameters, and C_3 is set to make the tail go to zero at the point of attachment, $x = a_w$, where a_w is an adjustable parameter expressed as a fraction of the gaussian width. The parameter, b, is used to kill the singularity at $x = 0$. Thus, there are four adjustable parameters associated with the tail. The final shape is shown in Fig. 1.

For the low excitation energy portion of the spectrum below the IAS, peaks are resolved and the fitting was done by matching the actual peaks. Above the IAS, the level spacing is much smaller than the experimental resolution, so it is not possible to fit visible peaks. From the IAS up to 8 MeV, we placed peaks at the energies reported by Garcia, *et al.* and varied only strengths. Of course, redistributing strengths among unresolved peaks has a negligible effect on the quality of the fit, so the fits are not unique. Above 8 MeV, where no information is available to use for guidance, we artificially placed a peak at every



Synthesized (p,n) spectrum plotted on raw data..

Figure 2. Fit to 100 MeV ^{37}Cl(p, n) spectrum overlaid on raw data.

100 keV and varied only the amplitudes to generate a fit that matched the spectrum. Since details finer than the actual resolution of about 250 keV cannot be observed anyway, this seems to be an adequate procedure for constructing the GT strength function. The quality of the fit to the 100 MeV data is shown in Fig. 2.

Our usual procedure for normalizing the (p,n) spectra to obtain values of B(GT) from the peak fits is to determine the number of counts in the Fermi component of the IAS and use the relationship between Fermi and Gamow-Teller cross sections to scale the spectrum. We expect $\hat{\sigma}(\mathrm{GT})/\hat{\sigma}(\mathrm{F}) = (\mathrm{E_p}/\mathrm{E_0})^2$ with $\mathrm{E_0} = 55 \pm 0.4$ MeV.[10] In the case of ^{37}Cl → ^{37}Ar we do not know the GT content of the IAS transition, which in general is not zero for an odd-mass nucleus, and the IAS is not resolved from surrounding GT peaks. Therefore, direct normalization to the IAS is not possible.

We have, instead, resorted to an indirect procedure. We assume that the ratio of GT to F cross section varies as the square of the bombarding energy. We, therefore, solve for the number of Fermi counts in the 100 MeV and the 160 MeV spectra by requiring that these numbers scale inversely as the energy, and that, after the subtraction, the spectra, normalized for the GT peaks, match. If we then choose a value for $\mathrm{E_0}$, we have an absolutely normalized spectrum. Figure 3 shows the 100 and 160 MeV spectra overlaid before and after the Fermi subtraction. To show the comparison, we have displayed the 100 MeV spectrum using the poorer resolution peak shape of the 160 MeV spectrum.

