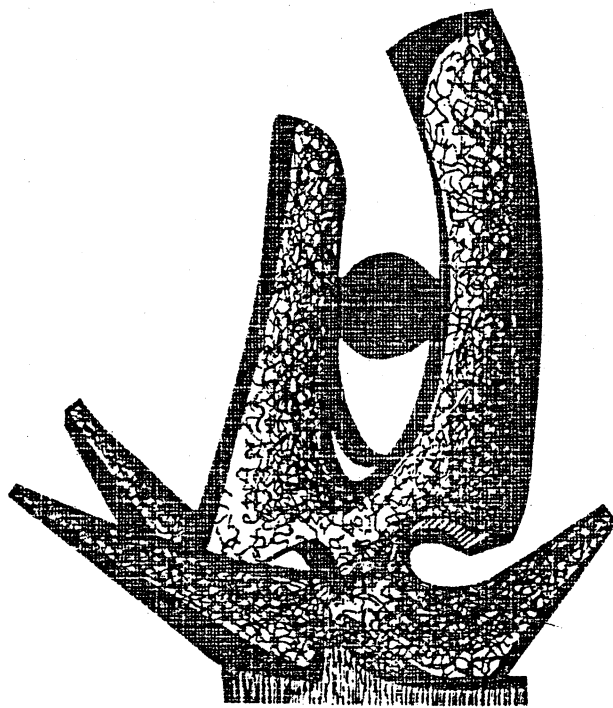


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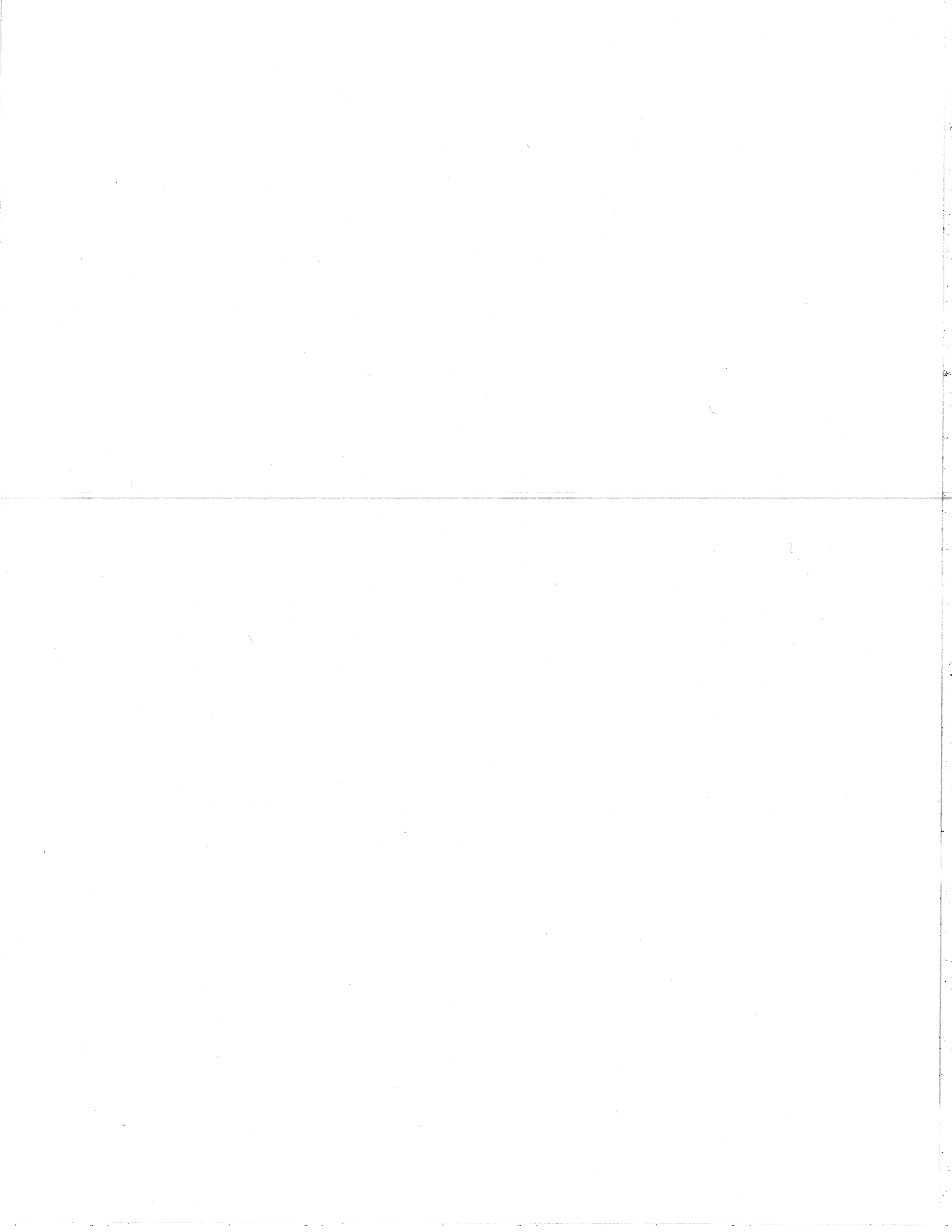
PREDICTED FEATURES OF THE BETA DECAY OF  
NEUTRON-RICH sd-SHELL NUCLEI

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**ABSTRACT:** The Gamow-Teller (GT) beta-decay transitions of sd-shell nuclei with five or more excess neutrons are calculated from complete  $(0d_{5/2}, 1s_{1/2}, 0d_{3/2})$ -space shell-model wave functions. These wave functions are obtained from diagonalizations of a model Hamiltonian formulation which reproduces observed energy-level structures throughout the sd-shell. The calculations are carried out with both the "free-nucleon" normalization for the GT single-nucleon matrix elements and one based on the empirical values obtained for these quantities from a comparison of corresponding theoretical and experimental GT magnitudes near the line of stability. The phase-space factors  $f$  which connect the reduced GT strengths to the total half-lives and the individual decay probabilities are calculated both from the energies obtained in the shell-model calculations and, alternatively, from hybrid energy spectra in which available experimental energies are substituted for the corresponding calculated values wherever possible. Comparisons of the beta-decay predictions to existing experimental results are presented and discussed.

**KEYWORDS:** [Predictions of total half-lives and decay probabilities to individual daughter states of the isotopes of O, F, Ne, Na, Mg, Al, Si and P which have neutron excesses of five and greater; shell-model calculations, complete  $(0d_{5/2}, 1s_{1/2}, 0d_{3/2})$ -space, empirical "USD" sd-shell Hamiltonian]

## I. INTRODUCTION

The spectroscopy of very-neutron-rich light nuclei adds a new dimension to our understanding of nuclear structure since these systems are constructed from combinations of neutrons and protons which necessarily have symmetries different from those studied in the stable and near-stable systems whose features are the foundation of our present knowledge. The last decade has witnessed significant advances in the experimental capabilities for both the production of far-from-stability nuclei and the measurement of their properties (Refs. 1-6). The continuing development of heavy-ion accelerators and associated particle-analysis systems promise still further progress in this field of study, (Ref 7, Ref 8, Ref 9, Ref 10) and it is reasonable to hope that by these developments the domain of nuclear spectroscopy can be significantly expanded. We present in this study predictions of the Gamow-Teller (GT) beta-decay properties of the sd-shell nuclei which have neutron excesses of five and greater. The creation of such nuclei and the measurements of their decays are at the frontier of current activities in this field.

Simply as a guide to the selection of experiments with which to study beta-unstable isotopes of unknown properties and as an aid to the design of the requisite experimental techniques, it is valuable to have realistic estimates of half-lives and decay patterns. This

practical need provides one rationale for the present calculations of these quantities. The more fundamental role of these predictions will develop, however, as data become available against which they can be thoroughly compared. The shell-model wave functions from which they derive (Ref 11) are generated in a scheme which requires that the degrees of freedom of the complete  $0d_{5/2} - 1s_{1/2} - 0d_{3/2}$  shell-model space yield a least-squares fit of Hamiltonian eigenvalues to the experimental energies of low-lying levels of known spin and isospin. The vast preponderance of these levels are taken from nuclei which have nearly equal numbers of neutrons and protons.

Beyond the limitation to the sd-shell model space, the theory used to obtain the present predictions has imposed upon it the constraint of a Hamiltonian which conserves isospin, which is limited to one- and two-body interactions and which has, more specifically, a fixed one-body spectrum and a single set of two-body matrix elements which are scaled for application to a given A-value by the factor  $0.3$ . Comparisons between predictions and experiment for systems lying outside the domain of data from which the Hamiltonian was determined provide crucial tests of the ultimate utility of this type of theoretical formulation. These tests concern first the adequacy of the model-space assumption for systems with large neutron excesses and then of the appropriateness of the Hamiltonian specification when it is used for systems quite different from those with whose energy levels it was fixed to agree.

A final goal of this study is to advance our knowledge of effective properties of nucleons in nuclei. Analysis of Gamow-Teller beta-decay data from near-stable nuclei with the corresponding members of the present family of wave functions suggests that the experimentally observed strengths are only 60% as large, on the average, as are the strengths generated from the model wave functions by the  $\sigma^{\dagger}$  operator normalized to agree with the free neutron half-life and  $\beta^+$  to  $\beta^+$  Fermi decay rates (Ref. 12). This result is consistent with a sequence of related earlier investigations (Refs. 13-16). Incorporation of data from the decay of more neutron-rich systems provides not just an expansion of the data base for such studies but, more importantly, opportunities to isolate in relative purity specific one-body transition terms which either do not occur with significant intensity in the existing near-to-stability data or are masked by mixing with other terms. Of course, progress towards this last goal is attendant upon confirmation that the predicted structural properties of the systems are in good enough general agreement with experiment to make this final stage of analysis meaningful.

## II. Discussion of the Calculations

### II.A. Model-space and Hamiltonian

The foundation of the present work is a new set (Ref. 11) of shell-model wave functions obtained in an attempt to reproduce all

features of sd-shell spectroscopy from a unified formulation of the model Hamiltonian. The wave functions span the complete spaces of  $0d_{5/2}, 1s_{1/2}, 0d_{3/2}$  configurations. This is a critical aspect in calculating matrix elements of operators such as the spin operator for which the transitions between the spin-orbit partners are crucial (Ref 17).

This calculation yields a family of wave functions  $\psi^{NTJ}$ , where  $N = A - 16$ ,  $T$  and  $J$  designate the total isobaric and angular momentum spin values and  $\nu$  the counting index which identifies a particular eigenstate of the NTJ set. In this family are wave functions which are presumed to correspond to the initial and final states of the neutron-rich beta decays we wish to calculate. From these wave functions we calculate the elements of the one-body-density-matrix (OBDM) operators  $\{a^{\dagger}(j) \otimes a(j')\}$  coupled to rank  $\Delta$   $J = 1$  and  $\Delta T = 1$ . The operators  $a^{\dagger}(j)$  and  $a(j')$  create and annihilate, respectively, nucleons in the shell-model orbits "j" of our model space, where j designates the single-nucleon state  $\rho(n, l, j)$ . We have the equation

$$\langle \psi^{N_1 T_1 J_1} | [ [ [ a^{\dagger}(j) \otimes a(j') ] ] ] \Delta J = 1, \Delta T = 1 | | \psi^{N_2 T_2 J_2} \rangle = \frac{-1/2}{(2 \Delta J + 1)} (2 \Delta T + 1) \times \dots$$

where the triple-bar indicates reduction in both ordinary and isobaric spin. There are seven such matrix elements in the sd-shell space.

corresponding to the  $j-j'$  transitions  $d_{5/2} - d_{5/2}$ ,  $d_{3/2} - d_{3/2}$ ,  $s_{1/2} - s_{1/2}$ ,  $s_{1/2} - d_{3/2}$ ,  $d_{3/2} - d_{5/2}$ ,  $d_{3/2} - s_{1/2}$  and  $d_{3/2} - d_{3/2}$ . These OBDM elements embody the entire predictive content of the shell-model calculations insofar as reduced Gamow-Teller strengths are concerned. They are uniquely and completely determined by the specification of the model Hamiltonian.

## II.2. The Gamow-Teller operator

In order to produce a theoretical reduced matrix element for a Gamow-Teller transition the OBDM elements from the shell-model calculation must be combined with the single-nucleon matrix elements (SNME) which give the amplitudes by which the Gamow-Teller process converts the model nucleons from one single-nucleon state to another. We have

$$\text{SNME}(\text{GT}; j, j') = \langle \rho(n_1 j) || \rho_{\text{GT}} || \rho(n'1, j') \rangle \quad (2)$$

where the Gamow-Teller operator is defined as

$$\rho_{\text{GT}} = \frac{1}{A} \sum_{\nu} \tau_{\nu} \sigma_{\nu} \quad (3)$$

The total Gamow-Teller matrix element is then defined as

$$B(\text{GT})^k = \{2[2J_A + 1]\}^{-1/2} \begin{pmatrix} T_A^+ & 1 & T_A^+ \\ -T_A^- & \Delta T_A & T_A^- \end{pmatrix} \times \sum_{j, j'} \text{OBDM}(j, j') \text{SNME}(\text{GT}; j, j') \quad (4)$$

In terms of the  $B(\text{GT})$  for a beta decay from  $N T_A^+ J_A^+ \nu$  to  $N T_A^- J_A^- \nu$ , the partial half-life for an individual daughter state is given by

$$t_{1/2}^k = C \{ [f_{\nu} + f_{\text{EC}}] B(\text{F}) + [f_{\nu} + f_{\text{EC}}] B(\text{GT})^k \}^{-1} \quad (5)$$

The term  $B(\text{F})$  is the Fermi matrix element

$$B(\text{F}) = \{ [T_A^+ + 1] - T_A^- T_A^+ \} S_{\nu}^k [1 - \epsilon] \quad (6)$$

The factor  $[1 - \epsilon]$  accounts for the reduction in the overlap between the initial and final state nuclear wave functions which arises from isospin mixing. The calculation of the phase-space factors  $f_{\nu}$  and  $f_{\text{EC}}$ , which depend upon the transition  $Q$ -values, is discussed in Section II.3. The term  $f_{\text{EC}}$  is the phase-space factor for electron capture. It is zero in the beta-minus decays which are our subject here. The values of the constants in Eqs. 5 and 6,  $C = 6170 \pm 4$  and  $\epsilon = 0.997 \pm 0.003$ , are determined empirically from the (pure) Fermi  $0^+ \rightarrow 0^+$  beta decays (Ref 18).

