UC San Diego

UC San Diego Previously Published Works

Title

Stellar weak-interaction rates for sd-shell nuclei. I - Nuclear matrix element systematics with application to Al-26 and selected nuclei of importance to the supernova problem

Permalink

<https://escholarship.org/uc/item/5cz8s9pd>

Journal

The Astrophysical Journal Supplement Series, 42(3)

ISSN

0067-0049

Authors

Fuller, GM
Fowler, WA
Newman, MJ

Publication Date

1980-03-01

DOI

10.1086/190657

Peer reviewed

STELLAR WEAK-INTERACTION RATES FOR *sd*-SHELL NUCLEI. I. NUCLEAR MATRIX ELEMENT SYSTEMATICS WITH APPLICATION TO ^{26}Al AND SELECTED NUCLEI OF IMPORTANCE TO THE SUPERNOVA PROBLEM¹

GEORGE M. FULLER² AND WILLIAM A. FOWLER

W. K. Kellogg Radiation Laboratory, California Institute of Technology

AND

MICHAEL J. NEWMAN

Max-Planck-Institut für Physik und Astrophysik; and Theoretical Division, Los Alamos Scientific Laboratory³

Received 1979 July 19; accepted 1979 September 14

ABSTRACT

Astrophysical positron emission, continuum electron capture, and neutrino energy loss rates are calculated for $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$, $^{30}\text{P} \rightarrow ^{30}\text{Si}$, $^{31}\text{S} \rightarrow ^{31}\text{P}$, $^{32}\text{S} \rightarrow ^{32}\text{P}$, $^{33}\text{S} \rightarrow ^{33}\text{P}$, and $^{35}\text{Cl} \rightarrow ^{35}\text{S}$. Measured nuclear level information and matrix elements are used where available. Unmeasured matrix elements for allowed transitions are assigned on the basis of simple shell model arguments and the results of detailed large-scale shell model calculations by Wildenthal and his collaborators. The experimentally determined matrix elements are found to dominate the rates over most of the range of temperatures and densities considered. The uncertainties in the rates are estimated. Appropriate average matrix elements for unmeasured Gamow-Teller transitions are estimated for use in other *sd*-shell nuclei. The rates presented agree roughly with those of Hansen over a wide range of conditions, but potentially important differences in the rates exist at temperatures and densities relevant for the production and destruction of ^{26}Al and for neutronization and neutrino loss in the late stages of presupernova evolution.

Subject headings: neutrinos — nuclear reactions — stars:

I. INTRODUCTION

The problem of nuclear β decay in the stellar environment has been an active area of investigation for many years. Cameron (1959) pointed out the importance of thermally populated excited states in enhancing weak decay rates, while Bahcall (1961, 1962*a*, *b*, *c*, 1964) and Peterson and Bahcall (1963) outlined the role of continuum electron capture and Pauli principle inhibition of phase-space, and the possibility of opening many otherwise unattainable electron capture channels at high density. These and other effects which can make weak-interaction rates in the stellar interior sensitive functions of temperature and density are briefly reviewed in § II. However, a continuing and vexing problem in astrophysical weak decay rate calculations is the assignment of nuclear matrix elements and the estimates of the uncertainties in the resulting stellar rates. Fowler and Hoyle (1964) calculated rates for a number of weak decays of interest in the supernova problem. Hansen (1966) surveyed weak rates for many nuclei using experimental information available at that time and an estimate for unknown matrix elements. Later, Mazurek *et al.* (1974) used a similar technique, but took into account the limitation on the strength of the weak interaction arising from the sum rule and applied it to the case of electron capture at high density. Iben (1978) studied Urca neutrino losses under conditions found in the carbon-oxygen cores of intermediate-mass stars and calculated weak-interaction rates involving a few excited states of parent and daughter nuclei in the mass range $21 \leq A \leq 57$. Takahashi and Yamada (1969), Takahashi (1971), Takahashi, Yamada, and Kondoh (1973), Egawa, Koichi, and Yamada (1975), and Takahashi, El Eid, and Hillebrandt (1978) have used the statistical treatment of the gross theory of β -decay to treat high density electron capture and have estimated ground state rates for many unstable nuclei.

As the temperature rises, additional transitions from nuclear parent states contribute to decay rates, while, as the density rises, electron capture transitions into additional nuclear daughter states also contribute. At the very high temperatures and densities which obtain in the later stages of supernova core collapse ($kT > 1$ MeV and peak

¹Supported in part by National Science Foundation grant PHY76-83685 at Caltech.

²Fannie and John Hertz Foundation Fellow.

³Present address.

electron Fermi energies well above 10 MeV) many decay channels contribute to each decay, and a statistical approach becomes possible. In this regime total Fermi and Gamow-Teller strengths, as well as their distribution with daughter excitation energy, become necessary for calculation of detailed rates. However, the technique used by Bethe *et al.* (1979) to treat weak-interaction transitions under these extreme conditions indicates that the dynamics of the collapse phase may be relatively insensitive to the exact electron capture rates.

In contrast, in the regime of less extreme temperatures and densities encountered in the late stages of precollapse evolution (core carbon-oxygen burning through hydrostatic silicon burning and the onset of collapse), and in the explosive burning phases following collapse and bounce, detailed weak-interaction rates of high accuracy may be quite important. The temperatures and densities most relevant to these environments are $0.1 \leq T_9 \leq 5$ and $10^5 \leq \rho/\mu_e \leq 10^9$, corresponding to conditions from mild degeneracy up to Fermi energies near 5 MeV. The nuclei whose rates are usually most important are those of intermediate mass (Weaver and Woosley 1979; Woosley, Arnett, and Clayton 1972). In the series of papers beginning with the present work, we propose to make weak-interaction rates available for general astrophysical application for nuclei of the *sd*-shell ($17 \leq A \leq 40$) over a somewhat larger grid of temperature ($0.01 \leq T_9 \leq 10$) and density ($10 \leq \rho/\mu_e \leq 10^9$).

The weak-interaction rates of the *sd*-shell nuclei at these intermediate temperatures and densities are particularly sensitive to the detailed properties of the low-lying discrete states of parent and daughter nuclei. Fortunately, a large body of experimental information concerning these nuclei has been accumulated in recent years (see the summaries by Endt and van der Leun 1973, 1978). Supplementing this information with shell model calculations for some unknown allowed transitions (shell model calculations are particularly effective for this mass range) and exploiting the isospin purity and symmetry in these nuclei, reliable rates can be obtained and uncertainties caused by unknown nuclear matrix elements can be estimated. We find that the experimentally determined matrix elements and the Fermi transitions dominate the rates over most of the range of temperature and density considered, but it is important to consider estimates of unmeasured Gamow-Teller matrix elements. We use three sources to assign these matrix elements: (1) the results of the detailed large-scale shell model calculations of Wildenthal (1977, 1979) and Chung (1976) where they are available;⁴ (2) simple shell model arguments where they can be reliably applied; and (3) an average Gamow-Teller matrix element characteristic of intermediate mass nuclei when a more accurate approach is not available. The average Gamow-Teller matrix element is distilled from experimental results and shell model calculations, and is designed to be applied in a survey of weak-interaction rates for *sd*-shell nuclei to identify those cases for which the considerable effort of a detailed shell model calculation is most urgently needed. The matrix element assignment procedure used here is described in detail in § III.

The recent discovery (Gray and Compston 1974; Lee and Papanastassiou 1974; Lee, Papanastassiou, and Wasserburg 1976) of anomalous amounts of ^{26}Mg in Allende inclusions has led to renewed interest in possible mechanisms for the formation of its unstable progenitor ^{26}Al (e.g., Arnould, Hillebrandt, and Thielemann 1978; Truran and Cameron 1978; Arnett and Wefel 1978). These considerations are complicated by the fact that the $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ β -decay rate (mean life 1.04×10^6 years in the laboratory) becomes a sensitive function of temperature and density in the stellar interior. As a first application of our techniques, we present in § IV astrophysical decay rates for $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ of relevance to the problem of the ^{26}Mg anomaly. In addition, since the 228 keV isomeric state of ^{26}Al is not thermalized at low temperatures (Ward and Fowler 1979), we have separately tabulated continuum electron capture and positron decay rates for the ground state and isomeric state systems. The simple structure of ^{26}Al and ^{26}Mg (ground states: two holes in the $1d_{5/2}$ shell) makes the shell model particularly appropriate for the description of this decay.

The decay $^{30}\text{P} \rightarrow ^{30}\text{Si}$ is another example of one in which the shell model is most appropriate. This decay and the decays $^{31}\text{S} \rightarrow ^{31}\text{P}$, $^{32}\text{S} \rightarrow ^{32}\text{P}$, $^{33}\text{S} \rightarrow ^{33}\text{P}$, and $^{35}\text{Cl} \rightarrow ^{35}\text{S}$ are particularly important (Weaver and Woosley 1979) for determining properties of the evolving stellar core through core oxygen and silicon burning and up to core collapse (Weaver, Woosley, and Zimmerman 1978). In particular, the electron capture and positron decay of these and other nuclei result in considerable neutronization before core collapse even begins. In addition, in the precollapse environment the neutrino energy loss associated with these decays may become competitive with neutrino losses due to thermal processes. This is primarily due to the effect of the degenerate electron gas which inhibits electron-positron pair creation and increases the plasma frequency, thereby restricting plasma decay to only the most energetic photons. Conversely, the high electron density *enhances* nuclear continuum electron capture. The lowering of the core temperature due to neutrino energy losses together with the hydrostatic neutronization influences the core composition in nuclear statistical equilibrium during the collapse phase. Decay rates and neutrino loss rates for these key nuclei are presented in § IV following the discussion of $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$.

⁴We have used expectation values of doubly reduced (in spin and isospin) β -decay operators from Wildenthal and Chung to calculate weak transition matrix elements.

II. BETA DECAY IN THE STELLAR INTERIOR

The rate of weak decay from the i th state of the parent to the j th state of the daughter nucleus is given by

$$\lambda_{ij} = \ln 2 \frac{f_{ij}(T, \rho, U_F)}{(ft)_{ij}}, \quad (1)$$

where $(ft)_{ij}$ is the comparative half-life, which is related to the allowed weak-interaction matrix elements by (Brown, Chung, and Wildenthal 1978)

$$(\log ft)_{GT} = 3.596 - \log |M_{GT}|^2, \quad (2a)$$

$$(\log ft)_F = 3.791 - \log |M_F|^2, \quad (2b)$$

where $|M_{GT}|^2$ and $|M_F|^2$ are the absolute squares of the Gamow-Teller and Fermi matrix elements, respectively. The phase space integral f_{ij} is given by an integral over total energy

$$f_{ij} = \int_1^{q_n} w^2 (q_n - w)^2 G(\pm Z, w) (1 - S_{\mp})(1 - S_{\nu}) dw \quad (3a)$$

for electron (*upper signs*) or positron (*lower signs*) emission, or by

$$f_{ij} = \int_{w_i}^{\infty} w^2 (q_n + w)^2 G(\pm Z, w) S_{\mp} (1 - S_{\nu}) dw \quad (3b)$$

for continuum positron (*lower signs*) or electron (*upper signs*) capture. In equations (3a) and (3b), w is the total rest mass and kinetic energy in units of $m_e c^2$, and

$$q_n = Q_n / m_e c^2 = (M_p - M_d + E_i - E_j) / m_e c^2 \quad (3c)$$

is the β -decay total energy in units of $m_e c^2$. In equation (3c) M_p is the nuclear mass of the parent and M_d that of the daughter, and E_i, E_j are the excitation energies of the nuclear states involved. We have calculated nuclear masses from the tabulated atomic masses by subtracting the mass of the atomic electrons, neglecting atomic binding energies. The w_i is the capture threshold total energy, rest plus kinetic, in units $m_e c^2$ for positron (or electron) capture. If the corresponding electron emission (or positron emission) total energy is such that $q_n > -1$, then $w_i = 1$, while for $q_n < -1$, $w_i = |q_n|$. S_+, S_-, S_{ν} are the positron, electron, and neutrino (or antineutrino) distribution functions, respectively. Neglecting possible corrections due to the presence of bound electrons and the ions, these are the Fermi-Dirac distribution functions. For electrons,

$$S_- = \left(\exp \left(\frac{U - U_F}{kT} \right) + 1 \right)^{-1}, \quad (4a)$$

where $U = (w - 1)m_e c^2$ is the kinetic energy, U_F is the electron chemical potential, and U_F/kT is the degeneracy parameter. In the positron distribution function S_+ , U_F is replaced by $-U_F - 2m_e c^2$. The chemical potential U_F is determined from the density ρ in g cm^{-3} by inverting the relation

$$\rho / \mu_e = \frac{1}{\pi^2 N_A} \left(\frac{m_e c}{\hbar} \right)^3 \int_0^{\infty} (S_- - S_+) p^2 dp \text{ moles cm}^{-3}, \quad (4b)$$

where μ_e is the mean molecular weight per electron associated with nuclei in g mole^{-1} , N_A is Avogadro's number in mole^{-1} , $p = (w^2 - 1)^{1/2}$ is the electron or positron momentum in units of $m_e c$, and the density of electron-positron pairs has been removed by subtracting S_+ from S_- . In Figure 1 it will be noted that for low density and high temperature $U_F(e^-) = -U_F(e^+) = -m_e c^2 = -0.511 \text{ MeV}$, while for any density and zero temperature

$$\begin{aligned} U_F(e^-) &= \left\{ \left[1.02 \times 10^{-4} (\rho / \mu_e)^{2/3} + 1 \right]^{1/2} - 1 \right\} \times 0.511 \text{ MeV} \\ &\approx 0.5 \times 10^{-2} (\rho / \mu_e)^{1/3} \text{ MeV} \quad \text{for } \rho / \mu_e \gtrsim 10^8. \end{aligned} \quad (4c)$$

Note that the inclusion of these electron distribution functions results in the phase-space integrals f_{ij} becoming sensitive functions of temperature and density. For our calculations, inhibition of final neutrino phase space never becomes important, so $S_\nu = 0$.