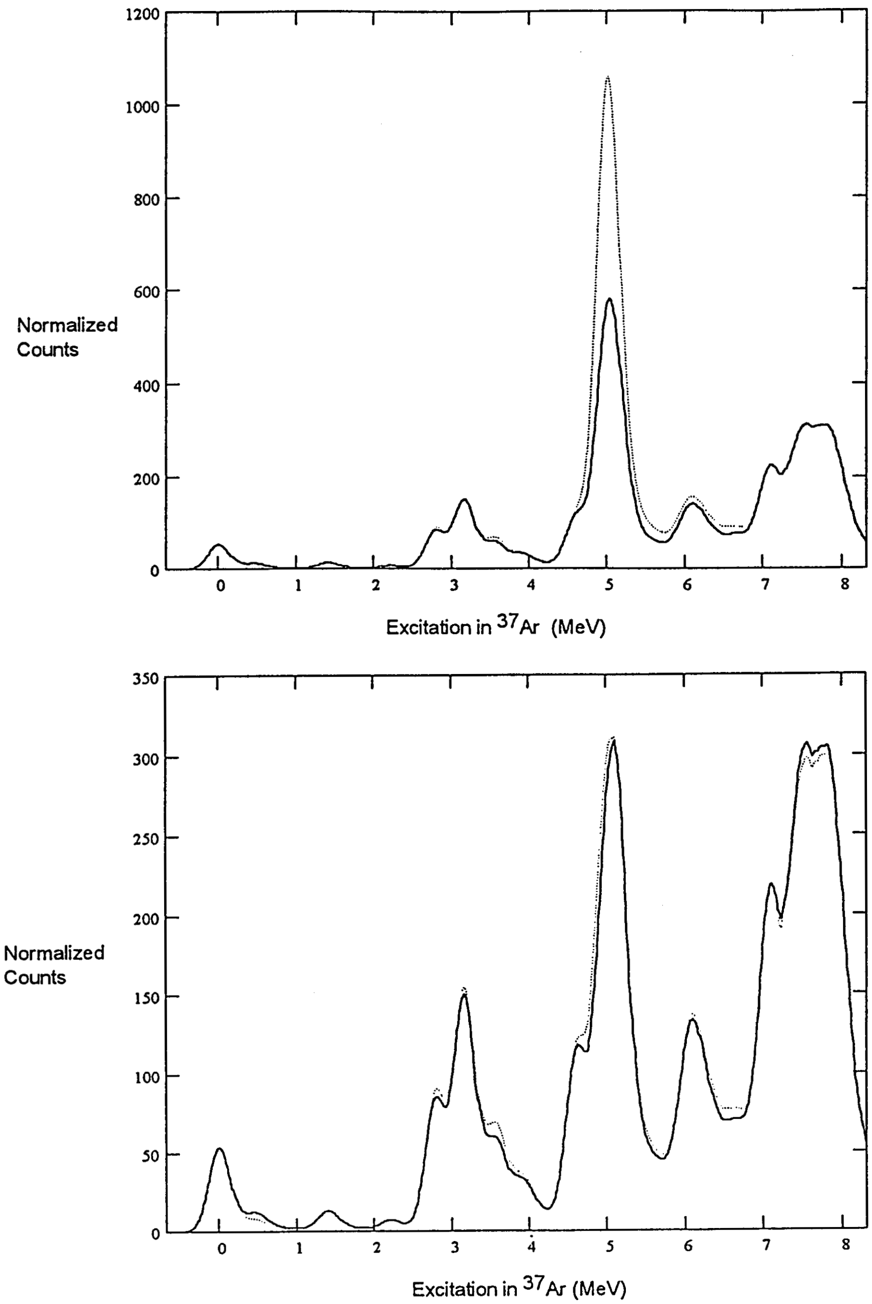


Figure 3. (a) Overlay of 100 MeV and 160 MeV data fits before subtraction of Fermi counts. (b) The same spectra after subtraction of the calculated Fermi counts.

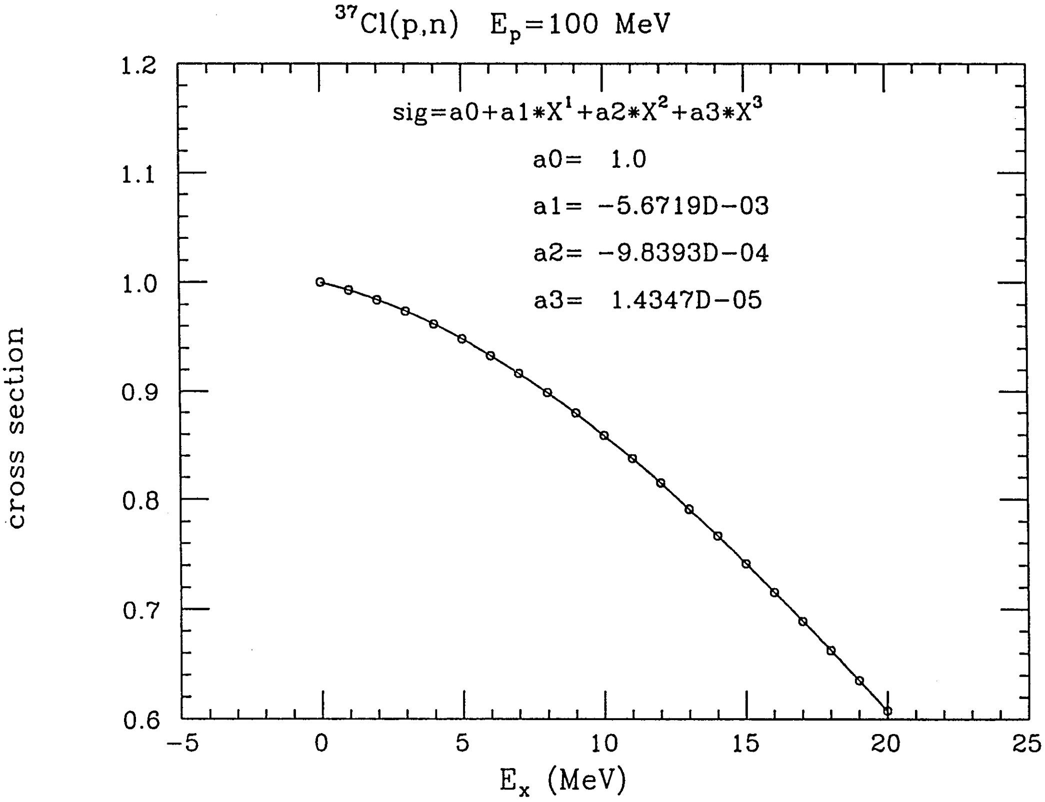


Figure 4. DWIA calculation of the dependence of the (p,n) cross section on excitation energy.

Actually, the spectrum is correctly normalized only in the vicinity of the IAS since a correction for momentum transfer is required. In Fig. 4 we show the calculated cross section as a function of excitation energy for E_p = 100 and 160 MeV. A careful comparison of the 100 MeV spectrum with the 160 MeV spectrum shows that the calculated correction should be a steeper function of excitation energy. However, for now we will use the calculated correction and proceed to a comparison of the (p,n) data with the Garcia data. For the (p,n) spectrum we use the fit to the 100 MeV data, E_0 = 55 MeV, and the calculated momentum transfer correction. We use the resolution and peak shape of the 100 MeV spectrum for generating the display spectra for the (p,n) and the Garcia spectra. The overlay is shown in Fig. 5. Note that there is no arbitrary normalization factor here.