For the beta-minus decays of the neutron-rich nuclei considered here, Eq. 5 reduces to

$$t_{1/2} = \{6170+/-4\} f_A^{-1} / B(GT) \quad (7)$$

The predicted value for  $B(GT)$  depends, as we have seen in Eq. 4, upon the values of the SNME of the Gamow-Teller operator. The conventional values for these matrix elements are obtained here by taking the value of  $|q_A/q_V| = 1.251+/-0.009$  in Eq. 3. (This value is consistent with the value  $1.2606+/-0.0075$  recently published in Ref 19 for the same quantity.) This normalization of the SNME is consistent with the half-life of the free neutron and we refer to it, and the matrix elements obtained by using it, with the term "free-nucleon". The values of these free-nucleon SNME of the Gamow-Teller operator for the sd-shell orbits are given in Table 1.

The same Hamiltonian which has yielded the wave functions of the neutron-rich nuclei presently under study has also been used to generate wave functions of the states involved in Gamow-Teller beta decay nearer the valley of stability. The ORDM elements from these wave functions have been used with the free-nucleon SNME to calculate values of  $B(GT)$  for these near-stability transitions and the results compared to the corresponding experimental values (Ref 12). As was the case with a similar analysis with wave functions of the Chung-Wildenthal Hamiltonian (Ref 20, Ref 16), but with better quantitative accuracy, these calculations succeed in describing the experimentally observed details of the relative variations in

magnitude from transition to transition quite well. The calculated matrix elements are, however, systematically larger in magnitude than the corresponding experimental values. The accuracy with which the calculations reproduce the relative features of the data is such as to suggest that the systematic discrepancy in the absolute magnitude scales of the measured values and calculated values based on the free-nucleon normalization is a consequence of limitations in the general underlying assumptions of the shell model rather than of a failure to optimally utilize in these specific calculations the degrees of freedom which these general assumptions allow.

From this perception it follows that it would be appropriate to introduce state-independent corrections to the original shell-model calculations in order to compensate for the characteristic limitations to neutron and proton coordinates and a single major oscillator shell. The proportionality of the experimental and calculated matrix elements suggests that these corrections can be made in terms of renormalized transition operators, or more specifically, renormalized or "effective" values of their single-nucleon matrix elements. In principle, these renormalizations should be calculable (Ref 21-25). Alternatively, empirical estimates for their values can be obtained by treating them as parameters in a fit (Ref. 16) of the theoretical expressions of  $B(GT)$  (see Eq. 4) to the corresponding experimentally determined magnitudes of  $B(GT)$ .

Such a fit has been carried out with this new family of wave functions (Ref 12). The values of the Gamow-Teller SNME thus empirically determined are smaller than the free-nucleon values by factors of  $0.77 \pm 0.02$ . This near constancy of the quenching of the individual SNME terms is a simpler result than the more orbit-dependent results obtained with the Chung-Wildenthal wave functions (Ref 16). This makes it possible to simply scale down the total  $B(GT)^2$  values obtained for the present neutron-rich decays with the free-nucleon GT SNME by factors of  $0.77$  in order to obtain the predictions based on this empirical estimate of the net sum of the renormalizations of the GT SNME.

The approach of extracting empirical estimates of such renormalization corrections from a comparison of the predictions of nuclear structure theory with experimental data follows the path laid out by Wilkinson (Ref 13) who, from a comparison of data in the p-shell and lower sd-shell ( $A = 17-22$ ) with the calculations of Cohen and Kurath (Ref 26) and ancestral versions of the present wave functions (Ref 27, Ref 15) extracted a reduction factor (assumed orbit independent) of  $0.897 \pm 0.035$  for  $g_A/g_V$ . The empirical renormalizations of Refs. Ref 16 and Ref 12 are not inconsistent with this pioneering result in as much as the data from the p-shell and the  $A = 17-22$  region do not overlap strongly with the full sd-shell data set and the evidence is that the p orbits and the  $d_{5/2}$  orbit near the  $^{16}O$  shell closure do not require as much quenching as is required overall for the entire sd shell.

### II.3. The phase-space factors $f$

The phase-space factors  $f_V$  and  $f_A$  are calculated in the present study as prescribed by Wilkinson (Ref 13, Ref 28, Ref 18). The analytic result for a nucleus of  $Z = 0$  is

$$f_{Z=0} = [1/60] \{ 2W_0^2 - 9W_0^2 - 8 \} p_0 + [1/4] W_0 \ln(W_0 + p_0) \quad (8)$$

In this expression  $W_0$  is the total electron (positron) endpoint energy and  $p_0 = (W_0^2 - 1)^{1/2}$ . Several correction factors are applied to Eq. (8) to obtain  $f_A$ , the relation being expressed as

$$f_A = \delta_D \delta_R \delta_{WM} f_{Z=0} \quad (9)$$

The most important of these correction factors is  $\delta_{WM}$ , the values of which are tabulated (Ref 28) by Wilkinson and Macfield in the form

$$\delta_{WM} = \exp \left( \sum_{n=0,3} a_n (\ln E_0)^n \right) \quad (10)$$

where  $E_0$  is the end-point energy of the electron in units of MeV. The calculation of  $\delta_{WM}$  uses electron wave functions generated



from a uniform spherical charge distribution whose radius is adjusted to fit electron scattering and muonic x-ray data and which is corrected for the screening of the atomic electrons. Also included in the values of  $\delta_{WM}$  are the effects of the energy-dependent "outer" radiative correction to order  $\alpha$  and of the finite mass of the nucleus. The parametrization of the values of  $\delta_{WM}$  by Eq. 10 is accurate to better than 0.1% throughout (Ref. 28).

The factor  $\delta_R$  incorporates the effects of the "outer" radiative correction to orders  $Z\alpha^2$  and  $Z^2\alpha^3$  and is given (Ref 13, Ref 28) by

$$\delta_R = 1 + 3.67 \times 10^{-4} |Z| + 3.60 \times 10^{-6} Z^2, \quad (11)$$

where  $Z$  is the proton number of the daughter nuclei. The factor  $\delta_b$  incorporates the effects of the diffuseness of the actual nuclear charge distribution (Ref 18)

$$\delta_b = 1 + 1.8 \times 10^{-5} |Z|^{1.36} - 1.2 \times 10^{-6} |Z| W_0. \quad (12)$$

The Fermi phase-space factor  $f_V$  is related (Ref 28) to the factor  $f_A$  by

$$f_V = \delta_V f_A, \quad (13)$$

where

$$\delta_V = 1 + /- [2/15] W_0 R \alpha Z - [4/105] [W_0 R]^2 \quad (14)$$

for beta plus/minus decay, where  $\alpha = 1/137$  and we have used

$$R = 1.35 [A]^{1/3} \text{ fm} \quad (15)$$

We have generated two different sets of  $f$  values for the transitions treated here, corresponding to two different procedures for choosing the  $Q$ -value of a transition. One procedure uses the shell-model predictions for the energies of the initial and final states combined with a Coulomb correction  $\Delta E_C(A, Z)$  for a given  $A, Z$  to  $A, Z+1$  decay. These Coulomb corrections are formulated according to

$$\Delta E_C(A, Z) = E_C(Z) \left\{ 2(Z+1)/A \right\}^{1/3} \quad (16)$$

The values of  $E_C(Z)$ , obtained independently of the shell-model calculations by combining the binding-energy differences of analog states with the neutron-proton mass difference, are listed in Table 2. We refer to these  $Q$ -values and the  $f$  factors calculated from them, together with the resulting partial half-lives, branching fractions and total half-lives, as the "shell-model" values.

The other of our procedures for obtaining  $Q$ -values uses the shell-model energies whenever experimental information is unavailable. Where experimental values for excitation energies or for ground-state

mass differences are available, these values are substituted for the corresponding "shell-model" values and a composite "empirical" spectrum of ground and excited state Q-values is constructed. Sets of "empirical" f factors and resulting partial half-lives, branching fractions and total half-lives are calculated from this alternate set of Q-values.

### III. Results and Discussion

#### III.1. Total half-lives

The total half-lives of the sd-shell neutron-rich nuclei which are predicted by our calculations are presented in Table 3 and Figure 1, along with available experimental data. The total half-lives of Table 3 are calculated according to the formula

$$\{T_{1/2}\}^{-1} = \sum_i \{t_{1/2}^i\}^{-1} \quad (17)$$

where the partial half-lives are calculated from the  $B(GT)^2$  and the f factors as presented in Table 4 according to Eq. 4. The results in Table 3 are grouped according to atomic number, those in Figure 1 according to isospin, or neutron excess. In Table 3, we list the ground-state Q-values for each decay as determined by the

shell-model calculation ("sm") and, if known, as experimentally measured ("emp"), followed by the predicted half-lives as calculated with the shell-model ground-state Q-values and excitation energies ("pure sm") and with the hybrid combination of shell-model and experimental ground-state Q-values and excitation energies ("sm + emp"). Both sets of half-life predictions incorporate the empirically determined GR SNME. Use of the "free-nucleon" instead of the "empirical" GR SNME would yield half-lives 0.6 as long as those listed. The asterisks by the entries for  $^{25}\text{O}$ ,  $^{26}\text{F}$  and  $^{29}\text{Ne}$  in Table 3 indicate that the present calculations for the binding energies of these systems predict them to be unbound to emission of either one or two neutrons. In the cases for which this is true, their beta decays would, presumably, not be observed. The shell-model predictions occasionally yield the incorrect ordering of closely-spaced ground-state multiplets. In these cases we have calculated the decays from the experimentally correct ground state. In the case of  $^{24}\text{F}$ , for which the theoretical energies of the first two states are almost identical and the experimental answer is unavailable, we have listed predictions for both possibilities.

We see from Table 3 and Figure 1 that for each of the isotope groups the least-neutron rich,  $T_Z = -5/2$ , member has a predicted half-life on the order of a second or longer. The shortest-lived isotopes, the most neutron-rich members of the O, F and Ne chains, have half-lives of the order of a millisecond. As a rough average, the half-life decreases by a factor of  $5^{+/-2}$  for each

increase in the neutron excess, the decrease being less rapid at the largest values. From Fig. 2, which displays the calculated Q-values for each  $T_2$  group plotted in the same arrangement as that used in Fig. 1 for the plot of the half-lives, we can see that these trends of half-lives with neutron excess, as well as a significant amount of the local variations within a  $T_2$  group, are correlated with the phase-space factors.

Total half-lives have been measured for all of the nuclei in the  $T_2 = -5/2$  group. We see from Table 3 and Fig. 1 that the predictions for these nuclei are in consistently good agreement with the experimental results. The predicted  $^{210}$  decay deviates from experiment (Ref. 29) by the largest amount. In the  $T_2 = -3$  group, the Si, Al and Mg predictions agree well with the experimental values, the Na and O predicted half-lives are significantly longer than the experimental values and the F and Ne decays are unmeasured. In the  $T_2 = -7/2, -4, -9/2$  and  $-5$  groups, measured values are reported (Ref. 4) only for the three remaining Na isotopes and  $^{31}\text{Mg}$ . The  $^{29}\text{Na}$  prediction and experiment are in good agreement with each other but the predictions for  $^{30}\text{Na}$  and  $^{31}\text{Na}$  are too short by a factor of two to three. Finally, the most significant discrepancy between experiment and theory for any of the nuclei studied, indeed the only glaring disagreement, is found in  $^{31}\text{Mg}$ , for which the predicted half-life is a factor of ten shorter than that experimentally quoted.

### III.2. Branching percentages to the daughter states

The detailed distributions of Gamow-Teller strength among the energetically accessible states of the daughter nuclei yield information about the nuclear structure of the systems involved which can be much more revealing than the total half-life values. This is because the total half-lives are so strongly affected by the Q-values and usually result from a sum over several competing branches. The predictions and measurements for individual transitions between parent and daughter states are presented in Table 4. In this Table we give the energies calculated for the states in the daughter nuclei whose population is allowed by the GT selection rule, the experimental values for these excitations where they are known, the  $f$  values calculated with the Coulomb-corrected energies from the shell-model calculation, the  $B(\text{GT})^2$  values as calculated with the free-nucleon GT SME and the percentages of the total decay which go to each daughter state, as calculated alternatively with the "pure sm" and the "sm + emp"  $f$  factors and as quoted experimentally. We also note at the bottoms of the energy columns the calculated and, where available, experimental values of the neutron-emission thresholds in the daughter systems. States above these energies which are populated in beta decay would not show up in subsequent gamma-ray spectra.

The branching percentages of Table 4 are calculated as

$$"g"_{i-1} = 100(T_{i-1}/T_i) \quad (18)$$

We have assumed that the states listed in Table 4 comprise all those that are appreciably populated in the decays. While in the cases of the largest Q-values more states than listed are energetically accessible, the phase-space factors are such as to render their contributions negligible. As alluded to above, the shell-model calculations (Ref 11) predict incorrect orderings of the ground-state doublets in  $^{24,24}\text{Na}$  and  $^{21}\text{Hg}$  and a several hundred keV inversion of the ground and first excited states in  $^{31}\text{Na}$ . This is reflected in a few negative excitation energy values in the relevant columns. In calculating the Q-values for these cases (listed in Table 3) we have used as the "shell-model" values the calculated energies of the experimentally correct ground states.

In quoting the experimental results for the branching percentages we do not, in keeping with the summary presentations in the original publications, attempt to assign uncertainties. Statistical uncertainties alone range from small to quite significant among the various data but uncertainties from correlation effects and systematic errors are often the dominant factors in limiting the accuracy of the quoted numbers. In many instances the experimental technique does not produce a value for the ground-state branch. In these instances we adopt a scale for the relative fractions of the measured branches to the excited states such that the sum of these fractions is equal to

the corresponding sum predicted for the excited states.