The remaining factor appearing in the phase space integral is

$$G(\pm Z, w) \equiv (p/w)F(\pm Z, w). \quad (5a)$$

$F(\pm Z, w)$ is the relativistic Coulomb barrier factor, given approximately by

$$F(\pm Z, w) \approx 2(1+s)(2pR)^{2(s-1)} e^{\pi\eta} \left| \frac{\Gamma(s+i\eta)}{\Gamma(2s+1)} \right|^2, \quad (5b)$$

where $s = [1 - (\alpha Z)^2]^{1/2}$, Z is the nuclear charge, α the fine structure constant, R the nuclear radius $= 2.908 \times 10^{-3} A^{1/3} - 2.437 A^{-1/3}$ in electron Compton wavelengths (Gove and Martin 1971) with A the nuclear mass number, $\eta = \pm \alpha Z w/p$, and the upper signs are for electron emission and capture, while the lower signs are for positron emission and capture. For emission processes Z is the nuclear charge of the daughter nucleus, while for capture processes it is that of the parent nucleus. Note that in the nonrelativistic limit, $w \approx 1$, $|\eta| \gg 1$ with $s \approx 1 - \frac{1}{2} \alpha^2 Z^2 \approx 1$ in our applications, one has

$$G_- \Rightarrow 2\pi\alpha Z |2\eta p R|^{-\alpha^2 Z^2} = 2\pi\alpha Z (2\alpha Z R)^{-\alpha^2 Z^2}, \quad (5c)$$

$$G_+ \Rightarrow G_- \exp - 2\pi|\eta|. \quad (5d)$$

In the extreme relativistic limit $p \approx w \gg 1$, $|\eta| \approx \alpha Z$, one has

$$G_- \Rightarrow (2pR)^{-\alpha^2 Z^2} \exp \pi|\eta|, \quad (5e)$$

$$G_+ \Rightarrow G_- \exp - 2\pi|\eta| = (2pR)^{-\alpha^2 Z^2} \exp - \pi|\eta|. \quad (5f)$$

In addition, the neutrino energy loss rate (in $m_e c^2 s^{-1}$) associated with the transition from level i of the parent to level j of the daughter is formed as in equation (1), except that the phase-space integral is replaced by

$$f_{ij}^\nu = \int_1^{q_n} w^2 (q_n - w)^3 G(\pm Z, w) (1 - S_\mp) (1 - S_\nu) dw, \quad (6a)$$

for electron (*upper signs*) or positron (*lower signs*) emission, and by

$$f_{ij}^\nu = \int_{w_i}^\infty w^2 (q_n + w)^3 G(\pm Z, w) S_\mp (1 - S_\nu) dw, \quad (6b)$$

for continuum positron (*lower signs*) or electron (*upper signs*) capture.

The phase-space integrals were performed numerically, and checked for electron and positron emission, at low temperature and density against the tables of $\log f$ by Gove and Martin (1971). The definite integrals for the electron and positron emission phase space factors were done by 64-point Gaussian quadrature. The integrands of the electron and positron capture phase-space integrals are modulated strongly by the electron (or positron) distribution function, so that the integrand has a characteristically slowly varying part and an exponentially decaying part, corresponding to the shape of the Fermi-Dirac distribution function. The portion of the improper integrals containing the slowly varying part of the integrand was done with 64-point Gaussian quadrature, and the exponential tail was treated with 32-point Gauss-Laguerre quadrature. For each nucleus a table of phase-space factors for positron emission and electron capture as a function of q_n was prepared at each temperature and density grid point, and the f_{ij} and f_{ij}^ν were obtained by cubic spline interpolation in q_n .

In summary, the weak decay rates of nuclei in the stellar environment become sensitive functions of temperature and density through the influence of the lepton distribution functions on the phase-space integrals, and because many decay channels open up due to thermal population of parent excited states and continuum electron capture at high Fermi energy into daughter excited states.

FIG. 1.—Thermodynamic grid employed. The electron chemical potential U_F in MeV is displayed as a function of temperature in kelvins (logarithmic scale) for various values of $\log \rho/\mu_e$ in moles cm^{-3} . The temperature grid used in all calculations extended from 10^7 to 10^{10} K with 5 points per decade roughly uniformly distributed in $\log T$. Density points were taken at each decade from $\log \rho/\mu_e = 1$ to 9 with additional points inserted at $\log \rho/\mu_e = 6.5, 7.5$, and 8.5 to improve the coverage in U_F . The curves not labeled correspond to $\log \rho/\mu_e = 1.0, 2.0, 3.0$, and 4.0 , respectively. Note the approach to the nondegenerate limit $U_F = 0.511$ MeV at sufficiently high temperature at each density.

The temperature and density regime considered in the calculations is shown in Figure 1. We see that the energies, spins, and parities for discrete states will be required for excitation energies up to several MeV in the parent and at least 4 or 5 MeV in the daughter. Typically, we use all discrete states known up to even higher energies in parent and daughter. All nuclear level information was taken from Endt and van der Leun (1978). We then require weak interaction transition matrix elements connecting these states; their assignment is the subject of § III.

We have not considered the effects of bound state electron capture, which is unimportant over most of the range of temperature and density considered, nor have we considered the screening of the nuclear charge by continuum electrons, which has the effect of moving $F(\pm Z, w)$ toward unity and of modifying the energies of charged particles in the plasma. This screening is a small effect over the range of temperature and density considered here (Takahashi, El Eid, and Hillebrandt 1978). While the omission of these corrections is justified along the temperature-density track of typical precollapse conditions ($0.1 \leq T_9 \leq 5$, $10^5 \leq \rho/\mu_e \leq 10^9$), screening corrections affect the rates at low temperature and/or extremely high density.

It finally remains to sum over the parent and daughter states in order to find λ , the destruction rate of the parent or the production rate of the daughter due to the emission or capture process under consideration. The destruction rate for the i th parent state is given by

$$\lambda_i = \sum_j \lambda_{ij}, \quad (7)$$

where the sum is over all states of the daughter to which the parent state is linked by the emission or capture process. The rate for destruction of the parent nucleus is then

$$\lambda = \sum_i P_i \lambda_i, \quad (8)$$

where the sum is over all parent states, and the occupation index P_i of state i is given for thermal equilibrium by

$$P_i = (2J_i + 1) \exp(-E_i/kT) / G, \quad (9a)$$

where J_i is the spin of level i , and G is the nuclear partition function for the parent nucleus

$$G = \sum_i (2J_i + 1) \exp(-E_i/kT). \quad (9b)$$

In our temperature range ($T_9 \leq 10$) the number of known discrete states is sufficient to yield an accurate value for G without considering continuum contributions (Tubbs and Koonin 1979).

If one defines the production rate for the j th daughter state as

$$\lambda_j = \sum_i P_i \lambda_{ij}, \quad (10a)$$

then it will be clear that the production of the daughter nucleus and the destruction of the parent nucleus can be stated as

$$\lambda = \sum_j \lambda_j. \quad (10b)$$

We add a note of caution. In this paper we do not present the *reverse* reaction rates to the cases we have treated. For example, we give $^{35}\text{Cl} \rightarrow ^{35}\text{S}$, but not $^{35}\text{S} \rightarrow ^{35}\text{Cl}$. We point out that the ground state of ^{35}S decays by electron emission to ^{35}Cl with maximum total energy equal to 0.679 MeV. Thus at low density and low temperature, our tabulated results do not give the complete picture. In a later paper of this series this will be rectified. For the moment we give the logarithm of the laboratory reverse rates due to electron emission. They are: -6.25 for ^{32}P to ^{32}S , -6.50 for ^{33}P to ^{33}S , and -7.04 for ^{35}S to ^{35}Cl . These laboratory reverse rates will hold in stellar environments at low density, $\rho/\mu_e < 10^6$, and temperature, $T_9 < 1$.

III. NUCLEAR MATRIX ELEMENTS

The comparative half-lives $(ft)_{ij}$ required in equation (1) are taken from laboratory measurements where they are available. Since there has been a vast increase in the number of measured β -transitions in recent years, we have used the latest tabulations of Endt and van der Leun (1978). In addition, we have used some unpublished measurements by Wilson and Kavanagh (1978) for the decay $^{30}\text{P} \rightarrow ^{30}\text{S}$. However, for many important transitions, particularly those involving excited states of parent or daughter nucleus, no measurement is available, and ft -values for these transitions must be assigned in another way. Only allowed transitions are considered in this work. Exploiting the isospin symmetry of these sd -shell nuclei allows us to calculate unmeasured Fermi transition matrix elements with great accuracy, and to extend the relevant set of "measured" matrix elements for a decay by considering transitions measured in the appropriate mirror decay. The remaining unmeasured Gamow-Teller matrix elements are handled in several different ways. Simple two-particle shell model approximations to the nuclear wave functions are used to calculate Gamow-Teller matrix elements and appropriate sum rules. This calculation gives a good overview of the Gamow-Teller strength and its distribution for the decays $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ and $^{30}\text{P} \rightarrow ^{30}\text{S}$. In addition, for some transitions in these and the other decays considered, Wildenthal (1979) has provided us with Gamow-Teller matrix elements calculated from the detailed wave functions of Chung (1976). For Gamow-Teller transitions not covered by either the two-particle approximation or Wildenthal's calculations, we use an appropriate mean $\log ft$, determined from averages of experimentally determined Gamow-Teller matrix elements in the sd -shell and all of the available Wildenthal calculations used for the six decays considered. The sensitivity of rates to uncertainties in the matrix element assignments are estimated, as are uncertainties in the rates caused by unknown Gamow-Teller strength which may lie beyond the last discrete levels considered in parent and daughter nucleus. The remainder of this section will describe this matrix element assignment procedure, but briefly, we will find that the experimentally determined transitions along with the Fermi and mirror decay matrix elements dominate the rates in most cases. Even in regimes of temperature and density where the unmeasured Gamow-Teller transitions are important, we feel that the rates are well determined. Regimes in which the uncertainty in matrix elements makes the rates uncertain will be explicitly mentioned for each decay.