The largest differences between the GT strength distribution from (p,n) and that from the delayed proton experiment occur for states below the IAS. The most striking difference is for the two $5/2^+$ states at 2.80 and 3.17 MeV. The analogs of these states in ^{37}K have been explored as resonances in proton capture on ^{36}Ar.[11,12] The analog of the 3.17 state was not seen at all in the earlier experiment and was shown to have a very small proton width in the later experiment. Thus, that state decays primarily by gamma emission. A shell model calculation also showed that the wave functions for these two states can be mixed so that the proton width vanishes for one of the states without noticeably affecting the rest of the GT distribution.[13] It should also be noted that these states lie below the

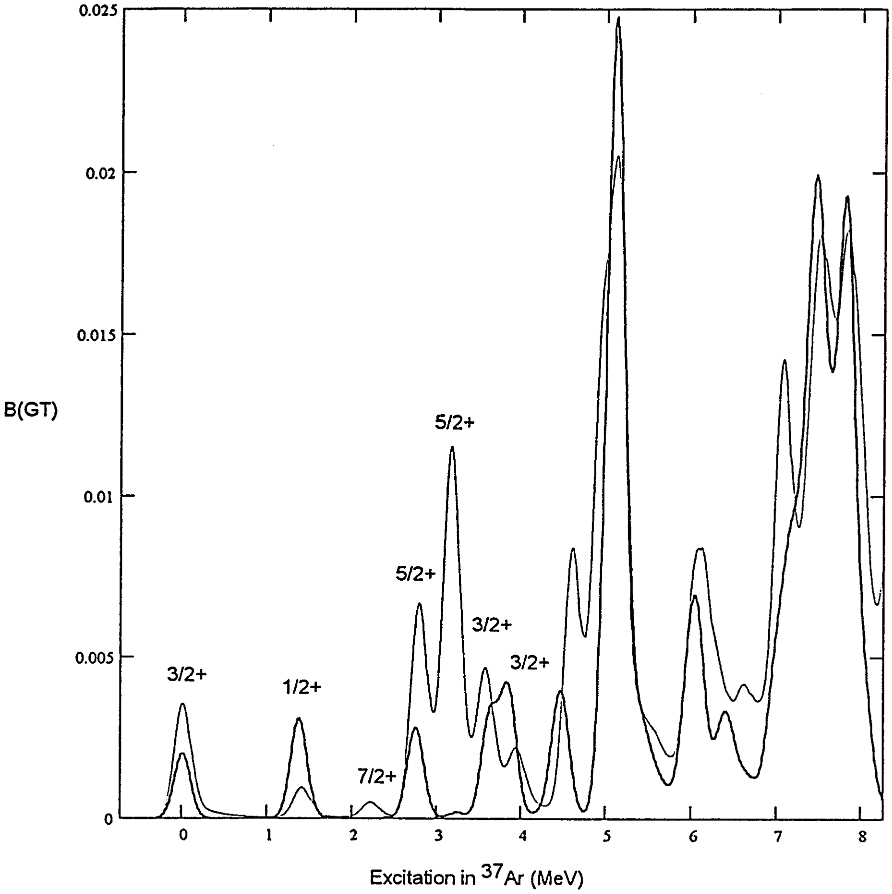


Figure 5. Comparison of the GT strength function deduced from (p,n) (light line) with that deduced from the delayed proton experiment of Ref. 4 (heavy line).

Coulomb barrier for proton emission from ^{37}K. One is therefore on shaky ground for interpreting the proton spectrum as a representation of the GT distribution in this region.

A difference between the spectra is also seen for the two $3/2^+$ states at 3.6 and 3.9 MeV. We have no clear information to tell us whether this is also due to proton width differences or differences in the actual GT distributions in the isospin mirror nuclei.

The analog of the $1/2^+$ state at 1.4 MeV lies below the proton emission threshold in ^{37}K, and the value of B(GT) reported in Garcia, *et al.*, is obtained by making the branching ratio sum unity. Since we know that some GT strength was missed, at least for the $5/2^+$ states, it is not surprising that the value reported for the $1/2^+$ state is too large.

The peak in the (p,n) spectrum at 2.2 MeV corresponds to a $7/2^+$ state and cannot be a GT transition. This indicates that there is some L=2 contamination, even in this 0° (p,n) spectrum.

The value of B(GT) for the ground state comes from the measured ft value for the decay of $^{37}\text{Ar} \rightarrow {}^{37}\text{Cl}$. It is apparent that the (p,n) cross section is larger than one would expect. The value of B(GT) is 0.031 out of a sum rule total strength of 9. Thus, it is not unreasonable that contributions from transition operators in addition to the simple spin-isospin operator might be visible at this level. In fact, a DWIA calculation shows the L=2 contribution to this transition to be almost as large as the GT contribution, in qualitative agreement with the experiment.

The summed strength up to 8 MeV from the (p,n) experiment is 2.27 compared to 1.92 reported by Garcia, *et al.* The (p,n) sum to 12 MeV is 4.22.

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