In this and the following paragraphs we review some of the salient results presented in Table 4. The decay of  $^{21}\text{O}$  to the ground state of  $^{21}\text{F}$ , though allowed, is predicted to be vanishingly small. The experimental technique (Ref 29) used to acquire the excited-state branches would not have detected the ground-state branch in any case. The two dominant decay branches of  $^{21}\text{O}$  are to the first  $3/2+$  state, at a (theoretical/experimental) excitation energy of (1853/1730) keV and the second  $5/2+$  state, at an excitation energy of (3681/3518) keV. The predicted and observed percentages of these branches are in good agreement with each other. Smaller but significant branches are observed to levels at 3460 and 4572 keV excitation energy. The predicted branch to the second  $3/2+$  state, at 3512 keV excitation energy, is consistent with the 3460 keV observation but the calculated 4097 keV excitation energy of the remaining large theoretical branch, to the third  $3/2+$  state, is rather far from the 4572 keV value of the remaining significant observed branch.

The decay pattern of  $^{23}\text{F}$  is complex. The unmeasured ground-state branch is predicted to be 34% of the total. In this normalization, the first and second  $3/2+$  states, at (1768/1822) and (3237/3432) keV excitation energy, respectively, the second and third  $5/2+$  states, at (2184/2315) and (3826/3831) keV excitation energy, respectively, and the third  $7/2+$  state at, (4395/4436) keV, are observed

(Ref 30) to have important branches. The predictions agree with the outline of these results, the most important aspect of which is the concentration of strength into the  $3/2$ ,  $5/2$  and  $7/2$  triplet near 4 Mev excitation energy. The principal failing of the predictions is to concentrate too much strength into the second  $3/2+$  and third  $5/2+$  states while leaving the first  $3/2+$  and second  $5/2+$  states too weak.

The decay of  $^{25}\text{Ne}$  to the ground state of  $^{25}\text{Na}$  is not allowed. The observed (Ref 31) dominant branches to the lowest  $3/2+$  and  $1/2+$  states, at (132/90) and (1159/1069) keV (theoretical/experimental) excitation energy, respectively, are accurately reproduced by the calculations. The decay of  $^{27}\text{Na}$  to the ground state of  $^{27}\text{Mg}$  is similarly not allowed. Experiment (Ref 32, Ref 4) and theory agree in assigning the preponderance of the  $^{27}\text{Na}$  decay intensity to the first  $3/2+$  state, at (895/985) keV excitation energy, with the other transition of consequence being that to the first  $5/2+$  state at (1667/1690) keV excitation energy.

The decay of  $^{24}\text{Mg}$  to the ground state of  $^{24}\text{Al}$  is predicted to be 49% of the total. The remaining 51% of the predicted decay strength is distributed over several states, with the lowest  $3/2+$  state, at (1959/2224) keV, and the third  $5/2+$  state at (3017/3184) keV (theoretical/experimental) excitation energy, receiving the majority. The experimental value of the ground-state decay percentage relative to those of the excited states is obtained

(Ref 4) from different data than those which establish the individual fractions (Ref 33, Ref 4) for the excited states. The experimental value quoted is appreciably smaller than the prediction. Within the relative values for the excited states, the agreement between experiment and theory is reasonably good; the most significant discrepancy is for the lowest  $1/2+$  state, at (1214/1318) keV excitation energy. The observed state has all of the strength seen for  $1/2+$  states while in the model spectrum much of this strength is fragmented into the second  $1/2+$  state. As an example of  $T = 5/2$  decays, the distribution of transition strength with excitation energy and the correspondence between theory and experiment are illustrated for this decay of  $^{29}\text{Mg}$  in Figure 3.

The decay of  $^{31}\text{Al}$  is predicted to proceed dominantly to the  $3/2+$  ground state of  $^{31}\text{Si}$ , with the only two appreciable branches to excited states proceeding to the first  $5/2+$  and second  $3/2+$  states. The experimental results (Ref 34, Ref 4) are very similar to the predictions in their pattern of decay intensities. The decay of  $^{33}\text{Si}$  to the ground state of  $^{33}\text{P}$ , on the other hand, is predicted to be very weak. The dominant decay branch is predicted to proceed to the first  $5/2+$  state, with the other appreciable branches going to the first and second  $3/2+$  states. As for the case of  $^{31}\text{Al}$ , there is good agreement between the predicted and observed (Ref 35) decay patterns.

The decay of the  $1+$  ground state of  $^{18}\text{Na}$  is predicted to

proceed principally to the ground and first excited  $0^+$  states of  $^{28}\text{Mg}$ . The residual strength is predicted to be distributed over the first two  $1^+$  states and first two  $2^+$  states. The agreement of these predictions with the experimental results (Ref 4) is satisfactory except for the first  $2^+$  state, for which the predicted strength is too small. The energy distribution of the  $^{28}\text{Na}$  decay strengths and the correspondence between theory and experiment is shown in Figure 4. Roughly 90% of the decay of  $^{30}\text{Mg}$  is predicted to go to the first predicted  $1^+$  state in  $^{30}\text{Al}$ , at 493 keV excitation energy and most of the remainder to the second predicted  $1^+$  state, at 2139 keV. These predictions are in good agreement with the reported branchings (Ref 4) of 84% and 3%, respectively. For transitions to levels observed at 685 and 2165 keV.

We recall that the total half-life of  $^{31}\text{Mg}$  was completely anomalous in the context of sd-shell systematics. We can now see from Table 4 and Figure 5 that the pattern of branchings in this decay is equally anomalous. The anomaly in both the total half-life and the branching pattern resides in the ground-state decay branch. This is predicted to be 77% of the total decay, a result which is similar to that for the corresponding decay branch of  $^{24}\text{Mg}$ . This theoretical result is easily understood, as the wave functions of ground states of the  $A = 31$  isotopes of Al and Mg should, and do in the model calculations, resemble those of the corresponding states in the  $A = 29$  isotopes. The difference between the  $A = 29$  and 31 states lies essentially only in the presence of an additional pair of

$d_{3/2}$  neutrons coupled to  $J = 0$ ,  $T = 1$ , and this additional pair does not radically affect the calculated beta decay. The experimental result (Ref 36) of only a 10% branch to the ground state is in sharp contradiction to the shell-model prediction. In effect, this means that it is anomalous with respect to sd-shell systematics and suggests that some non-sd-shell effect is present in this decay. Since  $^{31}\text{Al}$  is closer to the "normal"  $N/Z$  ratio and its decay is itself "well-behaved", it is reasonable to locate the source of the anomaly in  $^{31}\text{Mg}$ .

Measurements of the individual decay branches of a beta-unstable nucleus conventionally involve detection of the gamma rays deexciting the daughter levels populated in the decay of the parent. In many instances, only these gamma rays are detected. It is hence important in planning experiments to estimate whether or not it is reasonable to expect strong branches to particle-bound excited states. In this context inspection of Table 4 suggests that of the presently unmeasured decays, those of  $^{21,21,24}\text{O}$ ,  $^{24,25,26,27}\text{F}$  and  $^{26,28}\text{Ne}$  would lend themselves to study. Of course, it is necessary to form the parent before observing its decay and the spectrum of excited states in the parent may inhibit the formation cross section of some of these examples (Ref. 8). Nuclei which are predicted to decay predominantly to the ground state of the daughter system and hence may be difficult to detect via gamma-ray measurements include  $^{16}\text{O}$ ,  $^{31}\text{Mg}$  and  $^{31,33}\text{Al}$ . Of course, this does not preclude measurement of their total half-lives, as is evident from the

recent (Ref 9) measurement for  $^{32}\text{Al}$ .

#### IV. Summary and conclusions

The predicted features of the Gamow-Teller beta decay of  $T_Z = -5/2$  nuclei obtained by using the empirically renormalized (quenched) single-nucleon matrix elements of the GT operator (Ref. 12) together with the complete sd-shell, USD-Hamiltonian model wave functions, agree well with experimentally measured values of the total half-lives and the branching percentages to individual final states for these systems. This result indicates that the basic assumptions of model space and Hamiltonian made in the USD calculations are valid for neutron excesses up through five. The agreement in magnitudes also confirms the insensitivity of the GT quenching factor, extracted from less neutron-rich systems, to significant excursions away from  $N = Z$ . Several of the present results involve strong  $d_{3/2}$  neutron to  $d_{5/2}$  proton one-body transitions. Direct information on this element is sparse in the beta decays closer to stability.

Experimental beta-decay results for nuclei with neutron excesses larger than five are progressively less abundant. Agreement between these data and the corresponding predictions is not significantly worse than for the  $T_Z = -5/2$  systems except for  $^{30}\text{Na}$ ,  $^{31}\text{Na}$  and, particularly, for  $^{31}\text{Mg}$ . For these three nuclei, the

predicted half-lives are too short. Information on the branching percentages is available for the case in which the discrepancy in half-life is worst,  $^{31}\text{Mg}$ . Experiment and theory disagree in this aspect of the decay as well, in that the predicted strong ground-state branch is observed to be quite weak, a feature which is consistent with the total half-life discrepancy.

These anomalies in the decays of the  $N = 19$  and 20 isotopes of Na and Mg are particularly interesting in the context of anomalies of comparable magnitude which have been revealed previously (Ref 1, Ref 5) in measurements of their masses. These are found to correspond to binding energies 1 or 2 MeV in excess of predictions (Ref 37, Ref 11) of shell-model calculations designed for less neutron-rich nuclei. Calculations in which orbits above the sd-shell are added to the model space can replicate these binding energy trends (Ref 38, Ref 39).

Further measurements (Refs. 3, 4, 6 and 36) on these systems have yielded the beta decays quoted here, electromagnetic moments and some excited-state energies. The electromagnetic-moment measurements do not yield conclusive information about the structures of the ground states, but a striking feature does emerge from the excitation-energy measurements (Ref. 4), namely a value for the first  $2^+$  state of  $^{26}\text{Mg}$  which is much lower than systematics would predict. To summarize, the experimentally observed features of the very-neutron-rich nuclei which

have been noted previously as being qualitatively different from sd-shell systematics are the masses of  $^{31}\text{Na}$ ,  $^{31}\text{Mg}$  and  $^{31}\text{Mg}$  and the first excited state energy of  $^{31}\text{Mg}$ . To this list the present analysis adds the half-life of  $^{31}\text{Mg}$ . The half-lives of  $^{30}\text{Na}$  and  $^{31}\text{Na}$  tend in the same direction but are not as dramatically in disagreement with the systematic trends.

It is plausible to hypothesize that these anomalies in the very-neutron-rich Na and Mg isotopes correspond to qualitatively different structures from those of the usual energy levels of the sd-shell. This different structure presumably involves an inversion of the lowest fp orbits with the highest sd orbits. Phenomena analogous to this have been long known in the neutron-rich members of the upper *0p* shell and recently have been suggested for the  $A=100$  region as well as for the present cases.

The present analysis thus shows that the anomalies present in the energies of the  $N = 19$  and  $20$  isotopes of Na and Mg also appear in their beta decays. This suggests that it will be possible to pursue this issue experimentally in situations where mass measurements themselves are not feasible. The analysis also indicates that this region of anomaly is rather tightly circumscribed, in that the decays of the lighter isotopes  $^{29}\text{Na}$  and  $^{30}\text{Mg}$  seem well understood in terms of sd-shell systematics, as do those of the relevant other (higher  $Z$ ) systems nominally within the shell for which

data are available.

The properties of the  $N = 20$  isotopes  $^{30}\text{Ne}$  and  $^{29}\text{F}$  are most crucial to a better understanding of the nature of the  $N = 19, 20$  behavior in the Na and Mg isotopes. However, the predictions for these decays suggest that measurements of their decays will be difficult with techniques currently at hand. The present calculations predict an even more pessimistic situation for the cases of the  $N = 19$  isotopes of F and Ne, namely that they are unbound. Of course, anomalies in F and Ne comparable to those found in Na and Mg might have the effect of making experimental measurements easier than our predictions suggest. In any case, our predictions for the  $N = 18$  isotopes of these elements indicate that measurements of their properties should be feasible. Such data, along with more detailed measurements on  $^{30}\text{Na}$  with which to compare our predictions of the branching pattern (see Table 4 and Figure 6), should go far towards clarifying whether the presently known anomalies are to be associated with  $N = 19$  and  $20$  in particular or with large neutron excesses in general.

In summary, we have seen that the juxtaposition of the present generation of nuclear structure predictions for neutron-rich sd-shell nuclei with the relatively sparse body of data serve to validate, within limits, the general assumptions and specific parameters of the shell model as formulated to reproduce systems near to  $N = Z$ . This limited validation highlights, in turn, the few sharp discrepancies between existing data and these predictions. It is reasonable to hope



that continued experimental progress against the background of realistic theoretical expectations will result in the quantitative explication of the present anomalies, if not in the unambiguous discovery of additional ones. We conclude with the observation that the presently available evidence vividly illustrates the fundamental interest of studies of very-neutron-rich nuclei in this region.

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Table 1. Values of the single-nucleon matrix elements of the Gamow-Teller operator in the "free-nucleon" normalization

$j - j'$	$\langle \rho(nlj)    \hat{G}_A / g_A \hat{\sigma}    \rho(nlj') \rangle$
5/2 5/2	8.88
5/2 3/2	-9.59
1/2 1/2	7.51
1/2 3/2	0.00
3/2 5/2	9.50
3/2 1/2	0.00
3/2 3/2	-4.75

Table 2. Values for the Coulomb energy correction constants  $E_C(Z)$  used in calculating the Q-values for the beta decays from isotopes of charge Z to charge Z+1 (see Eq. 16)

Z	$E_C$ (keV)
8	3509
9	3999
10	4300
11	4787
12	5020
13	5495
14	5695
15	6086

Table 3 O-values and half-lives of sd-shell nuclei which have five or more excess neutrons. Asterisks mark cases predicted to be unstable to neutron emission.