The isospin purity and symmetry of the nuclear energy levels in sd -shell nuclei allows considerable simplification and accuracy in the assignment of some matrix elements. In particular, the Fermi matrix element depends only on the nuclear isospin, T , and its projection $T_z = (Z - N)/2$ for the parent or daughter nucleus, and may be written for

positron emission or electron capture as

$$|M_F|^2 = \frac{1}{2J_i + 1} \sum_{m_i} \sum_{m_f} \left| \langle \psi_f m_f | \sum_N \tau_N^- | \psi_i m_i \rangle \right|^2$$

$$= T(T+1) - T_z^i(T_z^i - 1), \quad (11)$$

where T_z^i is the z projection of the parent isospin, $|\psi_i m_i\rangle$ is the initial parent state, $|\psi_f m_f\rangle$ the final daughter state, and the matrix element is averaged over initial and summed over final nuclear spins. Note that the sum on nucleons $\sum_N \tau_N^-$ is the minus component of an isovector, spatial scalar operator T^- which commutes with the total isospin T^2 , a good quantum number in these nuclei, implying the selection rules $\Delta\Pi=0$; $\Delta J=0$; $\Delta T=0$; $T_z^f = T_z^i - 1$, which have been applied in the second equality of equation (11). In $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ Fermi transitions, for instance, $|M_F|^2=2$, and so from equation (2) $\log(ft)_F=3.49$. This is very fast compared to the average Gamow-Teller matrix element corresponding to about $\log ft=5.0$ (see discussion later in this section). In addition, essentially all of this Fermi strength is concentrated in the isobaric analog state. Fortunately, in this mass range ($17 \leq A \leq 40$) several analog states occur within 5 MeV of the ground state and are accessible in the precollapse environment. For example, several Fermi transitions can be seen for the decays $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ and $^{30}\text{P} \rightarrow ^{30}\text{Si}$ in Tables 1 and 2, respectively.

Isospin symmetry allows assignment of matrix elements for some unmeasured transitions in particular decays. If a measured matrix element is available for a transition in the mirror system, then it can be taken over directly for the appropriate transition in the original decay, after correcting for initial and final spin degeneracy. For example, several matrix elements are measured in the $^{26}\text{Si} \rightarrow ^{26}\text{Al}$ decay; these can be taken over with spin degeneracy corrections into the $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ decay, and are included in Table 1. The mirror systems of all six decays were examined, and many important matrix elements were obtained in this way.

After the above procedure is completed, there are still many Gamow-Teller transitions without assigned matrix elements. Since Gamow-Teller matrix elements are observed to vary over three or four orders of magnitude, it is important to obtain a good handle on their behavior in this mass range. To this end we have used (1) results of the large-scale shell model calculations of Wildenthal (1979), (2) a simple two-particle approximation to the nuclear wave functions, and (3) averages based on shell model calculations and measured decays in the sd -shell. The two-particle approximation was used for the decays $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ and $^{30}\text{P} \rightarrow ^{30}\text{Si}$ because the very simple shell model picture was most appropriate there.

The shell model indicates that the primary configuration of the ^{26}Al ground state is one neutron hole and one proton hole in a filled $1d5/2$ shell, and of ^{26}Mg is two proton holes in the same shell. Similarly, the primary configuration of the ^{30}P ground state is one proton and one neutron outside a closed $1d5/2$ shell, while for ^{30}Si it is two neutrons outside the same closed shell. This suggests that the low-lying states of these systems may be predominantly described in terms of two-particle (two-hole) wave functions, where only the angular momenta of the valence particles are coupled to give the total angular momentum. The possible values of J^π ; T (spin, parity; isospin) are constructed for each two-particle sd -shell configuration forming a "bank" of states for each nucleus. Since the low-lying states of these nuclei have well measured excitation energies and spins and parities, it is possible to identify physical states with states in the J^π bank, taking into account the energy orderings of the simple shell model configurations. We note that the first 16 states of ^{26}Al exhaust 13 of the 14 possible $T=0$ two-particle sd -shell states and three of the expected low-lying $T=1$ states, before a state of ^{26}Al is encountered which cannot be understood in this simple model. Similarly, in ^{26}Mg the lowest 12 states are well accounted for; states 13 and 15 apparently have large many-particle components, but states 14 and 16 match well the remaining $T=1$ states in our ^{26}Mg J^π bank. The first 14 states of ^{30}P exhaust 12 of the 14 possible $T=0$ two-particle states and two of the expected $T=1$ states before an obvious many-particle state is found. Similarly, in ^{30}Si the lowest 10 states are well accounted for, and four others match up with the $T=1$ states remaining in the J^π bank for ^{30}Si . The pure two-particle configuration assignments are displayed for $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ in Table 1, and for $^{30}\text{P} \rightarrow ^{30}\text{Si}$ in Table 2, the notation being, e.g., for ^{26}Al , $55 \equiv p(1d5/2)n(1d5/2)$, $51 \equiv p(1d5/2)n(2s1/2)$, etc., where p denotes the proton configuration and n the neutron configuration.

The weak interaction matrix elements are calculated using the assigned two-particle sd -shell wave functions. The Fermi matrix element is done as above. The Gamow-Teller matrix element is given by

$$|M_{GT}|^2 = \frac{1}{2J_i + 1} \sum_{m_i} \sum_{m_f} \left| \langle \psi_f m_f | \sum_N \tau_N^- \sigma_N | \psi_i m_i \rangle \right|^2, \quad (12)$$

TABLE 1
LOG *ft*-VALUES FOR $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$

STATE			^{26}Al	1	2	3	4	5	6	7	8
ENERGY				0.000	0.228	0.417	1.058	1.759	1.851	2.069	2.070
$J^\pi; T$				5^+	$0^+; 1$	3^+	1^+	2^+	1^+	4^+	$2^+; 1$
^{26}Mg			CONF	55	55	55	55	51	53	53	55
1	0	$0^+; 1$	55		EF 3.48		S 4.01 P 3.63 M 4.58 W 3.85		S 4.29 P 3.87 M 4.58 W 4.34		
2	1.809	$2^+; 1$	55	E14.18		P 3.63 M 4.66 W 5.17	P 3.36 M 4.63 W 3.63	M 4.46	P 3.72 M 4.63 W 4.40		FP 3.34 FM 3.45
3	2.938	$2^+; 1$	51	E13.35		M 4.66 W 4.07	M 4.63 W 5.49	P 3.31 M 4.46	M 4.63 W 4.47		M 4.90
4	3.588	$0^+; 1$	11				M 4.58 W 5.72		M 4.58 W 5.36		
5	3.941	$3^+; 1$	51			M 4.98		P 3.37 M 4.43			M 4.58
6	4.320	$4^+; 1$	55	P 3.99 M 4.10		P 3.63 M 4.34				P 3.99 M 3.84	
7	4.332	$2^+; 1$	53			P 3.68 M 4.66 W 4.97	P 3.91 M 4.63 W 5.22	M 4.46	M 4.63 W 7.57		P 3.61 M 4.90
8	4.350	$3^+; 1$	53			P 3.74 M 4.98		M 4.43			P 4.31 M 4.58
9	4.835	$2^+; 1$	31			M 4.66 W 4.78	M 4.63 W 4.87	P 4.69 M 4.46	M 4.63 W 6.16		M 4.90
10	4.901	$4^+; 1$	53	P 3.39 M 4.10		P 4.84 M 4.34				P 3.09 M 3.84	
11	4.972	$0^+; 1$	33				M 4.58 W 7.50		P 3.69 M 4.58 W 4.53		
12	5.291	$2^+; 1$	33			M 4.66 W 4.94	M 4.63 W 6.34	M 4.46	P 4.69 M 4.63 W 6.57		M 4.90
13	5.474	$4^+; 1$	—								
14	5.690	$1^+; 1$	53		P 3.39 M 4.19		P 3.55 M 4.83	M 4.79	M 4.83		P 3.94 M 4.03
15	5.715	$4^+; 1$	—								
16	6.127	$1^+; 1$	31				M 4.83	P 3.74 M 4.79	M 4.83		M 4.03
LOG(<i>ft</i>) _i				3.29	3.39	3.06	2.97	2.95	3.26	3.04	3.28

TABLE 1—*Continued*

9	10	11	12	13	14	15	16	22	24	ANLG	ANLG
2.072	2.365	2.545	2.661	2.739	2.913	3.074	3.159	3.719	3.745	5.9184	6.3534
1 ⁺	3 ⁺	3 ⁺	2 ⁺	1 ⁺	2 ⁺	3 ⁺	2 ⁺ ;1	1 ⁺	0 ⁺ ;1	1 ⁺ ;1	1 ⁺ ;1
11	51	53	53	31	31	33	51	33	11	53	31
S 4.98											
M 4.08											
W 4.28											
W 4.77											
W 4.77											
M 4.63	M 4.66	P 4.46	P 3.61							P 3.72	
W 4.96	W 4.99	M 4.66	M 4.46	M 4.63	M 4.46	M 4.66	M 4.90	M 4.63		M 4.25	M 4.25
W 5.22											
M 4.63	P 3.52	M 4.66	M 4.46	P 3.52	P 4.69		FP 3.47				P 3.52
W 5.35	M 4.66	M 4.66		M 4.63	M 4.46	M 4.66	FM 3.45	M 4.63		M 4.25	M 4.25
W 6.81											
W 6.35											
W 5.18											
W 5.57											
W 4.90											
W 5.24											
F 3.49											
M 4.75											
M 4.75											
M 4.43											
M 4.43											
M 4.98											
M 4.58											
M 4.34											
M 4.34											
P 3.61											
M 4.63	M 4.66	M 4.66	M 4.46	M 4.63	M 4.46	M 5.24	M 4.90	P 3.37		P 3.37	
W 5.25	W 4.99	W 5.72		W 4.68		M 4.66		M 4.63		M 4.25	M 4.25
W 5.20											
P 4.09											
M 4.98											
M 4.58											
P 4.69											
M 4.63	M 4.66	M 4.66	M 4.46	P 3.69	P 3.31	M 4.66	M 4.90	M 4.63		M 4.25	P 3.34
W 6.31	W 5.43	W 5.13		M 4.63	M 4.46	W 4.91		W 9.24			M 4.25
W 5.03											
P 3.28											
M 4.34											
M 4.34											
M 4.34											
M 4.58											
W 9.65											
P 3.99											
M 4.58											
W 4.36											
P 3.69											
M 4.75											
M 4.75											
P 4.69											
M 4.63	M 4.66	P 3.34	P 3.85			P 4.22	M 4.90	P 3.79		P 4.25	M 4.25
W 5.85	W 5.88	M 4.66	M 4.46	M 4.63	M 4.46	M 4.66		M 4.63			
W 6.12											
W 6.06											
W 7.60											
M 4.83											
M 4.83											
M 4.19											
FM 3.44											
M 4.70											
P 3.91											
M 4.79											
P 3.74											
M 4.03											
M 4.83											
M 4.70											
FM 3.46											
P 3.23											
2.99											

TABLE 2
LOG *ft*-VALUES FOR $^{30}\text{P} \rightarrow ^{30}\text{Si}$

STATE			^{30}P	1	2	3	4	5	6	7	8	9	10
ENERGY				0.0	0.6772	0.7090	1.454	1.973	2.538	2.7232	2.8388	2.9378	3.0186
$J^\pi; T$				1^+	$0^+; 1$	1^+	2^+	3^+	3^+	2^+	3^+	$2^+; 1$	1^+
^{30}Si			CONF	11	11	13	13	33	51	51	55	13	33
1	0	$0^+; 1$	11	E 4.83 P 3.30 M 4.61 W 5.53	EF 3.49	E 6.18							S 3.99
2	2.2354	$2^+; 1$	31	E 5.80 M 4.62 W 4.83		P 3.69 M 4.62 W 4.58	P 3.31 M 4.46	M 4.63 W 5.31	P 3.69 M 4.63 W 5.19	P 4.69 M 4.46	M 4.63 W 5.92	FP 3.45	M 4.62 W 6.02
3	3.4987	$2^+; 1$	33	M 4.62 W 4.17		M 4.62 W 5.98	M 4.46	P 4.22 M 4.63 W 5.10	M 4.63 W 4.69	M 4.46	M 4.63 W 6.95	M 5.00	P 3.79 M 4.62 W 4.73
4	3.7697	$1^+; 1$	31	M 4.83		M 4.83	P 3.91 M 4.80			P 3.74 M 4.80		M 4.66	M 4.83
5	3.7879	$0^+; 1$	33	M 4.61 W 5.01		M 4.61 W 4.58							P 3.99 M 4.61 W 5.53
6	4.8092	$2^+; 1$	51	M 4.62 W 5.33		P 3.52 M 4.62 W 4.43	P 4.69 M 4.46	M 4.63 W 4.62	P 3.52 M 4.63 W 6.70	P 3.31 M 4.46	M 4.63 W 6.32	M 4.69 M 5.00	M 4.62 W 5.65
7	4.8307	$3^+; 1$	51				P 3.55 M 4.43	M 4.98	M 4.98	P 3.37 M 4.43	M 4.98	P 3.54 M 4.23	
8	5.2306	$3^+; 1$	53				M 4.43	P 4.09 M 4.98	M 4.98	M 4.43	P 3.74 M 4.98	M 4.23	
9	5.2795	$4^+; 1$	53					P 3.28 M 4.45	M 4.45		P 4.84 M 4.45		
10	5.3720	$0^+; 1$	55	M 4.61 W 4.43		M 4.61 W 4.83							M 4.61 W 5.88