A-Z (J)	A-Z f	O-value (keV)	t(1/2) (seconds)	exp.	Ref
		( $\delta m$ ) (emp)	(pure sm)	(sm + emp)	
21 O (5/2)	21 F	8487	3.70	4.70	Ref 29
22 O (0)	22 F	6449	2.50	2.06	Ref 29
23 O (1/2)	23 F	11628 (11628)	0.141	(0.141)	Ref 9
24 O (0)	24 F	11107 (11107)	0.034	(0.034)	Ref 9
25 O (3/2)	25 F	16772 (16772)	0.0069*	(0.0069)*	Ref 9
26 O (0)	26 F	16249 (16249)	0.0032	(0.0032)	Ref 9
27 O (3/2)	27 F	20714 (20714)	0.0023*	(0.0023)*	Ref 9
28 O (0)	28 F	19342 (19342)	0.0015*	(0.0015)*	Ref 9
23 F (5/2)	23 Ne	8556	2.32	2.52	Ref 30
24 F (3)	24 Ne	14121 (14121)	0.171	0.171	Ref 30
24 F (2)	24 Ne	14218 (14218)	0.317	0.321	Ref 30
25 F (5/2)	25 Ne	13413 (13413)	0.061	(0.061)	Ref 30
26 F (1)	26 Ne	18128 (18128)	0.0092	(0.0092)	Ref 30
27 F (5/2)	27 Ne	17105 (17105)	0.0078	(0.0078)	Ref 30
28 F (3)	28 Ne	21926 (21926)	0.0045*	(0.0045)*	Ref 30
29 F (5/2)	29 Ne	20486 (20486)	0.0027	(0.0027)	Ref 30
25 Ne (1/2)	25 Na	7525	0.627	0.759	Ref 31
26 Ne (0)	26 Na	7135	0.162	0.170	Ref 31
27 Ne (3/2)	27 Na	12766 (12766)	0.035	(0.035)	Ref 31
28 Ne (0)	28 Na	11829 (11829)	0.0169	0.0169	Ref 31
29 Ne (3/2)	29 Na	16974 (16974)	0.0074*	(0.0074)*	Ref 31
30 Ne (0)	30 Na	16008 (16008)	0.0037	(0.0037)	Ref 31
27 Na (5/2)	27 Mg	8797	0.312	0.300	Ref 32
28 Na (1)	28 Mg	14186	0.0398	0.0460	Ref 32
29 Na (3/2)	29 Mg	12981	0.0456	0.0374	Ref 32
30 Na (2)	30 Mg	18200	0.0238	0.0247	Ref 32
31 Na (3/2)	31 Mg	17280	0.0066	0.0118	Ref 32
29 Mg (3/2)	29 Al	7715	0.940	1.210	Ref 33
30 Mg (0)	30 Al	6575	0.340	0.389	Ref 33
31 Mg (3/2)	31 Al	12496 (12496)	0.0274	0.0274	Ref 34
32 Mg (0)	32 Al	11892 (11892)	0.0110	(0.0110)	Ref 34
31 Al (5/2)	31 Si	7581	0.734	0.593	Ref 34
32 Al (1)	32 Si	13076 (13076)	0.0358	0.0363	Ref 34
33 Al (5/2)	33 Si	11711 (11711)	0.0341	(0.0341)	Ref 34
33 Si (3/2)	33 P	6316	4.64	7.41	Ref 35
34 Si (0)	34 P	4545	3.07	2.90	Ref 35
35 P (1/2)	35 S	3692	71.1	48.3	Ref 41
				48.1+/-1.4	Ref 41
				0.644+/-0.025	Ref 34
				0.945+/-0.425	Ref 9
				0.035+/-0.005	Ref 9
				6.18+/-0.18	Ref 35
				2.77+/-0.20	Ref 40
				0.280+/-0.020	Ref 32
				0.304+/-0.007	Ref 1
				0.326+/-0.062	Ref 9
				0.0305+/-0.0004	Ref 1
				0.062+/-0.033	Ref 9
				0.0429+/-0.0015	Ref 1
				0.053+/-0.003	Ref 1
				0.0169+/-0.0007	Ref 1
				1.20+/-0.13	Ref 33
				1.09+/-0.12	Ref 4
				1.790+/-0.365	Ref 9
				0.325+/-0.030	Ref 4
				0.270+/-0.135	Ref 9

Table 4 . Excitation energies of allowed final states in the Gamow-Teller beta decay of sd-shell nuclei with five or more excess neutrons, the values of their phase-space factors  $f$ , and their calculated and, where available, measured branching percentages

21		21					
0(5/2+) →		F					
2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp <sup>a)</sup>
3	1853	1730	4.279	0.200	30.75	34.21	37.0
3	3512	(3460)	3.653	0.166	5.65	5.63	(12.3)
3	4097	(4572)	3.366	0.366	15.41	14.04	(10.5)
3	4660		3.076	0.095	0.56	0.49	
3	4892		2.944	0.197	1.81	1.53	
3	6534		1.646	0.009	0.00	0.00	
3	7660		-0.328	0.141	0.00	0.00	
3	8182			0.410	0.00	0.00	
5	0	0	4.763	0.000	0.00	0.00	
5	3681	3518	3.628	0.389	26.38	29.08	29.5
5	4269		3.282	0.144	1.98	1.78	
5	5122		2.804	0.045	0.07	0.06	
5	5956		2.201	0.145	0.21	0.15	
5	6284		1.905	0.639	2.23	1.48	
5	6562		1.615	0.004	0.00	0.00	
5	6790		1.342	0.327	0.19	0.11	
5	7313		0.521	0.099	0.00	0.00	
5	7435		0.265	0.205	0.01	0.00	
7	3611	3639	3.576	0.057	0.60	0.55	1.0
7	4427		3.124	0.166	2.23	1.66	
7	5283		2.700	0.393	4.31	3.49	
7	5602		2.478	0.503	4.46	3.44	
7	5720		2.390	0.444	2.89	2.18	
7	6956		1.117	0.461	0.25	0.13	
7	7459		0.210	0.054	0.00	0.00	
7	7945		-1.581	0.186	0.00	0.00	
7	8245			0.240	0.00	0.00	
B(n)	8168	8102 (8)					

22		22					
0(0+) →		F					
2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp
2	1629	1570	3.788	0.019	0.04	0.04	
2	2327		3.466	1.193	83.30	82.48	
2	3250		2.993	0.889	14.85	15.40	
2	3966		2.535	0.069	0.03	0.03	
2	4221		2.344	0.656	1.67	1.88	
2	5118		1.484	0.482	0.10	0.14	
2	5794		0.442	0.640	0.01	0.02	
2	6135		-0.434	0.059	0.00	0.00	
B(n)	5060	5197 (31)					

23 (1/2+) -> F

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log (F)	B (GT) $\frac{1}{2}$	th (sm) $\frac{1}{2}$	BRANCHING	th (emp)	exp
1	1	1776			5.146	0.536	54.58	54.58	3.34	54.58
1	1	5333			4.232	0.380	3.34	3.34	5.99	3.34
1	1	6379			3.867	0.775	5.99	5.99	3.34	3.34
1	1	7790			3.248	0.308	0.23	0.23	5.99	3.34
1	1	8116			3.075	0.634	0.65	0.65	5.99	3.34
1	1	8970			2.540	0.340	0.05	0.05	5.99	3.34
1	1	9105			2.441	0.627	0.15	0.15	5.99	3.34
1	1	9970			1.665	0.374	0.01	0.01	5.99	3.34
1	1	10345			1.207	0.179	0.00	0.00	5.99	3.34
1	1	10726			0.597	0.321	0.00	0.00	5.99	3.34
3	3	3497			4.752	0.517	20.48	20.48	5.99	3.34
3	3	4404			4.511	0.389	6.66	6.66	5.99	3.34
3	3	5653			4.126	0.526	6.66	6.66	5.99	3.34
3	3	6425			3.849	0.079	0.06	0.06	5.99	3.34
3	3	6767			3.714	0.529	1.96	1.96	5.99	3.34
3	3	7612			3.336	0.473	0.66	0.66	5.99	3.34
3	3	8082			3.093	0.099	0.02	0.02	5.99	3.34
3	3	8294			2.974	0.034	0.00	0.00	5.99	3.34
3	3	8450			2.881	0.221	0.05	0.05	5.99	3.34
3	3	8575			2.804	0.328	0.09	0.09	5.99	3.34

23 (5/2+) -> Ne

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log (F)	B (GT) $\frac{1}{2}$	th (sm) $\frac{1}{2}$	BRANCHING	th (emp)	exp
3	3	1768		1822	4.365	0.027	0.41	0.42	19.12	10.0
3	3	3237		3432	3.812	0.350	21.94	0.42	19.12	10.0
3	3	3778		3988	3.582	0.032	0.11	0.11	19.12	10.0
3	3	4920		5000	3.085	0.104	0.34	0.31	19.12	10.0
3	3	5434			2.831	0.102	0.17	0.17	19.12	10.0
3	3	6003			2.442	0.129	0.11	0.11	19.12	10.0
3	3	6444			2.081	0.004	0.00	0.00	19.12	10.0
3	3	6737			1.800	0.115	0.02	0.02	19.12	10.0
5	5	0		0	4.856	0.140	31.95	33.60	33.60	(33.6) (c)
5	5	2184		2315	4.211	0.000	0.00	0.00	32.62	24.3
5	5	3826		3831	3.649	0.552	31.78	0.00	32.62	24.3
5	5	5057			3.054	0.105	0.29	0.30	32.62	24.3
5	5	5433			2.831	0.107	0.18	0.19	32.62	24.3
5	5	5955			2.477	0.134	0.13	0.13	32.62	24.3
5	5	6366			2.149	0.032	0.00	0.00	32.62	24.3
5	5	6755			1.782	0.286	0.12	0.12	32.62	24.3
7	7	1759		1701	4.402	0.046	1.16	1.26	7.09	10.1
7	7	3605			3.743	0.145	2.69	2.78	7.09	10.1
7	7	4395		(4436)	3.396	0.344	6.91	7.09	7.09	10.1
7	7	5535			2.767	0.258	0.93	0.93	7.09	10.1
7	7	5773			2.608	0.188	0.34	0.34	7.09	10.1
7	7	6194			2.293	0.054	0.01	0.01	7.09	10.1
7	7	6513			2.018	0.344	0.30	0.30	7.09	10.1
7	7	6976			1.539	0.313	0.09	0.08	7.09	10.1

24 24  
O(0+) -> F

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp
2	861		5.227	1.231	83.46	83.46	
2	2996		4.747	0.261	1.24	1.24	
2	4099		4.449	1.046	10.03	10.03	
2	4790		4.239	0.246	0.34	0.34	
2	5230		4.093	1.070	4.63	4.63	
2	6691		3.523	0.137	0.02	0.02	
2	7069		3.347	0.509	0.19	0.19	
2	7458		3.149	0.394	0.07	0.07	
2	8091		2.781	0.253	0.01	0.01	
2	8335		2.620	0.232	0.01	0.01	
B(n)	3410						

24 24  
F(3+) -> Ne

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp
4	2145	1981	5.589	0.193	22.36	23.66	
4	3742	3867	5.239	0.198	11.87	11.11	
4	5339		4.920	0.203	5.65	5.60	
4	5957		4.771	0.124	1.49	1.48	
4	6610		4.601	0.061	0.24	0.24	
4	7265		4.415	0.281	3.38	3.36	
4	7618		4.308	0.032	0.03	0.03	
4	8322		4.078	0.185	0.67	0.67	
4	8582		3.986	0.190	0.57	0.57	
4	8811		3.901	0.194	0.49	0.49	
6	4568		5.093	0.077	1.20	1.19	
6	5472		4.889	0.025	0.08	0.08	
6	6927		4.513	0.394	8.34	8.27	
6	7240		4.423	0.204	1.80	1.79	
6	7842		4.238	0.284	2.30	2.28	
6	8683		3.949	0.507	3.76	3.73	
6	8880		3.875	0.151	0.28	0.28	
6	9187		3.755	0.110	0.11	0.11	
6	9875		3.458	0.161	0.12	0.12	
6	10023		3.388	0.174	0.12	0.12	
8	3996		5.213	0.327	28.70	28.46	
8	5645		4.848	0.023	0.06	0.06	
8	5941		4.775	0.167	2.73	2.71	
8	7394		4.377	0.130	0.67	0.66	
8	7701		4.283	0.252	2.01	1.99	
8	7744		4.269	0.035	0.04	0.04	
8	7983		4.192	0.052	0.07	0.07	
8	8560		3.994	0.084	0.11	0.11	
8	8840		3.890	0.033	0.01	0.01	
8	9110		3.786	0.268	0.72	0.72	
B(n)	8921	8865 (11)					

24  
E(2+) -> Ne

2JF	B(n)	EXC. ENERGY (keV)	Log (f)	B(GT) $\frac{1}{2}$	th(sm)	th(emp)	BRANCHING	exp
2	2	7391	4.407	0.373	10.82	10.94		
2	2	7976	4.226	0.249	3.19	3.22		
2	2	8555	4.030	0.038	0.05	0.49		
2	2	8857	3.920	0.139	0.49	0.16		
2	2	9296	3.750	0.096	0.16	0.00		
2	2	9467	3.680	0.015	0.00	0.00		
2	2	9716	3.573	0.009	0.00	0.00		
2	2	10095	3.400	0.222	0.38	0.38		
4	4	2145	5.606	0.114	14.96	16.13		
4	4	3742	5.259	0.253	37.34	35.65		
4	4	5339	4.943	0.082	1.81	1.83		
4	4	5957	4.795	0.012	0.03	0.03		
4	4	6610	4.627	0.217	6.09	6.16		
4	4	7265	4.444	0.142	1.71	1.73		
4	4	7618	4.338	0.151	1.52	1.53		
4	4	8322	4.111	0.465	8.52	8.61		
6	6	4568	5.114	0.016	0.10	0.10		
6	6	5472	4.912	0.114	3.26	3.30		
6	6	6927	4.540	0.231	5.65	5.71		
6	6	7240	4.451	0.071	0.44	0.44		
6	6	7842	4.269	0.048	0.13	0.13		
6	6	8683	3.984	0.051	0.08	0.08		
6	6	8880	3.912	0.271	1.82	1.84		
6	6	9187	3.793	0.279	1.47	1.49		

25  
O(3/2+) -> F

2JF	B(n)	EXC. ENERGY (keV)	Log (f)	B(GT) $\frac{1}{2}$	th(sm)	th(emp)	BRANCHING	exp
1	1	911	6.136	0.194	3.38	3.38		
1	1	4069	5.673	0.118	0.43	0.43		
1	1	6017	5.327	0.435	2.64	2.64		
1	1	7083	5.112	0.255	0.55	0.55		
3	3	3073	5.830	0.047	0.10	0.10		
3	3	3987	5.686	0.155	0.77	0.77		
3	3	5049	5.506	0.075	0.12	0.12		
3	3	5461	5.432	0.323	1.86	1.86		
5	5	0	6.252	0.799	75.05	75.05		
5	5	3756	5.723	0.462	7.43	7.43		
5	5	4799	5.550	0.526	6.47	6.47		
5	5	5631	5.400	0.270	1.21	1.21		

25  
F(5/2+) → Ne

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(sm)	exp
3	1687		5.517	0.350	23.40	23.40	
3	2967		5.278	0.055	0.33	0.33	
3	4595		4.929	0.223	2.46	2.46	
3	5676		4.661	0.138	0.51	0.51	
3	6174		4.526	0.342	2.28	2.28	
3	6409		4.459	0.230	0.88	0.88	
3	6895		4.313	0.105	0.13	0.13	
3	7341		4.170	0.225	0.43	0.43	
5	1779		5.501	0.224	9.24	9.24	
5	2971		5.277	0.303	10.09	10.09	
5	4226		5.013	0.443	11.73	11.73	
5	4648		4.916	0.052	0.13	0.13	
5	5574		4.688	0.498	7.03	7.03	
5	5741		4.644	0.205	1.07	1.07	
5	6182		4.524	0.334	2.16	2.16	
5	6561		4.414	0.274	1.13	1.13	
5	7027		4.272	0.598	3.88	3.88	
5	7409		4.147	0.050	0.02	0.02	
7	3639		5.141	0.484	18.79	18.79	
7	4249		5.008	0.029	0.05	0.05	
7	4692		4.906	0.028	0.04	0.04	
7	6175		4.526	0.177	0.61	0.61	
7	6205		4.517	0.188	0.68	0.68	
7	6775		4.350	0.082	0.09	0.09	
7	7080		4.255	0.519	2.82	2.82	
7	7324		4.176	0.015	0.00	0.00	
B(n)	4093	4278 (96)					

25  
Ne(1/2+) → Na

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp <sup>d</sup>
1	1159	1069	4.202	0.439	21.94	22.38	19.2
1	4048		2.891	0.443	1.41	1.11	
1	5134		2.096	0.317	0.14	0.09	
1	5725		1.486	0.370	0.06	0.03	
3	132	90	4.501	0.556	70.57	71.38	76.8
3	2130	2202	3.793	0.297	4.67	4.00	2.0
3	3304		3.302	0.232	0.93	0.79	
3	3623		3.136	0.149	0.27	0.22	
B(n)	9047	9011 (7)					

26  
F(0+) -> F

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)
2	2	0		
2	2	2054		
2	2	4633		
2	2	5105		
2	2	5874		
2	2	6418		
2	2	7316		
2	2	7797		
		1201		

2JF	B(GT) <sup>1/2</sup>	th(sm)	th(emp)	exp
6.186	1.326	82.70	82.70	
5.904	0.268	1.76	1.76	
5.487	0.595	3.33	3.33	
5.401	0.907	6.35	6.35	
5.253	0.175	0.17	0.17	
5.142	0.381	0.62	0.62	
4.945	1.354	4.95	4.95	
4.831	0.239	0.12	0.12	

26  
F(1+) -> Ne

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)
0	0	0		
0	0	3812		
0	0	5539		
0	0	7257		
0	0	8468		
0	0	9442		
2	2	4356		
2	2	6210		
2	2	7285		
2	2	8399		
2	2	8910		
2	2	9154		
4	4	2011		
4	4	3448		
4	4	4717		
4	4	5796		
4	4	5.618		
4	4	5.572		
4	4	5.489		
4	4	5.425		
4	4	5.327		
		5868		

2JF	B(GT) <sup>1/2</sup>	th(sm)	th(emp)	exp
6.425	0.353	29.24	29.24	
5.932	0.347	9.08	9.08	
5.665	0.186	1.40	1.40	
5.360	0.125	0.31	0.31	
5.116	0.012	0.00	0.00	
4.898	0.208	0.30	0.30	
5.851	0.077	0.37	0.37	
5.551	0.153	0.74	0.74	
5.355	0.161	0.52	0.52	
5.131	0.135	0.22	0.22	
5.020	0.278	0.71	0.71	
4.965	0.115	0.11	0.11	
6.179	0.471	29.57	29.57	
5.984	0.389	12.87	12.87	
5.796	0.008	0.00	0.00	
5.618	0.511	9.56	9.56	
5.572	0.193	1.22	1.22	
5.489	0.360	3.51	3.51	
5.425	0.104	0.26	0.26	
5.327	0.019	0.01	0.01	

26  
Ne(0+) -> Na

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)
2	2	-181		
2	2	1349		
2	2	2090		
2	2	2538		
2	2	3348		
2	2	3871		
2	2	4174		
2	2	4567		
		5606		

2JF	B(GT) <sup>1/2</sup>	th(sm)	th(emp)	exp
4.542	1.266	90.50	90.50	
3.927	0.458	3.97	3.97	
3.814	0.609	3.74	3.74	
3.648	0.340	0.76	0.76	
3.351	0.024	0.00	0.00	
3.077	0.850	1.02	1.02	
2.901	0.054	0.00	0.00	
2.648	0.089	0.00	0.00	



27 27  
O(3/2+) -> F

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	BRANCHING		exp
	(sm)	(emp)			th(sm)	th(emp)	
1	1997		6.482	0.120	0.97	0.97	
1	3299		6.331	0.375	6.70	6.70	
1	7479		5.758	0.075	0.07	0.07	
1	8527		5.587	0.183	0.29	0.29	
1	9114		5.484	0.332	0.75	0.75	
1	10300		5.261	0.336	0.46	0.46	
1	11087		5.099	0.377	0.40	0.40	
1	11308		5.051	0.000	0.00	0.00	
3	2861		6.383	0.785	33.13	33.13	
3	4436		6.190	0.150	0.77	0.77	
3	5772		6.011	0.194	0.86	0.86	
3	6228		5.946	0.318	1.99	1.99	
3	7031		5.828	0.050	0.04	0.04	
3	7584		5.742	0.440	2.38	2.38	
3	7726		5.719	0.141	0.23	0.23	
3	9388		5.435	0.179	0.19	0.19	
5	0		6.694	0.116	1.48	1.48	
5	3385		6.321	0.762	27.05	27.05	
5	4445		6.189	0.697	16.69	16.69	
5	5676		6.024	0.162	0.62	0.62	
5	6736		5.872	0.379	2.39	2.39	
5	7432		5.766	0.441	2.53	2.53	
5	8496		5.592	0.003	0.00	0.00	
5	9120		5.483	0.038	0.01	0.01	
B(n)	2674						

27 27  
F(5/2+) -> Ne

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	BRANCHING		exp
	(sm)	(emp)			th(sm)	th(emp)	
3	0		6.303	0.419	26.38	26.38	
3	2539		5.968	0.036	0.09	0.09	
3	3371		5.846	0.413	8.91	8.91	
3	4678		5.638	0.150	0.73	0.73	
3	5041		5.576	0.015	0.01	0.01	
3	5697		5.460	0.232	1.16	1.16	
3	5773		5.446	0.178	0.66	0.66	
3	6389		5.331	0.238	0.91	0.91	
5	2171		6.020	0.539	22.72	22.72	
5	2582		5.962	0.330	7.46	7.46	
5	3265		5.862	0.355	6.86	6.86	
5	4579		5.654	0.160	0.86	0.86	
5	4896		5.601	0.363	3.93	3.93	
5	5184		5.551	0.045	0.05	0.05	
7	2017		6.041	0.381	11.96	11.96	
7	4253		5.707	0.248	2.34	2.34	
7	4662		5.640	0.063	0.13	0.13	
7	5092		5.567	0.371	3.79	3.79	
7	5791		5.443	0.211	0.92	0.92	
7	6215		5.364	0.097	0.16	0.16	
B(n)	1605						

27 Na(3/2+) -> 27

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log (F)	B (GT) <sup>2</sup>	th (sm)	th (emp)	exp
1	1	1630			5.420	0.074	0.48	0.48	
1	1	3741			4.987	0.118	0.45	0.45	
1	1	4406			4.830	0.354	2.81	2.81	
1	1	4759			4.742	0.045	0.04	0.04	
1	1	5342			4.588	0.147	0.28	0.28	
1	1	5811			4.456	0.315	0.94	0.94	
1	1	6441			4.263	0.265	0.43	0.43	
1	1	7138			4.029	0.151	0.08	0.08	
3	3	14			5.701	0.162	4.40	4.40	
3	3	3121			5.124	0.517	11.81	11.81	
3	3	3643			5.009	0.314	3.34	3.34	
3	3	3749			4.985	0.042	0.06	0.06	
3	3	4431			4.824	0.157	0.55	0.55	
3	3	4794			4.733	0.000	0.00	0.00	
5	5	0			5.704	0.494	41.00	41.00	
5	5	2671			5.218	0.456	11.41	11.41	
5	5	3571			5.025	0.362	4.60	4.60	
5	5	3922			4.946	0.538	8.47	8.47	
5	5	4337			4.847	0.466	5.07	5.07	
5	5	4902			4.705	0.186	0.58	0.58	
5	5	5123			4.647	0.117	0.20	0.20	
5	5	5655			4.501	0.535	3.01	3.01	

6812 (47)

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log (F)	B (GT) <sup>2</sup>	th (sm)	th (emp)	exp
3	3	895			4.740	0.734	85.89	85.29	86.0, 84
3	3	3162		3490	3.865	0.056	0.10	0.07	
3	3	3632			3.719	0.189	0.79	0.54	
3	3	5226			3.220	0.023	0.00	0.00	
3	3	5404			3.124	0.150	0.07	0.09	
3	3	5656			2.981	0.165	0.06	0.08	
3	3	5887			2.841	0.193	0.06	0.07	
3	3	6428			2.471	0.037	0.00	0.00	
3	3	6648			2.300	0.039	0.00	0.00	
3	3	7230			1.762	0.365	0.02	0.02	
5	5	1667		1698	4.549	0.278	7.64	7.91	14.0, 13
5	5	1978		1940	4.480	0.121	1.17	1.28	> 3.5, 1
5	5	4032			3.768	0.011	0.00	0.00	
5	5	4201			3.698	0.201	0.53	0.58	
5	5	4719			3.470	0.196	0.29	0.33	
5	5	5101			3.284	0.324	0.51	0.58	
5	5	5454			3.097	0.357	0.39	0.46	
5	5	6086			2.713	0.040	0.00	0.00	
5	5	6483			2.430	0.066	0.00	0.00	
5	5	6759			2.208	0.236	0.02	0.03	
7	7	3149			4.098	0.082	0.22	0.24	
7	7	3300			4.045	0.218	1.41	1.52	
7	7	4616			3.517	0.193	0.31	0.35	
7	7	5206			3.230	0.279	0.33	0.38	
7	7	5481			3.081	0.119	0.04	0.05	
7	7	5813			2.887	0.251	0.12	0.14	

6444 (<2)

28 28  
O(0+) -> F

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp
2	1847		6.341	1.474	70.25	70.25	
2	2774		6.227	0.767	14.63	14.63	
2	6904		5.629	0.773	3.75	3.75	
2	8080		5.423	0.075	0.02	0.02	
2	9549		5.134	2.246	10.14	10.14	
2	11418		4.699	1.275	1.20	1.20	
B(n)	**						

28 28  
F(3+) -> Ne

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp
4	1785		6.645	0.002	0.00	0.00	
4	3678		6.439	0.337	13.48	13.48	
4	4300		6.366	0.286	8.26	8.26	
4	5343		6.239	0.141	1.49	1.49	
4	6203		6.127	0.153	1.36	1.36	
4	6888		6.035	0.267	3.34	3.34	
4	7892		5.891	0.066	0.15	0.15	
4	8514		5.796	0.056	0.09	0.09	
6	5106		6.268	0.340	9.28	9.28	
6	5838		6.175	0.127	1.05	1.05	
6	7039		6.014	0.493	10.89	10.89	
6	7535		5.943	0.538	11.03	11.03	
6	8400		5.814	0.062	0.11	0.11	
6	8782		5.754	0.149	0.55	0.55	
6	9724		5.600	0.033	0.02	0.02	
6	9895		5.570	0.006	0.00	0.00	
8	3301		6.481	0.353	16.35	16.35	
8	5182		6.259	0.412	13.35	13.35	
8	6868		6.037	0.300	4.25	4.25	
8	6979		6.022	0.231	2.43	2.43	
8	7821		5.901	0.043	0.06	0.06	
8	8261		5.835	0.069	0.14	0.14	
8	8619		5.780	0.261	1.78	1.78	
8	8898		5.736	0.153	0.55	0.55	
B(n)	4336						

28 28  
Ne(0+) -> Na

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp
2	0		5.545	0.912	47.33	47.33	
2	1567		5.251	1.051	31.99	31.99	
2	2167		5.127	0.450	4.41	4.41	
2	2704		5.010	0.760	9.58	9.58	
2	3803		4.747	0.836	6.33	6.33	
2	3900		4.722	0.011	0.00	0.00	
2	4510		4.559	0.250	0.37	0.37	
2	4939		4.436	0.027	0.00	0.00	
B(n)	3442	3576 (141)					

28 Na(1+) -> Mg

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log (f)	B(GT) <sup>1/2</sup>	th(sm)	th(emp)	BRANCHING	exp (f)
0	0	0	0	0	5.886	0.367	44.09	45.77		63.0
0	0	3802	0	0	5.210	0.632	29.55	28.67		21.0
0	0	6187	0	0	4.669	0.107	0.25	0.55		
0	0	6855	0	0	4.484	0.201	0.58	0.24		
0	0	7867	0	0	4.169	0.178	0.23	0.21		
0	0	8900	0	0	3.792	0.110	0.04	0.03		
2	2	4396	4561	5193	5.061	0.355	7.04	6.41	(5.0) (9)	
2	2	5412	0	0	4.917	0.401	5.36	5.88		
2	2	6863	0	0	4.482	0.213	0.65	0.61		
2	2	7381	0	0	4.326	0.205	0.42	0.39		
2	2	8229	0	0	4.045	0.397	0.86	0.77		
4	4	1543	1473	0	5.653	0.126	3.00	3.16		11.0 (5.0) (9)
4	4	4264	4557	0	5.062	0.193	2.23	1.91		
4	4	4773	0	0	4.990	0.024	0.03	0.03		
4	4	5402	0	0	4.867	0.067	0.15	0.14		
4	4	6013	0	0	4.714	0.067	0.15	0.14		
4	4	6757	0	0	4.512	0.322	2.47	2.37		
4	4	7330	0	0	4.342	0.171	1.63	1.54		
4	4	7420	0	0	4.314	0.338	1.12	1.04		