DESIGNATIONS FOR LOG *ft*-VALUES IN TABLES 1 AND 2: S $\equiv$ CALCULATED FROM ISOBARIC SYMMETRY; P $\equiv$ PURE TWO-PARTICLE GAMOW-TELLER VALUE; M $\equiv$ MIXED TWO-PARTICLE GAMOW-TELLER VALUE + 0.5; W $\equiv$ CALCULATED FROM WILDENTHAL RESULTS; E $\equiv$ EXPERIMENTAL VALUE; F $\equiv$ CALCULATED FERM I VALUE; EF $\equiv$ EXPERIMENTAL FERM I VALUE; FP $\equiv$ CALCULATED FERM I AND PURE G-T VALUE; FM $\equiv$ CALCULATED FERM I AND MIXED G-T VALUE + 0.5. CONF = TWO-PARTICLE CONFIGURATION; ANLG = ANALOGUE STATE.

evaluate the isospin matrix element and, in spherical tensor notation, we find

$$|M_{GT}|^2 = \frac{1}{2J_1+1} \cdot \frac{1}{2} \cdot \sum_{m_i} \sum_{m_f} \sum_k (-1)^k \langle m_f | -\sigma_1^k + \sigma_2^k | m_i \rangle \cdot \langle m_i | -\sigma_1^{-k} + \sigma_2^{-k} | m_f \rangle. \quad (14)$$

We have used the shorthand notation for the matrix elements

$$\langle m_f | \sigma_1^k | m_i \rangle = \langle J_f(j_1' j_2)(l_1 l_2) \left(\frac{1}{2} \frac{1}{2}\right) m_f | \sigma_1^k | J_i(j_1 j_2)(l_1 l_2) \left(\frac{1}{2} \frac{1}{2}\right) m_i \rangle, \quad (15)$$

where j_1 is the initial j -shell angular momentum of particle one, j_1' is the final j -shell angular momentum of particle one, l_1 the corresponding orbital angular momentum, and $1/2$ the spin, and similarly for particle two. Using the Wigner-Eckart theorem, the above expression becomes, after some tedious angular momentum algebra,

$$\begin{aligned} \langle m_f | \sigma_1^k | m_i \rangle &= (-1)^{1/2+m_f+l_1+j_1+j_1'+j_2+J_i+J_f} \\ &\cdot [6(2J_f+1)(2J_1+1)(2j_1+1)(2j_1'+1)]^{1/2} \\ &\cdot \begin{pmatrix} J_f & 1 & J_i \\ -m_f & k & m_i \end{pmatrix} \begin{Bmatrix} \frac{1}{2} & j_1' & l_1 \\ j_1 & \frac{1}{2} & 1 \end{Bmatrix} \begin{Bmatrix} j_1' & J_f & j_2 \\ J_i & j_1 & 1 \end{Bmatrix}. \end{aligned} \quad (16)$$

A similar expression can be derived for $\langle m_f | \sigma_2^k | m_i \rangle$, and the orthogonality property of the 3- j symbols exploited to give equation (13) in terms of 6- j symbols which are easily evaluated. This calculation was carried out for allowed transitions between all two-particle sd -shell configurations and all possible J^π corresponding to those configurations.

Given the complicated nature of the expression for $|M_{GT}|^2$, it is useful to check against an explicit calculation of the two-particle sum rule. The sum rule is the total amount of Gamow-Teller strength available for an initial state (Takahashi, Yamada, and Kondoh 1973), and is here given by summing over a complete set of final states in $|M_{GT}|^2$ to yield

$$S_i^{GT} = \frac{1}{2J_i + 1} \sum_{m_i} \langle \psi_i m_i | \left(\sum_N \tau_N^- \sigma_N \right)^\dagger \left(\sum_N \tau_N^- \sigma_N \right) | \psi_i m_i \rangle. \quad (17)$$

Considering just the two valence nucleons results in the expression

$$S_i^{GT} = 3 \langle \psi_i^{\text{iso}} | \tau_1^- \tau_1^+ + \tau_2^- \tau_2^+ | \psi_i^{\text{iso}} \rangle + \langle \psi_i^{\text{iso}} | \tau_1^- \tau_2^+ + \tau_1^+ \tau_2^- | \psi_i^{\text{iso}} \rangle \cdot \Sigma^{GT}, \quad (18)$$

where ψ_i^{iso} is the isospin part of the two-particle wave function, and Σ^{GT} is spatial expectation value which can be shown to be

$$\begin{aligned} \Sigma^{GT} &= \frac{1}{2J_i + 1} \sum_{m_i} \langle \psi_i m_i | \sigma_1 \cdot \sigma_2 | \psi_i m_i \rangle \\ &= -2 \left[\frac{3}{4} + j_2(j_2 + 1) - l_2(l_2 + 1) \right] \cdot \left[\frac{3}{4} + j_1(j_1 + 1) - l_1(l_1 + 1) \right] \cdot \frac{j_1(j_1 + 1) + j_2(j_2 + 1) - J_i(J_i + 1)}{j_1 j_2 (2j_1 + 2)(2j_2 + 2)}. \end{aligned} \quad (19)$$

The strength due to the interaction with core nucleons in the above analysis is assumed to be at nuclear excitation energies high enough to be irrelevant to the astrophysical rates. Since we have identified all of the two-particle sd -shell states in, for instance, daughter ^{26}Mg , each state of parent ^{26}Al explicitly saturates the two-particle sum rule. To the extent that the nuclear wave functions are well represented by the two-particle configurations, this sum rule gives a rough idea of the total Gamow-Teller strength in the range of stellar energies to be expected for each state of the parents ^{26}Al and ^{30}P . The approximate validity of the two-particle assignments in these decays is demonstrated by the way hindered values (unusually large ft values for allowed transitions) of the pure configuration matrix elements track fairly well the hindered values of Wildenthal's calculation (see below).

Configuration mixing resulting from the residual interaction between valence nucleons is an important aspect of the wave functions of sd -shell nuclei. Its major effects will be to "smear out" the two-particle strength in parent and daughter and to mix many-particle configurations into low-lying states, thus spreading the two-particle strength to higher energies. In the two-particle picture, we treat the first effect by an averaging procedure: We completely mix states of a given J_p^π in the parent and completely mix states of a given J_d^π in the daughter, add up the pure configuration strength for all the $J_p^\pi \rightarrow J_d^\pi$ transitions, and divide by the total number of such transitions. Then each such transition is assigned this average matrix element. This result is termed the mixed configuration matrix element set. The effect on the rate of the distribution of Gamow-Teller strength can be tested by first computing the stellar rate with the pure configuration set of matrix elements and then with the mixed configuration set. In both calculations the measured, mirror-decay, and Fermi-transition $\log ft$ values were employed. We find that the rates calculated in these two cases are substantially the same for the temperatures and densities considered here, indicating that the stellar rates are relatively insensitive to the placement of the low-lying unmeasured Gamow-Teller strength in the range of excitation energy covered in parent and daughter nuclei. However, the second effect of configuration mixing, the admixture of high-lying configurations and the true many-body nature of the wave functions, results in a decrease in Gamow-Teller matrix elements, especially at the higher excitation energies in parent and daughter. This trend is seen in the results of the large-scale shell model calculations of Gamow-Teller matrix elements done by Wildenthal, and is treated here by slowing down the mixed configuration transition rates by adding 0.5 in $\log ft$.

Wildenthal's calculations employ a full sd -shell basis and a realistic residual interaction. The wave functions are then the result of an iterative calculation which fits the energies of 199 levels for nuclei between masses 18 and 24. The results obtained for Gamow-Teller transitions in the sd -shell agree quite well with experiments where comparison is possible (Brown, Chung, and Wildenthal 1978). Matrix elements from these calculations were available for many, but not all transitions in the decays considered. Where a calculated matrix element exists, two values are provided: one corresponding to the value of the axial vector coupling constant C_A relevant for free nucleon decay (the so-called "free" value), and one corresponding to the value of C_A renormalized by mesonic exchange currents and the effects of truncation of the basis to just the sd -shell configurations. The latter result was obtained by fitting

to measured Gamow-Teller transitions in the sd -shell and hence is termed the “fit” value. The fit values are a better representation of the matrix elements over the entire sd -shell, and in general the fit matrix elements are slightly smaller ($\log ft$ is somewhat larger) than the corresponding free values. However, we have adopted the free values because they seem to give slightly better agreement with experimentally measured matrix elements and with those determined from mirror decays in the transitions considered.

Table 1 presents all the experimental, mirror symmetry, pure, mixed (plus 0.5) and free Wildenthal $\log ft$ values used in the calculations for the $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ decay. Table 2 presents the $\log ft$ values used for the states of lowest excitation considered in the $^{30}\text{P} \rightarrow ^{30}\text{Si}$ decay. The actual calculations involved states up to 4.3 MeV in ^{30}P and up to 7.5 MeV in ^{30}Si . In these tables, entries with an E are experimentally observed, those with an S are observed in the mirror decays, while entries with an F have a Fermi component. Also appearing in the tables are the $\log ft$ values from the pure configuration, denoted by a P, and the mixed configuration, denoted by an M. The small and vanishing pure configuration matrix elements are a result of l -forbiddenness and two-particle interference effects. Where no entry denoted by P or M exists, the matrix element is zero in the two-particle model. Note that in the $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ decay the hindered transitions of Wildenthal roughly track the small matrix element transitions of the two-particle approximation. This effect is not as pronounced in the $^{30}\text{P} \rightarrow ^{30}\text{Si}$ decay, probably due to less domination by two-particle configurations in the actual nuclear wave functions. The numbers at the bottom of the tables are the effective $\log ft$ corresponding to the two-particle Gamow-Teller sum rule for each of the parent states of ^{26}Al and are given by

$$\log(ft)_i \equiv -\log \sum_j 1/(ft)_{ij} = 3.596 - \log S_i^{\text{GT}}.$$

These numbers give an estimate of the total Gamow-Teller strength to be expected for each parent state. Finally, the free Wildenthal $\log ft$ are denoted by W. All the decays considered in this paper have available roughly similar numbers of $\log ft$ values calculated from the results of Wildenthal.

For $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ the $\log ft$ calculated on the basis of the two-particle approximation do well in the two cases where comparison with experiment is possible. The $4 \rightarrow 1$ transition (Table 1: state 4 of ^{26}Al to state 1 of ^{26}Mg) is measured in the mirror system and when corrected for spin-degeneracy factors yields $\log ft = 4.01$. (Hereafter we will just refer to such a $\log ft$ value as “measured.”) This measured value is bracketed by the pure, $\log ft = 3.63$, and mixed (plus 0.5), $\log ft = 4.58$, results. The $6 \rightarrow 1$ transition is measured as $\log ft = 4.29$, and is approximated by the pure result as $\log ft = 3.87$ and by the mixed (plus 0.5) result as $\log ft = 4.58$. In the $^{30}\text{P} \rightarrow ^{30}\text{Si}$ decay the $1 \rightarrow 1$ transition is measured as $\log ft = 4.83$ and is approximated by the pure configuration result as $\log ft = 3.30$ and by the mixed configuration (plus 0.5) result as $\log ft = 4.61$. The Wildenthal calculation gives $\log ft = 5.34$ (free) for this transition. The $1 \rightarrow 2$ transition in this decay is measured as $\log ft = 5.8$, and is approximated by the pure result as $\log ft = \infty$ (zero matrix element) and by the mixed (plus 0.5) result as $\log ft = 4.89$. Here the Wildenthal calculation gives $\log ft = 4.83$ (free) and $\log ft = 5.17$ (fit). In general, the Wildenthal calculations agree very well with experimental data in the six decays considered, and only very rarely differ by as much as an order of magnitude. For instance, the worst case occurs in the decay $^{32}\text{S} \rightarrow ^{32}\text{P}$. The $1 \rightarrow 1$ transition is measured to be $\log ft = 7.42$ and is calculated by Wildenthal to be $\log ft = 4.90$ (free) and $\log ft = 5.43$ (fit). However, the other measured transitions in this decay are reproduced very well by Wildenthal’s results: transition $2 \rightarrow 1$ measured as $\log ft = 4.74$ (Wildenthal free $\log ft = 4.68$); transition $3 \rightarrow 1$ measured as $\log ft = 5.03$ (Wildenthal free $\log ft = 5.05$); transition $4 \rightarrow 1$ measured as $\log ft = 5.52$ (Wildenthal free $\log ft = 5.78$); transition $9 \rightarrow 1$ measured as $\log ft = 5.01$ (Wildenthal free $\log ft = 5.06$); transition $15 \rightarrow 1$ measured as $\log ft = 4.97$ (Wildenthal free $\log ft = 4.65$).