29 F(5/2+) -> Ne

2JF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log (f)	B(GT) <sup>1/2</sup>	th(sm)	th(emp)	BRANCHING	exp (f)
3	3	0	0	0	6.679	0.034	0.14	0.14		
3	3	3006	0	0	6.347	0.583	19.43	19.43		
3	3	4658	6.139	0	6.144	0.144	0.73	0.73		
3	3	5940	5.963	0	5.963	0.346	2.83	2.83		
3	3	7152	5.781	0	5.781	0.287	1.28	1.28		
3	3	7672	5.698	0	5.698	0.208	0.55	0.55		
5	5	2087	6.454	0	6.454	0.007	0.00	0.00		
5	5	4155	6.204	0	6.204	0.394	6.40	6.40		
5	5	4811	6.119	0	6.119	0.739	18.50	18.50		
5	5	5372	6.043	0	6.043	0.585	9.72	9.72		
5	5	6436	5.890	0	5.890	0.057	0.06	0.06		
5	5	7113	5.787	0	5.787	0.464	3.39	3.39		
7	7	2023	6.461	0	6.461	0.173	2.23	2.23		
7	7	3647	6.268	0	6.268	0.818	31.96	31.96		
7	7	5198	6.066	0	6.066	0.092	0.25	0.25		
7	7	5946	5.962	0	5.962	0.326	2.50	2.50		

29                      29  
 Ne(3/2+) -> Na

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm) §	BRANCHING	
	(sm)	(emp)				th(emp)	exp
1	1825		6.060	0.023	0.04	0.04	
1	3269		5.851	0.115	0.67	0.67	
1	3611		5.799	0.299	4.01	4.01	
1	5771		5.433	0.332	2.13	2.13	
1	5960		5.398	0.317	1.79	1.79	
1	7121		5.168	0.013	0.00	0.00	
3	0		6.297	0.353	17.64	17.64	
3	2669		5.940	0.216	2.91	2.91	
3	4037		5.731	0.009	0.00	0.00	
3	4379		5.676	0.170	0.98	0.98	
3	4968		5.576	0.511	7.04	7.04	
3	5521		5.479	0.122	0.32	0.32	
5	-137		6.314	0.432	27.41	27.41	
5	3085		5.879	0.419	9.49	9.49	
5	4122		5.717	0.244	2.22	2.22	
5	4454		5.663	0.509	8.51	8.51	
5	4676		5.626	0.667	13.43	13.43	
5	5409		5.499	0.250	1.40	1.40	
B(n)	5017	4292 (199)					

29                      29  
 Na(3/2+) -> Mg

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm) §	BRANCHING	
	(sm)	(emp)				th(emp)	exp
1	-39		5.810	0.107	2.78	2.68	
1	2398		5.393	0.611	33.16	33.09	
1	5221		4.779	0.522	5.52	5.88	
1	5803		4.627	0.178	0.44	0.48	
1	6621		4.394	0.150	0.18	0.20	
1	6752		4.354	0.068	0.03	0.04	
1	7219		4.206	0.015	0.00	0.00	
1	7873		3.979	0.178	0.09	0.11	
3	0		5.804	0.333	26.35	25.40	
3	2153		5.439	0.073	0.53	0.53	
3	3187		5.238	0.511	16.03	16.24	
3	4796		4.883	0.028	0.02	0.02	
5	1503		5.556	0.055	0.40	0.39	
5	2999		5.276	0.272	4.99	5.03	
5	3492		5.175	0.188	1.87	1.91	
5	3934		5.081	0.180	1.37	1.41	
5	4895		4.860	0.375	3.47	3.66	
5	4944		4.848	0.340	2.77	2.93	
B(n)	3622	3753 (51)					

ZJF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log(f)	B(GT) <sup>2</sup>	th(sm)	th(emp)	BRANCHING	exp
1	1	1214	1398	3433	4.218	0.119	2.80	2.72	2.72	15.0
1	1	3330			3.415	0.393	5.01	4.65		
1	1	4229			2.993	0.158	0.00	0.00		
1	1	4650			2.731	0.155	0.00	0.00		
1	1	5470			2.100	0.141	0.02	0.04		
1	1	5803			1.776	0.031	0.00	0.01		
1	1	6214			1.287	0.161	0.00	0.00		
1	1	6482			0.887	0.163	0.00	0.00		
1	1	7499			-5.251	0.154	0.00	0.00		
3	3	1959	2224	2866	3.928	0.327	12.06	10.52	21.0	
3	3	2735			3.671	0.227	2.99	2.81		
3	3	3578			3.344	0.325	2.64	2.72		
3	3	3976			3.137	0.436	3.01	3.02		
3	3	4459			2.854	0.008	0.00	0.00		
3	3	5064			2.436	0.212	0.16	0.14		
3	3	5591			1.988	0.047	0.00	0.00		
3	3	6113			1.419	0.154	0.01	0.01		
5	5	0	0	0	4.635	0.313	43.10	49.00	26.0	
5	5	2801	3062	3184	3.586	0.434	10.29	8.45	5.0	
5	5	3017			3.531	0.622	17.19	15.27	27.0	
5	5	3816			3.223	0.136	0.35	0.36		
5	5	4128			3.052	0.016	0.00	0.00		
5	5	4501			2.828	0.042	0.01	0.01		
5	5	5281			2.263	0.135	0.04	0.04		
5	5	5648			1.933	0.259	0.08	0.07		

ZJF	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log(f)	B(GT) <sup>2</sup>	th(sm)	th(emp)	BRANCHING	exp
2	2	66			6.166	1.065	59.36	59.36	59.36	
2	2	2511			5.819	0.531	6.65	6.65		
2	2	3251			5.702	1.124	22.72	22.72		
2	2	4115			5.557	0.728	6.81	6.81		
2	2	5443			5.312	0.468	1.60	1.60		
2	2	5922			5.216	0.312	0.57	0.57		
2	2	6500			5.094	0.384	0.65	0.65		
2	2	7406			4.889	0.767	1.63	1.63		

30                    30  
Mg(0+) -> Al

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp <sup>f</sup>
2	493	(685)	4.143	1.316	91.21	89.95	84.5
2	2139	(2163)	3.579	0.786	7.65	8.75	3.0
2	2538		3.394	0.032	0.01	0.01	
2	2981		3.167	0.019	0.00	0.00	
2	3185		3.054	0.161	0.10	0.11	
2	3551		2.835	0.672	1.01	1.15	
2	4100		2.455	0.119	0.01	0.02	
2	4573		2.062	0.143	0.01	0.01	
B(n)	5583	5751 (41)					

30                    30  
Na(2+) -> Mg

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm)	BRANCHING	
	(sm)	(emp)				th(emp)	exp
2	5242		5.728	0.053	0.36	0.36	
2	5959		5.610	0.377	13.73	13.72	
2	7304		5.366	0.290	4.66	4.63	
2	8449		5.135	0.071	0.17	0.17	
2	8837		5.051	0.117	0.37	0.37	
2	9065		5.000	0.003	0.00	0.00	
2	9366		4.930	0.403	3.33	3.28	
2	10115		4.747	0.161	0.35	0.35	
4	1671	(1484)	6.238	0.161	10.53	10.63	
4	3466		5.997	0.234	12.86	12.94	
4	4802		5.798	0.229	7.79	7.81	
4	5192		5.736	0.392	19.86	19.89	
4	6495		5.516	0.295	6.77	6.76	
4	6746		5.471	0.062	0.27	0.27	
4	7315		5.364	0.288	4.59	4.56	
4	7792		5.271	0.098	0.43	0.43	
6	4692		5.815	0.067	0.69	0.70	
6	6499		5.515	0.188	2.76	2.75	
6	7267		5.373	0.285	4.57	4.55	
6	7450		5.338	0.137	0.98	0.98	
6	8247		5.178	0.094	0.32	0.32	
6	8667		5.088	0.318	2.97	2.94	
6	8852		5.047	0.136	0.49	0.49	
6	9221		4.964	0.226	1.14	1.12	
B(n)	6778						

31  
Mg (3/2+) ->

2JF	B(n)	EXC. ENERGY (keV)	Log (f)	B (GT) <sup>2</sup>	th (sm)	th (emp)	BRANCHING	exp
1	1	2366	5.804	0.209	3.02	3.15		
1	1	3745	5.578	0.721	22.56	22.24		
1	1	5604	5.228	0.017	0.01	0.01		
1	1	6090	5.127	0.122	0.23	1.02		
1	1	7662	4.761	0.396	1.34	1.02		
1	1	8619	4.503	0.465	1.12	0.78		
3	3	0	6.144	0.261	9.53	10.73		
3	3	3206	5.669	0.445	10.37	10.48		
3	3	4649	5.415	0.503	7.88	7.43		
3	3	5329	5.284	0.382	3.48	3.16		
3	3	6865	4.954	0.055	0.04	0.03		
3	3	7233	4.867	0.159	0.26	0.21		
5	5	1550	5.928	0.272	6.61	7.10		
5	5	3232	5.665	0.711	26.17	26.40		
5	5	4268	5.485	0.439	6.93	6.66		
5	5	5415	5.267	0.071	0.12	0.10		
5	5	6209	5.101	0.011	0.00	0.00		
5	5	6422	5.055	0.144	0.32	0.27		

31  
Mg (3/2+) ->

2JF	B(n)	EXC. ENERGY (keV)	Log (f)	B (GT) <sup>2</sup>	th (sm)	th (emp)	BRANCHING	exp
1	1	944	5.517	0.046	0.18	0.18		17
1	1	3314	5.044	0.069	0.14	0.14		
1	1	4982	4.635	0.030	0.01	0.00		
1	1	5561	4.472	0.016	0.00	0.00		
1	1	6867	4.052	0.497	0.73	0.73		
1	1	7543	3.797	0.190	0.06	0.06		
1	1	7955	3.625	0.238	0.06	0.06		
1	1	8565	3.342	0.087	0.00	0.00		
3	3	1744	5.369	0.165	1.67	1.67		14
3	3	3793	4.934	0.120	0.32	0.32		
3	3	4052	4.873	0.228	1.02	1.02		8
3	3	4752	4.696	0.159	0.33	0.33		
3	3	5227	4.567	0.159	0.24	0.24		
3	3	5633	4.451	0.131	0.13	0.13		
3	3	6178	4.284	0.010	0.00	0.00		
3	3	6349	4.229	0.454	0.92	0.92		
5	5	0	5.680	0.781	76.84	76.84		10
5	5	3171	5.076	0.083	0.21	0.21		0.9
5	5	3239	4.897	0.750	11.68	11.68		24
5	5	4781	4.688	0.504	3.27	3.27		5
5	5	5245	4.562	0.184	0.33	0.33		
5	5	5905	4.369	0.505	1.57	1.57		
5	5	6057	4.322	0.191	0.20	0.20		
5	5	6445	4.197	0.120	0.06	0.06		



<sup>31</sup>Al(5/2+) → <sup>31</sup>Si

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm) %	BRANCHING		i)
	(sm)	(emp)				th(emp)	exp <sup>f)</sup>	
3	0	0	4.736	0.457	65.72	64.72	65.0	(65)
3	2295	2317	4.031	0.636	23.70	24.79	26.0	23
3	3825	4260	3.181	0.216	0.57	0.40		
3	5129		2.651	0.109	0.02	0.03		
3	5709		2.204	0.130	0.01	0.02		
3	6215		1.714	0.140	0.00	0.01		
5	1606	1695	4.245	0.298	9.17	8.88	7.5	11
5	2871	2789	3.854	0.079	0.21	0.25		1
5	5037		2.714	0.061	0.01	0.01		
5	5398		2.455	0.137	0.02	0.03		
5	5764		2.156	0.773	0.30	0.49		
5	6074		1.863	0.282	0.02	0.03		
5	6640		1.185	0.038	0.00	0.00		
5	6884		0.801	0.198	0.00	0.00		
5	7198		0.154	0.081	0.00	0.00		
5	7414		-0.478	0.092	0.00	0.00		
7	3697	3875	3.379	0.076	0.08	0.08		
7	4711		2.922	0.149	0.08	0.11		
7	5632		2.269	0.308	0.06	0.10		
7	6170		1.763	0.192	0.01	0.01		
7	6506		1.367	0.557	0.02	0.04		
7	6555		1.303	0.270	0.00	0.01		
7	7009		0.569	0.288	0.00	0.00		
7	7302		-0.123	0.021	0.00	0.00		
B(n)	6326	6588 (<2)						

<sup>32</sup>Mg(0+) → <sup>32</sup>Al

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm) %	BRANCHING	
	(sm)	(emp)				th(emp)	exp
2	0		5.577	1.531	93.87	93.87	
2	2547		5.080	0.313	1.25	1.25	
2	5071		4.438	0.047	0.01	0.01	
2	5309		4.367	1.025	2.59	2.59	
2	6012		4.139	0.848	1.05	1.05	
2	6738		3.876	0.758	0.46	0.46	
2	7211		3.685	1.207	0.75	0.75	
2	7500		3.559	0.254	0.02	0.02	
B(n)	3841						

32 Al(1+) -> SI

2Jf	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log (f)	B (GT) $\frac{1}{2}$	th (sm)	th (emp)	BRANCHING	exp
0	0	0	0	0	5.784	0.608	77.38	78.43		
0	0	4809	4983	0	4.797	0.785	14.67	13.45		
0	0	5755	0	0	4.593	0.045	0.03	0.03		
0	0	8056	0	0	3.835	0.012	0.03	0.03		
0	0	8813	0	0	3.513	0.170	0.03	0.03		
0	0	9877	0	0	2.955	0.177	0.01	0.01		
0	0	10987	0	0	2.153	0.268	0.00	0.00		
0	0	11464	0	0	1.682	0.097	0.00	0.00		
2	2	5582	0	0	4.640	0.253	0.96	0.97		
2	2	7457	0	0	4.060	0.576	1.31	1.33		
2	2	7869	0	0	3.908	0.261	0.19	0.19		
2	2	8419	0	0	3.687	0.155	0.04	0.04		
2	2	9031	0	0	3.410	0.229	0.05	0.05		
2	2	9435	0	0	3.205	0.392	0.08	0.09		
4	4	2094	1941	4232	5.452	0.117	1.25	1.36		
4	4	4212	0	0	4.978	0.276	2.51	2.52		
4	4	5649	0	0	4.622	0.048	0.03	0.03		
4	4	7076	0	0	4.191	0.229	0.28	0.28		
4	4	7631	0	0	3.997	0.366	0.46	0.46		
4	4	7968	0	0	3.870	0.366	0.46	0.46		
4	4	8193	0	0	3.781	0.295	0.22	0.22		
4	4	8485	0	0	3.659	0.421	0.37	0.37		
4	4	8485	0	0	3.659	0.289	0.13	0.13		

33 Al(5/2+) -> SI

2Jf	B(n)	EXC. ENERGY (keV)	(sm)	(emp)	Log (f)	B (GT) $\frac{1}{2}$	th (sm)	th (emp)	BRANCHING	exp
3	3	4421	0	0	4.584	0.472	2.80	2.80		
3	3	4693	0	0	4.507	0.320	1.08	1.08		
3	3	6327	0	0	3.975	0.468	0.68	0.68		
3	3	7290	0	0	3.584	0.052	0.00	0.00		
3	3	7763	0	0	3.362	0.652	0.32	0.32		
3	3	8530	0	0	2.944	0.153	0.01	0.01		
3	3	8797	0	0	2.777	0.152	0.00	0.00		
5	5	4378	0	0	4.596	0.343	1.52	1.52		
5	5	5677	0	0	4.203	0.501	1.31	1.31		
5	5	5994	0	0	4.095	0.215	0.19	0.19		
5	5	6279	0	0	3.992	0.460	0.68	0.68		
5	5	7160	0	0	3.641	0.455	0.30	0.30		
5	5	7959	0	0	3.263	0.194	0.02	0.02		
5	5	8329	0	0	3.062	0.564	0.12	0.12		
5	5	8549	0	0	2.933	0.181	0.01	0.01		
7	7	3985	0	0	4.702	0.117	0.23	0.23		
7	7	6609	0	0	3.868	0.556	0.75	0.75		
7	7	7106	0	0	3.665	0.390	0.23	0.23		
7	7	7546	0	0	3.467	0.131	0.02	0.02		
7	7	8165	0	0	3.153	0.620	0.18	0.18		
7	7	8544	0	0	2.935	0.027	0.00	0.00		
7	7	8850	0	0	2.742	0.088	0.00	0.00		
7	7	9240	0	0	2.465	0.590	0.03	0.03		

33                      33  
Si(3/2+) → P

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm) <sup>§</sup>	BRANCHING	
	(sm)	(emp)				th(emp)	exp <sup>j)</sup>
1	0	0	4.124	0.043	1.64	1.72	(2)
1	4242		1.598	0.302	0.58	0.26	
1	5728		-3.882	0.105	0.00	0.00	
3	1531	1432	3.558	0.019	0.09	0.09	4.2
3	2646	2539	2.985	0.386	11.35	10.27	8.8
3	3606		2.230	0.337	2.26	1.37	
3	4997		0.430	0.459	0.21	0.04	
5	1997	1848	3.360	0.703	78.15	80.67	85
5	3787	3490	2.327	0.599	5.31	5.41	
5	3888		1.974	0.150	0.28	0.15	
5	5153		0.062	0.478	0.14	0.02	
B(n)	10371	10103 (3)					

34                      34  
Si(0+) → P

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm) <sup>§</sup>	BRANCHING	
	(sm)	(emp)				th(emp)	exp <sup>k)</sup>
2	0	0	3.717	0.621	50.77	55.91	(56)
2	1408	1608	2.902	1.390	48.43	42.98	44
2	2954		1.840	0.758	0.80	1.11	
2	4233		-0.374	0.285	0.00	0.00	
B(n)	6024	6295 (9)					

35                      35  
P(1/2+) → S

2Jf	EXC. ENERGY (keV)		log(f)	B(GT) <sup>1/2</sup>	th(sm) <sup>§</sup>	BRANCHING	
	(sm)	(emp)				th(emp)	exp <sup>l)</sup>
1	1557	1572	2.387	0.937	99.39	99.43	100.00
3	0	0	3.367	0.005	0.04	0.03	
3	2800	2939	0.828	0.416	0.58	0.54	
B(n)	6824	6986 (<2)					

- a) Ref 29  
 b) Ref 30  
 c) experimental ground-state percentage set equal to theoretical value and relative excited-state percentages renormalized to make a total of 100%  
 d) Ref 31  
 e) Ref 32  
 f) Ref 4  
 g) experimental levels unresolved  
 h) Ref 36  
 i) Ref 34  
 j) Ref 35  
 k) Ref 40  
 l) Ref 41

## FIGURE CAPTIONS:

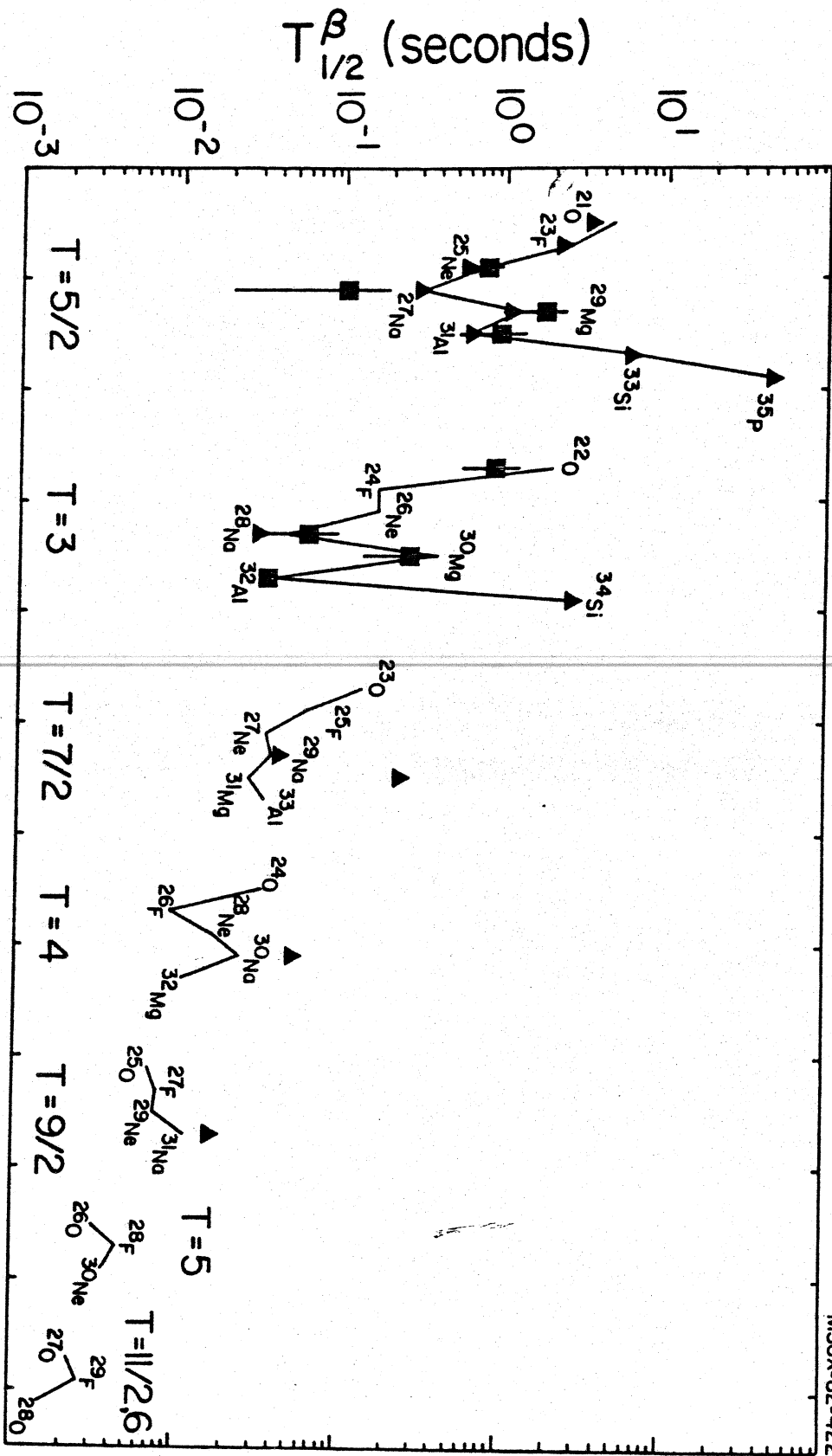
1. Comparison of half-lives calculated for the Gamow-Teller beta decay of the sd-shell nuclei with five or more excess neutrons with experimental measurements. The measured values, taken from Table 3, are shown as squares (Ref. 9) and triangles (all other experimental references), while the calculated values, also taken from Table 3, are connected by the solid lines.
2. Comparison of beta Q-values calculated for the decays of the sd-shell nuclei with five or more excess neutrons with experimental values. The measured values, taken from Table 3, are shown as squares, while the calculated values, also taken from Table 3, are connected by the solid lines.
3. Comparison of the calculated and measured branching percentages of the decay of  $^{28}\text{Mg}$ .
4. Comparison of the calculated and measured branching percentages of the decay of  $^{28}\text{Na}$ .
5. Comparison of the calculated and measured branching percentages of the decay of  $^{31}\text{Mg}$ .
6. The calculated branching percentages of the decay of  $^{30}\text{Na}$ .