Finally, we distill from this information an average Gamow-Teller matrix element, appropriate for the sd -shell, which is to be used for unmeasured Gamow-Teller transitions not covered by Wildenthal’s calculations or, in the case of $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ and $^{30}\text{P} \rightarrow ^{30}\text{Si}$, a two-particle calculation. Averages of all Wildenthal calculated matrix elements used in the rate computations were taken for each of the six decays considered. The average Gamow-Teller $\log ft$ for each decay is remarkably consistent: $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ (free $\log ft = 4.80 \pm 0.4$), $^{30}\text{P} \rightarrow ^{30}\text{Si}$ (free $\log ft = 4.86 \pm 0.4$), $^{32}\text{S} \rightarrow ^{32}\text{P}$ (free $\log ft = 4.78 \pm 0.5$), $^{31}\text{S} \rightarrow ^{31}\text{P}$ (free $\log ft = 4.84 \pm 0.4$), $^{33}\text{S} \rightarrow ^{33}\text{P}$ (free $\log ft = 5.05 \pm 0.4$), $^{35}\text{Cl} \rightarrow ^{35}\text{S}$ (free $\log ft = 4.93 \pm 0.4$). The overall average for all Wildenthal calculated Gamow-Teller transitions is $\log ft$ (free) $= 4.86 \pm 0.5$ and $\log ft$ (fit) $= 5.09 \pm 0.5$. This mean includes roughly 400 matrix elements for transitions between states usually lying at or below excitation energies of 6 MeV. An average of experimentally determined Gamow-Teller transitions in the sd -shell taken from Endt and van der Leun (1978) gives $\log ft = 4.8 \pm 0.6$. This average is taken only for decays with large nuclear Q -values ($\gtrsim 3$ MeV), wherein many Gamow-Teller transitions could be sampled at excitation energies near those required for parent state sum rule saturation. In light of these results, we choose $\log ft = 5.0$ for use in otherwise undetermined Gamow-Teller transitions. This is to be compared with $\log ft = 5.7$ used by Hansen (1966) in his survey of these nuclei which, though it looks much slower, makes little difference in the

stellar rates except at the higher temperatures and densities due to the dominant role of more accurately determined transitions. Our best stellar rates are computed using, in order of priority, experimental matrix elements and those determined by isospin symmetry (Fermi and mirror transitions), Gamow-Teller values from Wildenthal results, two-particle Gamow-Teller calculations (mixed values plus 0.5), and finally the average Gamow-Teller value of $\log ft = 5.0$. This order of priority reflects the associated rank of confidence in each type of matrix element determination and, fortunately, also reflects in general the level of contribution of each type to the rates.

The contribution of each matrix element type to the rates and the sensitivity of these rates to errors in the matrix elements are determined by assigning an uncertainty to each of the matrix element types. Experimentally determined values are assigned a formal uncertainty of zero in $\log ft$, as are those $\log ft$ values determined by isospin symmetry. The Wildenthal and two-particle matrix elements are assigned an error of ± 0.4 in $\log ft$, reflecting the average deviation of these numbers from experimentally determined values seen in these decays and in the rest of the *sd*-shell. The average value of $ft = 10^5$ used for the remaining undetermined Gamow-Teller transitions is taken to be uncertain by a factor of 10 (± 1.0 in $\log ft$). The values of $\log ft = 4, 5, 6$ correspond to fast, intermediate, and relatively hindered Gamow-Teller matrix elements. This uncertainty is about twice the standard deviation for the average Gamow-Teller transition. A rough rate uncertainty is estimated by the following scheme: The slowest rates are computed using the assigned $\log ft$ values with their uncertainties added; likewise, the fastest rates are computed using the assigned $\log ft$ values with their uncertainties subtracted. In addition, for the fastest rates, "continuum" states are assigned at energies slightly beyond the last state of parent and daughter nucleus employed and each transition into and out of these states is assigned $\log ft = 3.5$, enough strength to take account of possible undetected high-lying Gamow-Teller strength. This latter computational device overestimates the uncertainty by oversaturating the Gamow-Teller sum rule in many cases and by putting all of this strength at the lowest possible excitation energy. The "rate uncertainty" Δ is then computed as the greater of the ratio of the fast rate to our best stellar rate and the ratio of our best stellar rate to the slow rate at each temperature and density point. Log Δ is tabulated in the rate tables, and shows for any temperature and density roughly which matrix element types contribute most to the rate and how much the rate could change due to matrix element errors and undetected high-lying strength. Note that where calculated or average-value Gamow-Teller transitions dominate the rate, Δ is a true measure of the matrix element induced uncertainty only if many such matrix elements contribute to the rate. This is because the assigned uncertainty in these cases reflects the standard deviation of a large ensemble of matrix elements, and any given individual assignment may be in error by a considerably larger factor. However, where Gamow-Teller transitions are important, many usually contribute, except at very low temperatures and high densities where a few Gamow-Teller electron capture channels can contribute (e.g., the $1 \rightarrow 6$ and $1 \rightarrow 10$ transitions in $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ have $\log ft = 4.10$ and make the substantial contribution to the rate for $\rho/\mu_e > 10^6$ and $T_9 < 1$; cf. § IV). In addition, the contribution of the different matrix element types is checked by computing the rate first with just the experimental and mirror decays and Fermi transitions, and then with the calculated Gamow-Teller transitions. Comparison of these rates gives a clear indication of where in temperature and density each matrix element type dominates. Furthermore, examination of the summations (10a) and (10b) term by term gives an explicit measure of the contributions of each individual parent and daughter state.

In summary, we conclude that over most of the range of temperature and density considered the rates are dominated by the most accurately determined matrix elements (experimental, Fermi, and mirror decays), and the rates are fairly well determined even at the highest temperatures and densities where unmeasured Gamow-Teller transitions dominate.

IV. APPLICATIONS AND DISCUSSION

In this section the stellar rates for the decays $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ ($Q_n = 3.494$ MeV), $^{30}\text{P} \rightarrow ^{30}\text{Si}$ ($Q_n = 3.716$ MeV), $^{31}\text{S} \rightarrow ^{31}\text{P}$ ($Q_n = 4.884$ MeV), $^{32}\text{S} \rightarrow ^{32}\text{P}$ ($Q_n = -2.221$ MeV), $^{33}\text{S} \rightarrow ^{33}\text{P}$ ($Q_n = -0.760$ MeV), and $^{35}\text{Cl} \rightarrow ^{35}\text{S}$ ($Q_n = -0.678$ MeV) are presented as functions of temperature and density. The first three columns of Tables 3, and 5–10, give the temperature $T_9 = T/10^9$ K, the Brigg's logarithm of ρ/μ_e where ρ is the density in g cm^{-3} , and μ_e is the mean molecular weight per electron in g mole^{-1} , and the electron chemical potential U_F in MeV, calculated for a perfect Fermi gas electron equation of state. U_F is the Fermi kinetic energy at high density. In the remaining columns the tables present $\log \beta^+$, where β^+ designates positron emission rates (all rates in s^{-1}); $\log \epsilon^-$ where ϵ^- designates the electron capture rate; $\log \Sigma$ where Σ is the total weak interaction rate $= \beta^+ + \epsilon^-$; $\log \Delta$, where Δ is the multiplicative uncertainty in Σ ; and $\log \nu$, where ν is the total neutrino energy loss rate in MeV s^{-1} corresponding to Σ . The level of uncertainty in the neutrino energy loss rates can be gauged by $\log \Delta$ for the associated weak decay rate Σ . A number of the decay rates are plotted in Figures 2 to 7.

At sufficiently high temperatures all parent ^{26}Al states are in thermal equilibrium and the stellar rate is given by equation (8) with statistical weighting factors (9). These rates are shown in Table 3. As we see in Figure 2a, the