## References

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Figure 1



MSUX-82-422

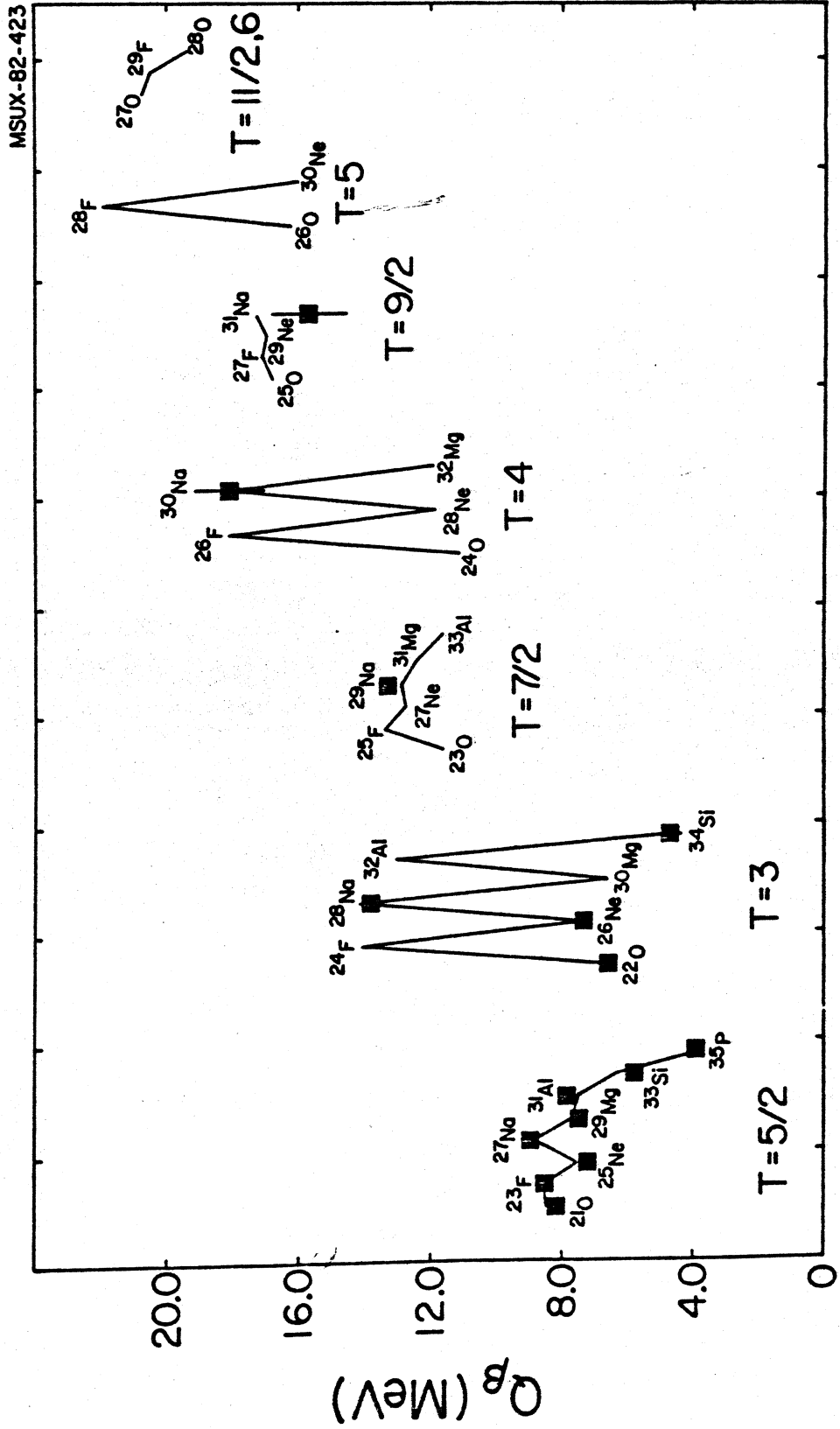


FIGURE 2

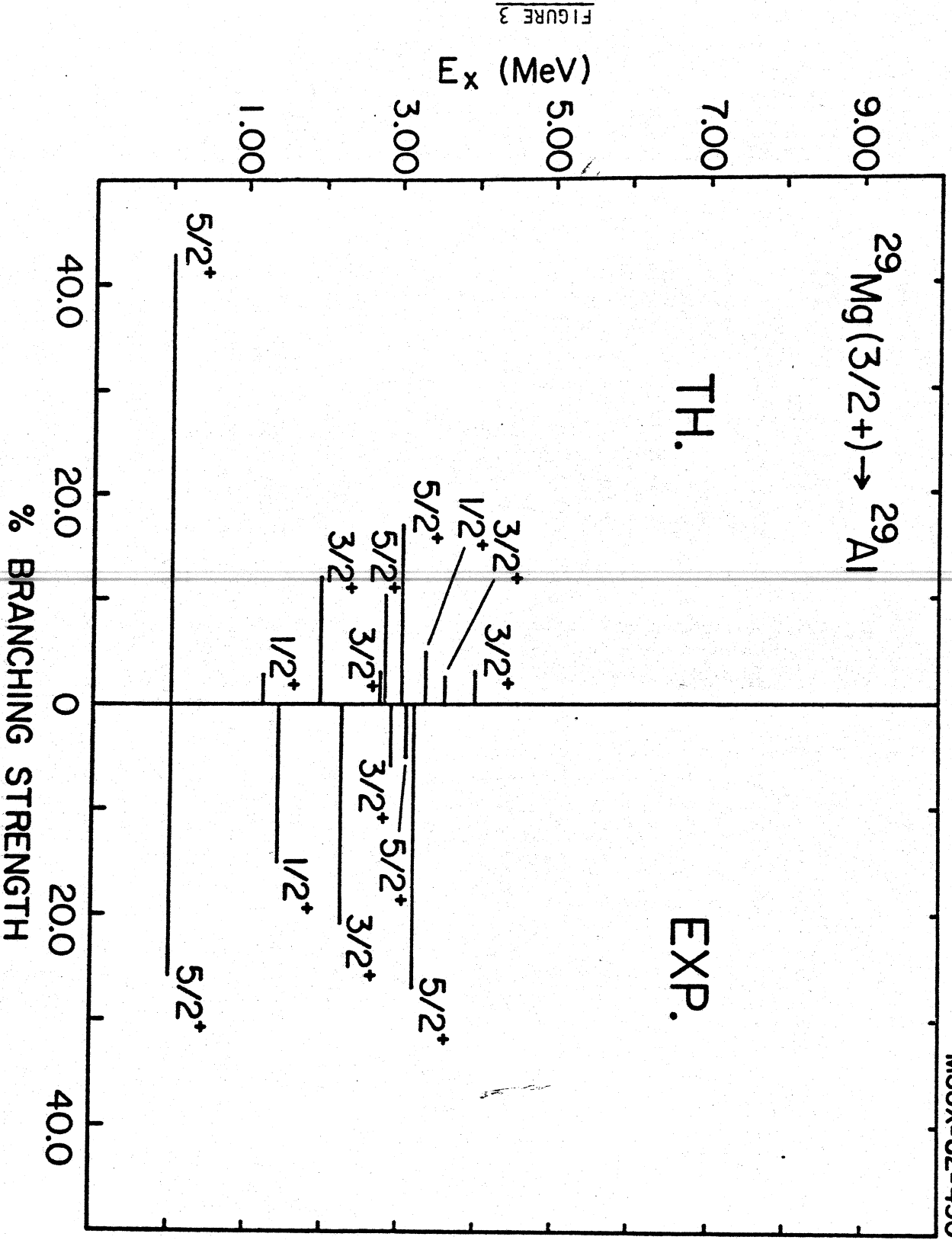


FIGURE 3



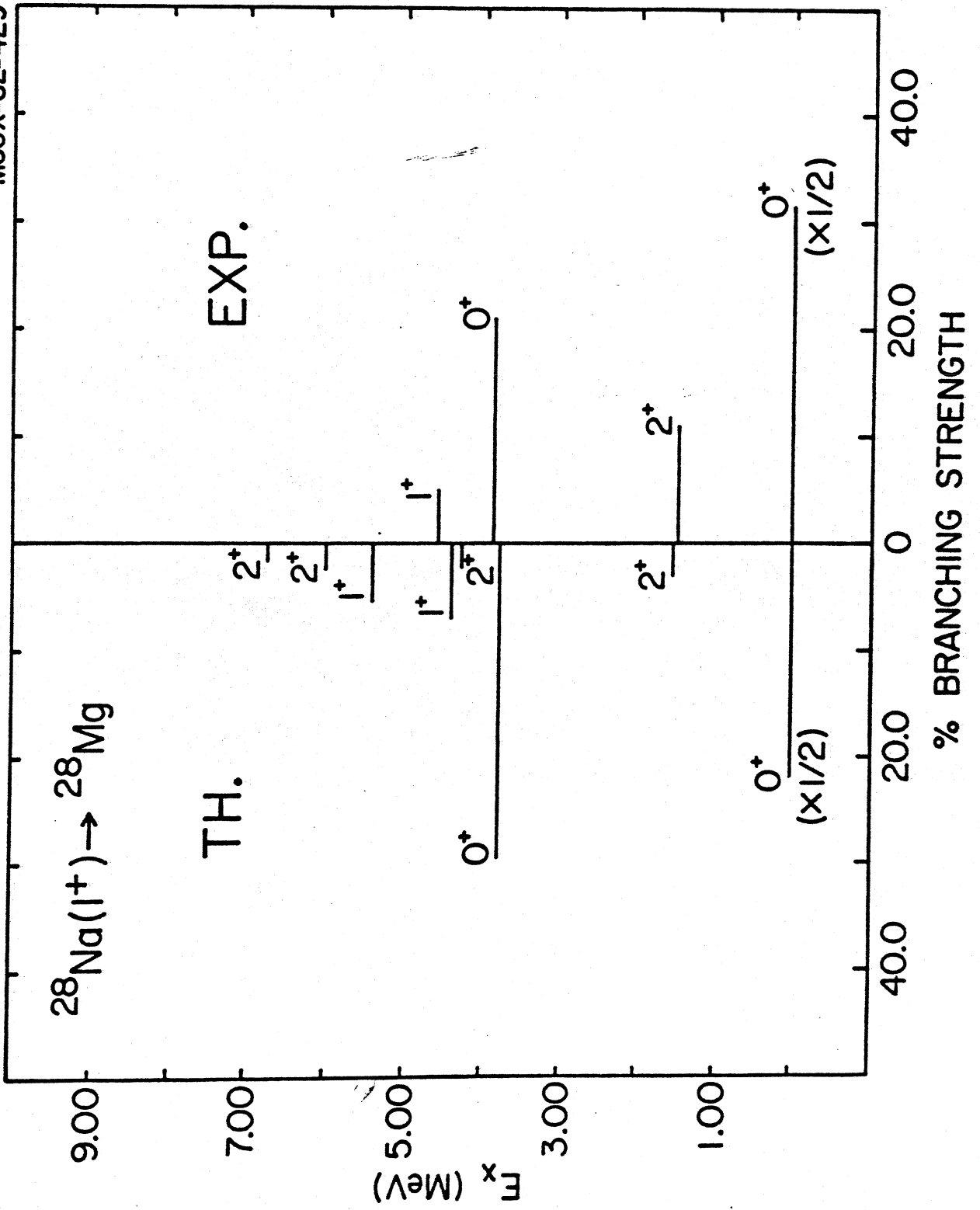


FIGURE 4

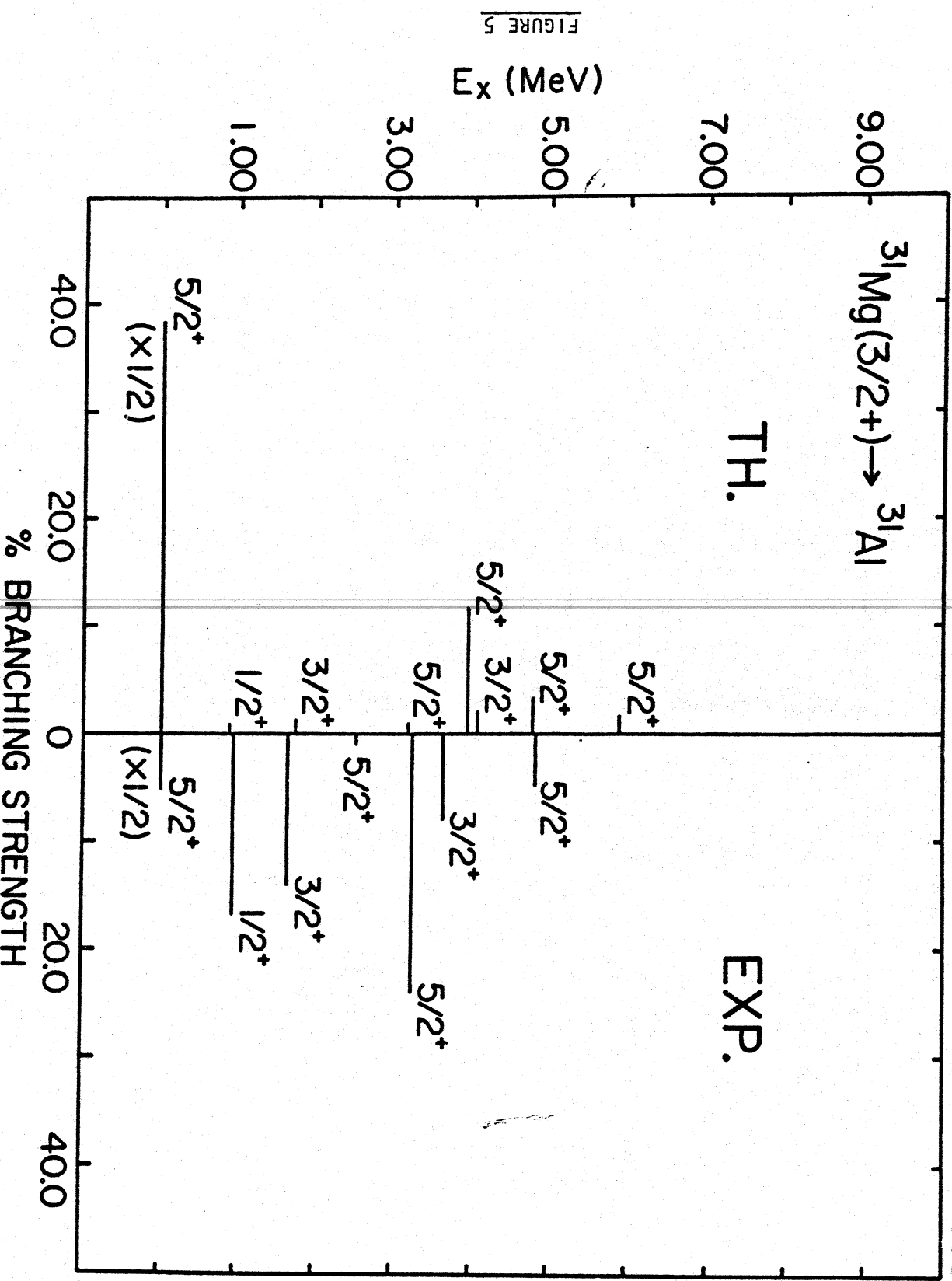


FIGURE 5

MSUX-82-427

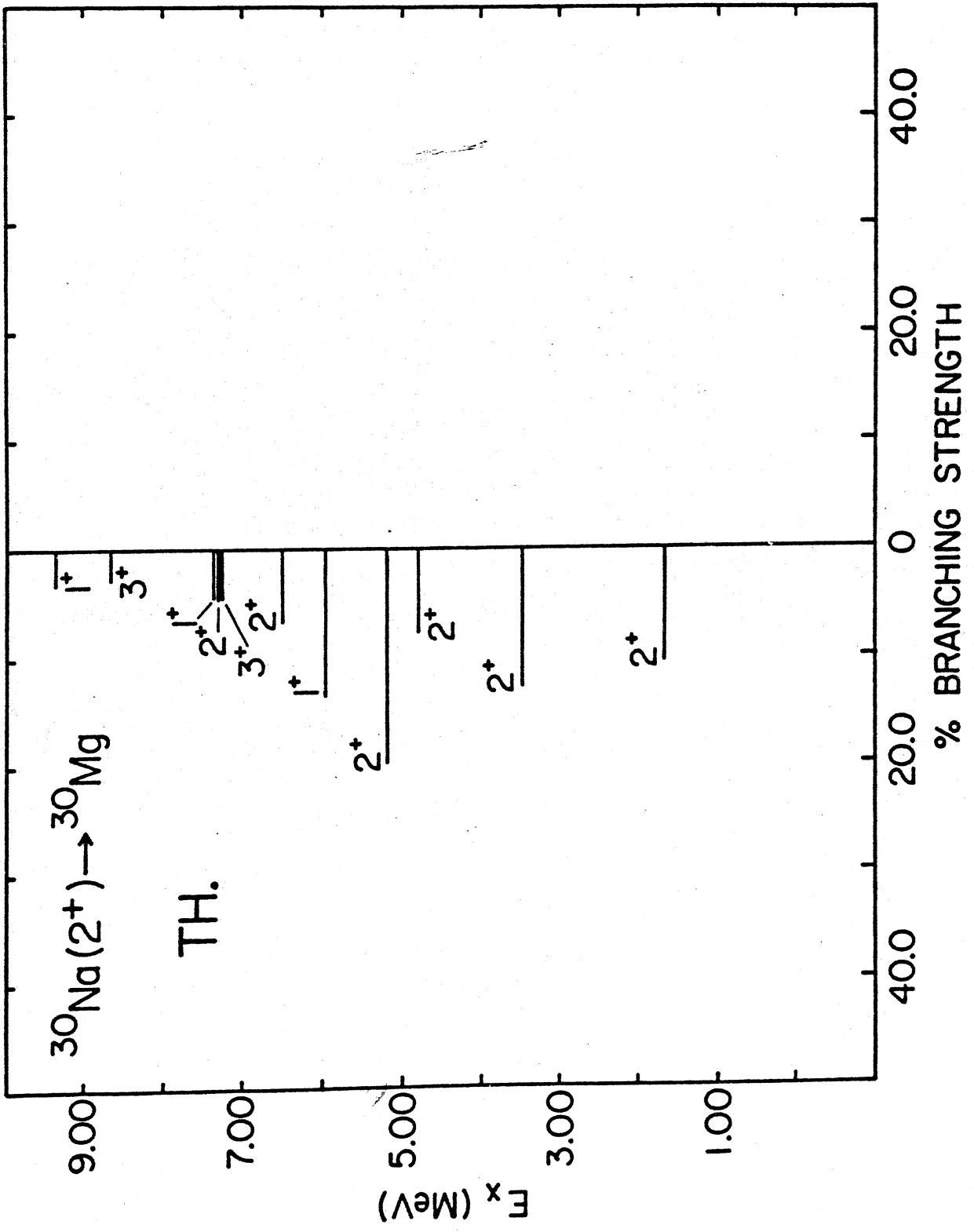


FIGURE 6