TABLE 3
DECAY RATES FOR $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$

T_9	$\log \rho/\mu_e$	U_T	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_9	$\log \rho/\mu_e$	U_T	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_9	$\log \rho/\mu_e$	U_T	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$
0.01	1.0	-0.003	-13.558	-17.022	-13.558	0.000	-13.722	0.01	5.0	0.053	-13.558	-13.706	-13.325	0.000	-13.310	0.01	7.5	1.197	-13.558	-2.945	-2.945	0.400	-3.113
0.02	1.0	-0.007	-13.558	-17.176	-13.558	0.000	-13.722	0.02	5.0	0.053	-13.558	-13.706	-13.325	0.000	-13.310	0.02	7.5	1.197	-13.558	-2.945	-2.945	0.400	-3.113
0.03	1.0	-0.013	-13.558	-17.367	-13.558	0.000	-13.722	0.03	5.0	0.053	-13.558	-13.706	-13.324	0.000	-13.310	0.03	7.5	1.197	-13.558	-2.945	-2.945	0.400	-3.112
0.05	1.0	-0.024	-13.558	-17.467	-13.558	0.000	-13.722	0.05	5.0	0.053	-13.558	-13.706	-13.324	0.000	-13.310	0.05	7.5	1.197	-13.558	-2.945	-2.945	0.400	-3.112
0.07	1.0	-0.037	-13.558	-17.567	-13.558	0.000	-13.722	0.07	5.0	0.053	-13.558	-13.706	-13.325	0.000	-13.310	0.07	7.5	1.197	-13.558	-2.944	-2.944	0.400	-3.112
0.10	1.0	-0.058	-13.558	-17.696	-13.558	0.000	-13.722	0.10	5.0	0.052	-13.558	-13.703	-13.308	0.000	-13.310	0.10	7.5	1.197	-13.558	-2.944	-2.944	0.400	-3.111
0.20	1.0	-0.134	-13.558	-17.841	-13.558	0.000	-13.722	0.20	5.0	0.047	-13.558	-13.703	-13.308	0.000	-13.310	0.20	7.5	1.197	-13.558	-2.942	-2.942	0.400	-3.108
0.30	1.0	-0.218	-13.558	-17.918	-13.558	0.000	-13.722	0.30	5.0	0.038	-13.558	-13.703	-13.308	0.000	-13.310	0.30	7.5	1.197	-13.558	-2.942	-2.942	0.400	-3.108
0.50	1.0	-0.398	-13.558	-18.047	-13.558	0.000	-13.722	0.50	5.0	0.011	-13.558	-13.703	-13.308	0.000	-13.310	0.50	7.5	1.196	-13.558	-2.936	-2.936	0.399	-3.108
0.70	1.0	-0.503	-13.558	-18.147	-13.558	0.000	-13.722	0.70	5.0	0.006	-13.558	-13.703	-13.308	0.000	-13.310	0.70	7.5	1.194	-13.558	-2.936	-2.936	0.399	-3.108
1.00	1.0	-0.511	-13.558	-18.199	-13.558	0.000	-13.722	1.00	5.0	0.002	-13.558	-13.703	-13.308	0.000	-13.310	1.00	7.5	1.194	-13.558	-2.936	-2.936	0.399	-3.108
2.00	1.0	-0.511	-13.558	-18.242	-13.558	0.000	-13.722	2.00	5.0	0.000	-13.558	-13.703	-13.308	0.000	-13.310	2.00	7.5	1.194	-13.558	-2.936	-2.936	0.399	-3.108
3.00	1.0	-0.511	-13.558	-18.278	-13.558	0.000	-13.722	3.00	5.0	0.000	-13.558	-13.703	-13.308	0.000	-13.310	3.00	7.5	1.194	-13.558	-2.936	-2.936	0.399	-3.108
5.00	1.0	-0.511	-13.558	-18.348	-13.558	0.000	-13.722	5.00	5.0	0.000	-13.558	-13.703	-13.308	0.000	-13.310	5.00	7.5	1.194	-13.558	-2.936	-2.936	0.399	-3.108
7.00	1.0	-0.511	-13.558	-18.383	-13.558	0.000	-13.722	7.00	5.0	0.000	-13.558	-13.703	-13.308	0.000	-13.310	7.00	7.5	1.194	-13.558	-2.936	-2.936	0.399	-3.108
10.00	1.0	-0.511	-13.558	-18.413	-13.558	0.000	-13.722	10.00	5.0	0.000	-13.558	-13.703	-13.308	0.000	-13.310	10.00	7.5	1.194	-13.558	-2.936	-2.936	0.399	-3.108
0.01	2.0	-0.001	-13.558	-16.043	-13.558	0.000	-13.719	0.01	6.0	0.215	-13.558	-12.801	-12.731	0.000	-12.565	0.01	8.0	1.936	-13.558	-1.771	-1.771	0.405	-1.695
0.02	2.0	-0.003	-13.558	-16.185	-13.558	0.000	-13.720	0.02	6.0	0.215	-13.558	-12.801	-12.731	0.000	-12.565	0.02	8.0	1.936	-13.558	-1.771	-1.771	0.404	-1.695
0.03	2.0	-0.007	-13.558	-16.271	-13.558	0.000	-13.720	0.03	6.0	0.215	-13.558	-12.801	-12.731	0.000	-12.565	0.03	8.0	1.936	-13.558	-1.771	-1.771	0.404	-1.695
0.05	2.0	-0.014	-13.558	-16.369	-13.558	0.000	-13.720	0.05	6.0	0.215	-13.558	-12.801	-12.731	0.000	-12.564	0.05	8.0	1.936	-13.558	-1.771	-1.771	0.404	-1.695
0.07	2.0	-0.023	-13.558	-16.436	-13.558	0.000	-13.721	0.07	6.0	0.215	-13.558	-12.801	-12.730	0.000	-12.564	0.07	8.0	1.936	-13.558	-1.771	-1.771	0.404	-1.695
0.10	2.0	-0.038	-13.558	-16.496	-13.558	0.000	-13.721	0.10	6.0	0.213	-13.558	-12.751	-12.628	0.000	-12.564	0.10	8.0	1.936	-13.558	-1.771	-1.771	0.405	-1.695
0.20	2.0	-0.095	-13.558	-16.574	-13.558	0.000	-13.717	0.20	6.0	0.213	-13.558	-12.751	-12.628	0.000	-12.470	0.20	8.0	1.936	-13.558	-1.771	-1.771	0.405	-1.695
0.30	2.0	-0.158	-13.558	-16.618	-13.558	0.000	-13.717	0.30	6.0	0.211	-13.558	-12.751	-12.628	0.000	-12.470	0.30	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
0.50	2.0	-0.299	-13.558	-16.749	-13.558	0.000	-13.717	0.50	6.0	0.202	-13.558	-12.751	-12.628	0.000	-12.470	0.50	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
0.70	2.0	-0.446	-13.558	-16.871	-13.558	0.000	-13.717	0.70	6.0	0.189	-13.558	-12.751	-12.628	0.000	-12.470	0.70	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
1.00	2.0	-0.506	-13.558	-16.949	-13.558	0.000	-13.717	1.00	6.0	0.161	-13.558	-12.751	-12.628	0.000	-12.470	1.00	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
2.00	2.0	-0.511	-13.558	-17.042	-13.558	0.000	-13.717	2.00	6.0	0.139	-13.558	-12.751	-12.628	0.000	-12.470	2.00	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
3.00	2.0	-0.511	-13.558	-17.143	-13.558	0.000	-13.717	3.00	6.0	0.119	-13.558	-12.751	-12.628	0.000	-12.470	3.00	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
5.00	2.0	-0.511	-13.558	-17.248	-13.558	0.000	-13.717	5.00	6.0	0.091	-13.558	-12.751	-12.628	0.000	-12.470	5.00	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
7.00	2.0	-0.511	-13.558	-17.353	-13.558	0.000	-13.717	7.00	6.0	0.063	-13.558	-12.751	-12.628	0.000	-12.470	7.00	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
10.00	2.0	-0.511	-13.558	-17.458	-13.558	0.000	-13.717	10.00	6.0	0.035	-13.558	-12.751	-12.628	0.000	-12.470	10.00	8.0	1.935	-13.558	-1.771	-1.771	0.404	-1.694
0.01	3.0	0.003	-13.558	-15.141	-13.547	0.000	-13.698	0.01	6.5	0.402	-13.558	-6.454	-6.454	0.400	-7.627	0.01	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.02	3.0	0.003	-13.558	-15.225	-13.548	0.000	-13.700	0.02	6.5	0.402	-13.558	-6.454	-6.454	0.400	-7.627	0.02	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.03	3.0	0.004	-13.558	-15.308	-13.550	0.000	-13.700	0.03	6.5	0.402	-13.558	-6.454	-6.454	0.400	-7.627	0.03	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.05	3.0	0.004	-13.558	-15.388	-13.551	0.000	-13.700	0.05	6.5	0.402	-13.558	-6.454	-6.454	0.400	-7.627	0.05	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.07	3.0	0.009	-13.558	-15.449	-13.552	0.000	-13.700	0.07	6.5	0.402	-13.558	-6.454	-6.454	0.400	-7.627	0.07	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.10	3.0	0.018	-13.558	-15.501	-13.552	0.000	-13.700	0.10	6.5	0.402	-13.558	-6.454	-6.454	0.400	-7.627	0.10	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.20	3.0	0.055	-13.558	-15.575	-13.552	0.000	-13.700	0.20	6.5	0.401	-13.558	-6.454	-6.454	0.400	-7.627	0.20	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.30	3.0	0.099	-13.558	-15.649	-13.552	0.000	-13.700	0.30	6.5	0.399	-13.558	-6.454	-6.454	0.400	-7.627	0.30	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.50	3.0	0.200	-13.558	-15.723	-13.552	0.000	-13.700	0.50	6.5	0.394	-13.558	-6.454	-6.454	0.400	-7.627	0.50	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.70	3.0	0.314	-13.558	-15.797	-13.552	0.000	-13.700	0.70	6.5	0.386	-13.558	-6.454	-6.454	0.400	-7.627	0.70	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
1.00	3.0	0.465	-13.558	-15.869	-13.552	0.000	-13.700	1.00	6.5	0.368	-13.558	-6.454	-6.454	0.400	-7.627	1.00	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
2.00	3.0	0.510	-13.558	-15.942	-13.552	0.000	-13.700	2.00	6.5	0.266	-13.558	-6.454	-6.454	0.400	-7.627	2.00	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
3.00	3.0	0.511	-13.558	-16.015	-13.552	0.000	-13.700	3.00	6.5	0.234	-13.558	-6.454	-6.454	0.400	-7.627	3.00	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
5.00	3.0	0.511	-13.558	-16.088	-13.552	0.000	-13.700	5.00	6.5	0.204	-13.558	-6.454	-6.454	0.400	-7.627	5.00	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
7.00	3.0	0.511	-13.558	-16.161	-13.552	0.000	-13.700	7.00	6.5	0.177	-13.558	-6.454	-6.454	0.400	-7.627	7.00	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
10.00	3.0	0.511	-13.558	-16.234	-13.552	0.000	-13.700	10.00	6.5	0.149	-13.558	-6.454	-6.454	0.400	-7.627	10.00	8.5	3.037	-13.558	-0.710	-0.710	0.449	-0.405
0.01	4.0	0.012	-13.558	-14.466	-13.507	0.000	-13.618	0.01	7.0	0.711	-13.558	-4.268	-4.268	0.400	-4.778	0.01	9.0	4.671	-13.558	0.271	0

FIG. 2a

FIG. 2b

FIG. 2c

FIG. 2.—(a) Positron emission rate for $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ with all ^{26}Al states assumed to be in thermal equilibrium. The values of $\log \beta^+$ from Table 3 are displayed for the temperature and density grid of Fig. 1. The density dependence of positron emission is negligible in most cases of interest. The rate is dominated by the changeover from the laboratory rate determined by the ground state decay to the much faster decays accessible from the metastable isomeric state at 0.228 MeV as it becomes thermally populated. (b) Electron capture rate for $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ with all ^{26}Al states assumed to be in thermal equilibrium. The values of $\log \epsilon^-$ from Table 3 are displayed as a function of temperature and density. The dramatic increase of more than six orders of magnitude from $\log \rho/\mu_e = 6.0$ to 6.5 at low temperature is due to the opening up of fast (allowed) upward transitions from the parent ground state (5^+) as the electron chemical potential becomes sufficiently large to overcome the energy interval. The equality of the rates at different density points for high temperature is the result of the similar behavior of U_F in Fig. 1. (c) Total decay rate (positron emission plus electron capture) for $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$ assuming all ^{26}Al states to be in thermal equilibrium. Log Σ from Table 3 is displayed as a function of temperature and density. Positron emission dominates below about $\log \rho/\mu_e = 6.0$, electron capture above.

positron emission rate is dominated by the very slow ground state transitions at low temperatures, but the much faster decay from the isomeric state takes over quickly with increasing temperature above $T_9=0.1$. This decay, transition 2→1 in Table 1, is a Fermi transition with $\log ft=3.49$. The large available decay phase space and small $\log ft$ -value of the isomeric state transition is difficult competition for other transitions to match. A rate based on the ground state and the isomeric state alone would match our curve well until very high temperatures are reached. The electron capture rate (Fig. 2*b*) is slower than the positron emission rate until $\log \rho/\mu_e \gtrsim 6$; above this value the electron capture component dominates the total rate (Fig. 2*c*). The electron capture rate for a given transition generally tends to increase smoothly as the density of electrons at the nucleus and the phase space integral, equation (3*b*), increase. The large increase in the ^{26}Al electron capture rate (Fig. 2*b*) from $\log \rho/\mu_e=6.0$ to 6.5 at low temperature is due to the opening up of the intrinsically fast ($\log ft \approx 4.1$) but energetically unfavorable upward transitions from the ground state 1→6 and 1→10. Above $\log \rho/\mu_e=6.0$ the chemical potential U_F (cf. Fig. 1) becomes large enough for the electrons in the tail of the Fermi-Dirac distribution to become sufficiently energetic to overcome the threshold kinetic energy, which is 0.313 MeV for 1→6 and 0.895 MeV for 1→10. These values result from subtracting the ^{26}Al - ^{26}Mg atomic Q -value, 4.005 MeV, from the excitation energies, 4.318 MeV for state 6 in Mg and 4.900 MeV for state 10.

Although the Fermi transition from the 0.228 MeV isomeric state of ^{26}Al dominates the equilibrium rate at even moderate temperatures, communication between the isomeric state and the ground state by electromagnetic transitions is poor, and at sufficiently low temperatures it is not a good assumption that this first excited state is in thermal equilibrium with the ground state. Ward and Fowler (1979) estimate that the time required for the 0.228 MeV state to equilibrate exceeds its lifetime against positron emission for $T_9 < 0.4$. Therefore, we have calculated positron emission and electron capture rates separately for the metastable state and those that communicate with it (the metastable state system $^{26}\text{Al}_m$) and the ground state and those that communicate with it (the ground state system $^{26}\text{Al}_g$). Several states are members of both systems; the gamma-ray branching (Table 26.13 of Endt and van der Leun (1978) has been used to make the fractional assignments of Table 4. Decay rates for the ground state and isomeric state systems are given in Tables 5*a* and 5*b*.

We have seen that the weak destruction rate by electron capture and positron emission of ^{26}Al becomes a sensitive function of temperature and density varying over many orders of magnitude for the more extreme conditions. Since the well studied isomeric state dominates at all but the highest temperatures considered, the positron emission rate agrees well with that of Hansen (1966) until $T_9 > 3$, at which point the fast transitions (4→1, 6→1, and 9→1 in Table 1) with $\log ft$ values given accurately by the mirror decays in ^{26}Si - ^{26}Al , increase the rate by a factor of 2–3 faster than Hansen's rates. However, this increase falls within the factor of 5 fitting error quoted by Hansen. At $T_9=2$, our electron capture rate ranges from a factor of 6 slower than Hansen at $\rho/\mu_e=10^2$ (a value outside the range of

TABLE 4
RESOLUTION OF ^{26}Al STATES INTO GROUND STATE ($^{26}\text{Al}_g$)
AND METASTABLE STATE ($^{26}\text{Al}_m$) SYSTEMS

State	E_x (MeV)	g	m
1.....	0	1.	0.
2.....	0.228	0.	1.
3.....	0.417	1.	0.
4.....	1.058	0.	1.
5.....	1.759	0.98	0.02
6.....	1.851	0.	1.
7.....	2.069	1.	0.
8.....	2.070	0.23	0.77
9.....	2.072	0.	1.
10.....	2.365	0.46	0.54
11.....	2.545	0.49	0.51
12.....	2.661	0.67	0.33
13.....	2.739	0.	1.
14.....	2.913	0.53	0.47
15.....	3.074	0.20	0.80
16.....	3.159	0.82	0.18
22.....	3.179	0.06	0.94
24.....	3.745	0.	1.
ANLG	5.918	0.5	0.5
ANLG	6.353	0.5	0.5

TABLE 5A
DECAY RATES FOR $^{26}\text{Al}_g \rightarrow ^{26}\text{Mg}$

T_g	$\log \rho/\mu_e$	U_f	$\log \beta^+$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_g	$\log \rho/\mu_e$	U_f	$\log \beta^+$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$
0.01	1.0	-0.003	-13.558	-17.022	-3.558	0.000	-13.722	0.01	5.0	0.053	-13.558	-13.706	-3.325	0.000	-13.310
0.02	1.0	-0.002	-13.558	-16.176	-3.558	0.000	-13.722	0.02	3.0	0.053	-13.558	-13.706	-3.325	0.000	-13.310
0.03	1.0	-0.013	-13.558	-17.267	-3.558	0.000	-13.722	0.03	3.0	0.053	-13.558	-13.706	-3.325	0.000	-13.310
0.05	1.0	-0.024	-13.558	-17.367	-3.558	0.000	-13.722	0.05	3.0	0.053	-13.558	-13.706	-3.325	0.000	-13.310
0.07	1.0	-0.037	-13.558	-17.437	-3.558	0.000	-13.722	0.07	3.0	0.053	-13.558	-13.706	-3.325	0.000	-13.310
0.10	1.0	-0.058	-13.558	-17.504	-3.558	0.000	-13.722	0.10	3.0	0.052	-13.558	-13.711	-3.277	0.000	-13.313
0.20	1.0	-0.134	-13.524	-17.585	-3.524	0.046	-13.680	0.20	3.0	0.047	-13.524	-13.639	-3.227	0.071	-13.283
0.30	1.0	-0.208	-13.524	-17.585	-3.524	0.046	-13.680	0.30	3.0	0.038	-11.149	-13.331	-3.093	0.389	-10.918
0.50	1.0	-0.388	-8.350	-12.635	-8.350	0.400	-8.411	0.50	3.0	0.011	-8.350	-8.345	-8.722	0.400	-8.133
0.70	1.0	-0.503	-7.150	-10.824	-7.150	0.400	-8.411	0.70	3.0	-0.026	-7.150	-6.766	-6.979	0.400	-6.933
1.00	1.0	-0.711	-6.251	-8.614	-6.249	0.400	-6.309	1.00	3.0	-0.098	-6.251	-5.670	-6.081	0.400	-6.030
2.00	1.0	-0.511	-5.207	-5.658	-5.076	0.404	-5.023	2.00	3.0	-0.383	-5.206	-5.339	-4.967	0.403	-4.864
3.00	1.0	-0.511	-4.625	-4.405	-4.200	0.434	-3.937	3.00	3.0	-0.476	-4.624	-4.347	-4.163	0.451	-3.915
5.00	1.0	-0.511	-3.450	-2.992	-2.862	0.536	-2.452	5.00	3.0	-0.502	-3.449	-2.983	-2.855	0.584	-2.445
7.00	1.0	-0.511	-2.780	-2.093	-2.013	0.656	-1.475	7.00	3.0	-0.507	-2.780	-2.093	-2.011	0.656	-1.472
10.00	1.0	-0.511	-2.282	-1.184	-1.151	0.708	-0.458	10.00	3.0	-0.509	-2.282	-1.183	-1.150	0.708	-0.458
0.01	2.0	-0.001	-13.558	-16.043	-3.556	0.000	-13.719	0.01	8.0	0.215	-13.558	-12.801	-12.731	0.000	-12.565
0.02	2.0	-0.003	-13.558	-16.185	-3.557	0.000	-13.720	0.02	8.0	0.215	-13.558	-12.801	-12.731	0.000	-12.565
0.03	2.0	-0.007	-13.558	-16.271	-3.557	0.000	-13.720	0.03	8.0	0.215	-13.558	-12.801	-12.731	0.000	-12.565
0.05	2.0	-0.014	-13.558	-16.369	-3.557	0.000	-13.720	0.05	8.0	0.215	-13.558	-12.801	-12.731	0.000	-12.564
0.07	2.0	-0.023	-13.558	-16.436	-3.557	0.000	-13.721	0.07	8.0	0.215	-13.558	-12.800	-12.730	0.000	-12.564
0.10	2.0	-0.038	-13.558	-16.504	-3.557	0.000	-13.721	0.10	8.0	0.214	-13.558	-12.758	-12.694	0.051	-12.564
0.20	2.0	-0.085	-13.524	-16.585	-3.524	0.047	-13.679	0.20	8.0	0.213	-13.524	-12.559	-12.558	0.359	-11.576
0.30	2.0	-0.158	-11.149	-11.637	-1.149	0.399	-1.210	0.30	8.0	0.202	-11.149	-8.987	-8.984	0.400	-9.85

TABLE 5B
DECAY RATES FOR $^{26}\text{Al}_m \rightarrow ^{26}\text{Mg}$

T_9	$\log \rho/\mu_e$	U_f	$\log \beta^*$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_9	$\log \rho/\mu_e$	U_f	$\log \beta^*$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_9	$\log \rho/\mu_e$	U_f	$\log \beta^*$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$
0.01	1.0	-0.003	-0.962	-6.166	-0.962	0.000	-0.713	0.01	5.0	0.053	-0.962	-2.863	-0.956	0.000	-0.700	0.01	7.5	1.197	-0.962	-0.456	-0.338	0.000	0.285
0.02	1.0	-0.007	-0.962	-6.321	-0.962	0.000	-0.713	0.02	5.0	0.053	-0.962	-2.863	-0.956	0.000	-0.700	0.02	7.5	1.197	-0.962	-0.456	-0.338	0.000	0.285
0.03	1.0	-0.013	-0.962	-6.406	-0.962	0.000	-0.713	0.03	5.0	0.053	-0.962	-2.863	-0.956	0.000	-0.700	0.03	7.5	1.197	-0.962	-0.456	-0.338	0.000	0.285
0.05	1.0	-0.024	-0.962	-6.513	-0.962	0.000	-0.713	0.05	5.0	0.053	-0.962	-2.863	-0.956	0.000	-0.700	0.05	7.5	1.197	-0.962	-0.456	-0.338	0.000	0.285
0.07	1.0	-0.037	-0.962	-6.584	-0.962	0.000	-0.713	0.07	5.0	0.053	-0.962	-2.863	-0.956	0.000	-0.700	0.07	7.5	1.197	-0.962	-0.456	-0.338	0.000	0.285
0.10	1.0	-0.058	-0.962	-6.652	-0.962	0.000	-0.713	0.10	5.0	0.053	-0.962	-2.863	-0.956	0.000	-0.700	0.10	7.5	1.197	-0.962	-0.456	-0.338	0.000	0.285
0.20	1.0	-0.134	-0.962	-6.775	-0.962	0.000	-0.713	0.20	5.0	0.047	-0.962	-2.881	-0.956	0.000	-0.701	0.20	7.5	1.197	-0.962	-0.456	-0.338	0.000	0.285
0.30	1.0	-0.218	-0.962	-6.839	-0.962	0.000	-0.713	0.30	5.0	0.047	-0.962	-2.881	-0.956	0.000	-0.701	0.30	7.5	1.197	-0.962	-0.456	-0.338	0.000	0.285
0.50	1.0	-0.398	-0.962	-6.904	-0.962	0.000	-0.713	0.50	5.0	0.026	-0.962	-2.957	-0.957	0.000	-0.702	0.50	7.5	1.194	-0.962	-0.455	-0.337	0.000	0.286
0.70	1.0	-0.503	-0.962	-6.904	-0.962	0.000	-0.713	0.70	5.0	0.026	-0.962	-2.957	-0.957	0.000	-0.702	0.70	7.5	1.194	-0.962	-0.455	-0.337	0.000	0.286
1.00	1.0	-0.511	-0.962	-6.904	-0.962	0.000	-0.713	1.00	5.0	-0.098	-0.962	-2.978	-0.957	0.000	-0.703	1.00	7.5	1.190	-0.962	-0.454	-0.336	0.000	0.288
2.00	1.0	-0.511	-0.962	-6.904	-0.962	0.000	-0.713	2.00	5.0	-0.098	-0.962	-2.978	-0.957	0.000	-0.703	2.00	7.5	1.182	-0.962	-0.454	-0.335	0.000	0.301
3.00	1.0	-0.511	-0.962	-6.904	-0.962	0.000	-0.713	3.00	5.0	-0.098	-0.962	-2.978	-0.957	0.000	-0.703	3.00	7.5	1.182	-0.962	-0.454	-0.335	0.000	0.301
5.00	1.0	-0.511	-0.962	-6.904	-0.962	0.000	-0.713	5.00	5.0	-0.098	-0.962	-2.978	-0.957	0.000	-0.703	5.00	7.5	1.182	-0.962	-0.454	-0.335	0.000	0.301
7.00	1.0	-0.511	-0.962	-6.904	-0.962	0.000	-0.713	7.00	5.0	-0.098	-0.962	-2.978	-0.957	0.000	-0.703	7.00	7.5	1.182	-0.962	-0.454	-0.335	0.000	0.301
10.00	1.0	-0.511	-0.962	-6.904	-0.962	0.000	-0.713	10.00	5.0	-0.098	-0.962	-2.978	-0.957	0.000	-0.703	10.00	7.5	1.182	-0.962	-0.454	-0.335	0.000	0.301
0.01	2.0	-0.001	-0.962	-5.187	-0.961	0.000	-0.713	0.01	6.0	0.215	-0.962	-2.000	-0.923	0.000	-0.625	0.01	8.0	1.936	-0.962	-0.125	-0.160	0.000	0.889
0.02	2.0	-0.003	-0.962	-5.330	-0.962	0.000	-0.713	0.02	6.0	0.215	-0.962	-2.000	-0.923	0.000	-0.625	0.02	8.0	1.936	-0.962	-0.125	-0.160	0.000	0.889
0.03	2.0	-0.007	-0.962	-5.416	-0.962	0.000	-0.713	0.03	6.0	0.215	-0.962	-2.000	-0.923	0.000	-0.625	0.03	8.0	1.936	-0.962	-0.125	-0.160	0.000	0.889
0.05	2.0	-0.014	-0.962	-5.515	-0.962	0.000	-0.713	0.05	6.0	0.215	-0.962	-2.000	-0.923	0.000	-0.625	0.05	8.0	1.936	-0.962	-0.125	-0.160	0.000	0.889
0.07	2.0	-0.023	-0.962	-5.583	-0.962	0.000	-0.713	0.07	6.0	0.215	-0.962	-2.000	-0.923	0.000	-0.625	0.07	8.0	1.936	-0.962	-0.125	-0.160	0.000	0.889
0.10	2.0	-0.038	-0.962	-5.653	-0.962	0.000	-0.713	0.10	6.0	0.214	-0.962	-2.000	-0.923	0.000	-0.625	0.10	8.0	1.936	-0.962	-0.125	-0.160	0.000	0.889
0.20	2.0	-0.095	-0.962	-5.776	-0.962	0.000	-0.713	0.20	6.0	0.214	-0.962	-2.000	-0.923	0.000	-0.625	0.20	8.0	1.935	-0.962	-0.125	-0.160	0.000	0.889
0.30	2.0	-0.158	-0.962	-5.839	-0.962	0.000	-0.713	0.30	6.0	0.214	-0.962	-2.000	-0.923	0.000	-0.625	0.30	8.0	1.935	-0.962	-0.125	-0.160	0.000	0.889
0.50	2.0	-0.299	-0.962	-5.907	-0.962	0.000	-0.713	0.50	6.0	0.202	-0.962	-2.001	-0.924	0.000	-0.625	0.50	8.0	1.933	-0.962	-0.126	-0.161	0.000	0.890
0.70	2.0	-0.446	-0.962	-5.950	-0.961	0.000	-0.713	0.70	6.0	0.189	-0.962	-2.001	-0.924	0.000	-0.624	0.70	8.0	1.931	-0.962	-0.126	-0.161	0.000	0.891
1.00	2.0	-0.506	-0.962	-5.950	-0.961	0.000	-0.713	1.00	6.0	0.189	-0.962	-2.001	-0.924	0.000	-0.624	1.00	8.0	1.931	-0.962	-0.126	-0.161	0.000	0.891
2.00	2.0	-0.511	-0.962	-5.950	-0.961	0.000	-0.713	2.00	6.0	0.189	-0.962	-2.001	-0.924	0.000	-0.624	2.00	8.0	1.925	-0.962	-0.126	-0.161	0.000	0.893
3.00	2.0	-0.511	-0.962	-5.950	-0.961	0.000	-0.713	3.00	6.0	0.189	-0.962	-2.001	-0.924	0.000	-0.624	3.00	8.0	1.925	-0.962	-0.126	-0.161	0.000	0.893
5.00	2.0	-0.511	-0.962	-5.950	-0.961	0.000	-0.713	5.00	6.0	0.189	-0.962	-2.001	-0.924	0.000	-0.624	5.00	8.0	1.925	-0.962	-0.126	-0.161	0.000	0.893
7.00	2.0	-0.511	-0.962	-5.950	-0.961	0.000	-0.713	7.00	6.0	0.189	-0.962	-2.001	-0.924	0.000	-0.624	7.00	8.0	1.925	-0.962	-0.126	-0.161	0.000	0.893
10.00	2.0	-0.511	-0.962	-5.950	-0.961	0.000	-0.713	10.00	6.0	0.189	-0.962	-2.001	-0.924	0.000	-0.624	10.00	8.0	1.925	-0.962	-0.126	-0.161	0.000	0.893
0.01	3.0	0.003	-0.962	-4.286	-0.961	0.000	-0.713	0.01	6.5	0.402	-0.962	-1.518	-0.855	0.000	-0.482	0.01	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.02	3.0	0.003	-0.962	-4.370	-0.961	0.000	-0.713	0.02	6.5	0.402	-0.962	-1.518	-0.855	0.000	-0.482	0.02	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.03	3.0	0.003	-0.962	-4.448	-0.961	0.000	-0.713	0.03	6.5	0.402	-0.962	-1.518	-0.855	0.000	-0.482	0.03	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.05	3.0	0.004	-0.962	-4.534	-0.961	0.000	-0.713	0.05	6.5	0.402	-0.962	-1.518	-0.855	0.000	-0.482	0.05	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.07	3.0	0.009	-0.962	-4.596	-0.961	0.000	-0.713	0.07	6.5	0.402	-0.962	-1.518	-0.855	0.000	-0.482	0.07	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.10	3.0	0.018	-0.962	-4.658	-0.961	0.000	-0.713	0.10	6.5	0.402	-0.962	-1.518	-0.855	0.000	-0.482	0.10	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.20	3.0	0.055	-0.962	-4.777	-0.961	0.000	-0.713	0.20	6.5	0.401	-0.962	-1.517	-0.855	0.000	-0.482	0.20	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.30	3.0	0.099	-0.962	-4.840	-0.961	0.000	-0.713	0.30	6.5	0.401	-0.962	-1.517	-0.855	0.000	-0.482	0.30	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.50	3.0	0.200	-0.962	-4.907	-0.961	0.000	-0.713	0.50	6.5	0.399	-0.962	-1.516	-0.855	0.000	-0.481	0.50	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.70	3.0	0.314	-0.962	-4.943	-0.961	0.000	-0.713	0.70	6.5	0.398	-0.962	-1.516	-0.855	0.000	-0.481	0.70	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
1.00	3.0	0.465	-0.962	-4.978	-0.961	0.000	-0.713	1.00	6.5	0.398	-0.962	-1.516	-0.855	0.000	-0.481	1.00	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
2.00	3.0	0.510	-0.962	-4.978	-0.961	0.000	-0.713	2.00	6.5	0.398	-0.962	-1.516	-0.855	0.000	-0.481	2.00	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
3.00	3.0	0.511	-0.962	-4.978	-0.961	0.000	-0.713	3.00	6.5	0.398	-0.962	-1.516	-0.855	0.000	-0.481	3.00	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
5.00	3.0	0.511	-0.962	-4.978	-0.961	0.000	-0.713	5.00	6.5	0.398	-0.962	-1.516	-0.855	0.000	-0.481	5.00	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
7.00	3.0	0.511	-0.962	-4.978	-0.961	0.000	-0.713	7.00	6.5	0.398	-0.962	-1.516	-0.855	0.000	-0.481	7.00	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
10.00	3.0	0.511	-0.962	-4.978	-0.961	0.000	-0.713	10.00	6.5	0.398	-0.962	-1.516	-0.855	0.000	-0.481	10.00	8.5	3.037	-0.962	-0.741	-0.749	0.003	1.558
0.01	4.0	0.012	-0.962	-3.613	-0.961	0.000	-0.711	0.01	7.0	0.711	-0.962	-1.004	-0.681	0.000	-0.180	0.01	9.0	4.671	-0.962	-1.391	-1.393	0.019	2.287
0.02	4.0	0.012	-0.962	-3.697	-0.961	0.000	-0.711	0.02	7.0	0.711	-0.962	-1.004	-0.681	0.000	-0.180	0.02	9.0	4.671	-0.962	-1.391	-1.393	0.019	2.287
0.03	4.0	0.012	-0.962	-3.781	-0.961	0.000	-0.711	0.03	7.0	0.711	-0.962	-1.004	-										

validity of Hansen's fit to his calculated rates) to a factor of 6 faster at $\rho/\mu_e = 10^9 \text{ g cm}^{-3}$. At higher temperatures our electron capture rates are faster by factors of 5–100, as a result of the many relatively fast electron capture channels which open up at higher temperatures and densities. (Note that in these cases the uncertainty in our rate is roughly a factor of 3.) Any detailed calculation of the production and destruction of ^{26}Al in stellar environments should take into account these results.

The remaining decays $^{30}\text{P} \rightarrow ^{30}\text{Si}$, $^{31}\text{S} \rightarrow ^{31}\text{P}$, $^{32}\text{S} \rightarrow ^{32}\text{P}$, $^{33}\text{S} \rightarrow ^{33}\text{P}$, and $^{35}\text{Cl} \rightarrow ^{35}\text{S}$ are most important in influencing neutronization of the core material prior to and during the initial phase of silicon burning in massive stars preceding the collapse which initiates the supernova event. In particular, Weaver, Woosley, and Zimmerman (1978) find that the ratio of ^{28}Si to ^{30}Si abundance at silicon ignition is determined partly by neutronization via these five decays, which were chosen as being most important on the basis of the product of rate and abundance. In turn, the composition of core and mantle material resulting from silicon burning depends on this ratio with interesting consequences for subsequent nucleosynthesis.

We find that our overall weak destruction rates agree well with the Hansen parametrized fits (1966, p. A-41) in most cases at low temperature and intermediate densities, but do differ significantly in some cases at temperatures and densities relevant to the neutronization-nucleosynthesis problem, motivating our detailed tabulation of these rates.

The decay $^{30}\text{P} \rightarrow ^{30}\text{Si}$ (Table 6) is similar to that of $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$. There is a comparable $Q_\alpha = 3.72 \text{ MeV}$ of available phase space in the ground state to ground state transition, and there is an isomeric state at 680 keV in ^{30}P . In contrast, the ground state to ground state transition $1 \rightarrow 1$ is relatively fast in this case ($\log ft = 4.83$). The fast Fermi transition ($2 \rightarrow 1$, $\log ft = 3.49$) from the isomeric state dominates the rates for temperatures higher than $T_9 \approx 1$. At still higher temperatures the fast decay ($10 \rightarrow 1$, $\log ft = 3.99$ from the mirror decay) becomes important. The positron emission rate agrees with the Hansen fit to within a factor of 2. The electron capture rate, on the other hand, is influenced partly by the relatively fast Gamow-Teller transitions at low excitation energy ($1 \rightarrow 2$, $1 \rightarrow 3$, $3 \rightarrow 2$, $3 \rightarrow 5$, and $3 \rightarrow 6$ of Table 2) and accessible at intermediate temperatures and densities, resulting in a rate 6 times faster than Hansen at $T_9 = 2$, $\rho/\mu_e = 10^8$. There is no dramatic density dependence due to upward transitions at low temperature in this case (Fig. 3); they do not compete well with the fast energetically favored transitions. At higher temperatures even faster Gamow-Teller channels open up at high density to give rates a factor of 4 to 40 times faster than Hansen's. The concurrent uncertainty in our rates is a factor of 3 at $T_9 = 10$, $\rho/\mu_e = 10^9$, showing that at even these extreme conditions, transitions with experimental, mirror, and calculated Gamow-Teller $\log ft$ values make the major contribution to the rate.

FIG. 3.—Total decay rate for $^{30}\text{P} \rightarrow ^{30}\text{Si}$; $\log \Sigma$ from Table 6. The ground state decay is fairly rapid, and the enhancement due to continuum electron capture at high densities shows only the smooth increase of U_F with $\log \rho/\mu_e$ (cf., Fig. 1).

TABLE 6
DECAY RATES FOR $^{30}\text{P} \rightarrow ^{30}\text{Si}$

T_9	$\log \rho/\mu_e$	U_F	$\log \beta^*$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_9	$\log \rho/\mu_e$	U_F	$\log \beta^*$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_9	$\log \rho/\mu_e$	U_F	$\log \beta^*$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$
0.01	1.0	-0.003	-2.323	-7.370	-2.323	0.000	-2.074	0.01	5.0	0.053	-2.323	-4.081	-2.316	0.002	-2.059	0.01	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.02	1.0	-0.007	-2.323	-7.525	-2.323	0.000	-2.074	0.02	5.0	0.053	-2.323	-4.081	-2.316	0.002	-2.059	0.02	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.03	1.0	-0.013	-2.323	-7.611	-2.323	0.000	-2.074	0.03	5.0	0.053	-2.323	-4.080	-2.316	0.002	-2.059	0.03	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.05	1.0	-0.024	-2.323	-7.719	-2.323	0.000	-2.074	0.05	5.0	0.053	-2.323	-4.078	-2.316	0.002	-2.059	0.05	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.07	1.0	-0.037	-2.323	-7.791	-2.323	0.000	-2.074	0.07	5.0	0.053	-2.323	-4.081	-2.316	0.002	-2.059	0.07	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.10	1.0	-0.058	-2.323	-7.861	-2.323	0.000	-2.074	0.10	5.0	0.052	-2.323	-4.087	-2.316	0.002	-2.059	0.10	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.20	1.0	-0.134	-2.323	-7.989	-2.323	0.000	-2.074	0.20	5.0	0.047	-2.323	-4.099	-2.316	0.002	-2.059	0.20	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.30	1.0	-0.218	-2.323	-8.055	-2.323	0.000	-2.074	0.30	5.0	0.038	-2.323	-4.119	-2.316	0.001	-2.060	0.30	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.50	1.0	-0.398	-2.323	-8.122	-2.323	0.000	-2.074	0.50	5.0	0.011	-2.323	-4.152	-2.317	0.001	-2.061	0.50	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.70	1.0	-0.503	-2.323	-8.122	-2.323	0.000	-2.074	0.70	5.0	0.026	-2.323	-4.174	-2.317	0.001	-2.061	0.70	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
1.00	1.0	-0.511	-2.323	-8.122	-2.323	0.000	-2.074	1.00	5.0	-0.098	-2.323	-4.191	-2.315	0.002	-2.059	1.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
2.00	1.0	-0.511	-2.323	-8.122	-2.323	0.000	-2.074	2.00	5.0	-0.098	-2.323	-4.191	-2.315	0.002	-2.059	2.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
3.00	1.0	-0.511	-2.323	-8.122	-2.323	0.000	-2.074	3.00	5.0	-0.098	-2.323	-4.191	-2.315	0.002	-2.059	3.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
5.00	1.0	-0.511	-2.323	-8.122	-2.323	0.000	-2.074	5.00	5.0	-0.098	-2.323	-4.191	-2.315	0.002	-2.059	5.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
7.00	1.0	-0.511	-2.323	-8.122	-2.323	0.000	-2.074	7.00	5.0	-0.098	-2.323	-4.191	-2.315	0.002	-2.059	7.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
10.00	1.0	-0.511	-2.323	-8.122	-2.323	0.000	-2.074	10.00	5.0	-0.098	-2.323	-4.191	-2.315	0.002	-2.059	10.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.01	2.0	-0.001	-2.323	-6.391	-2.323	0.000	-2.074	0.01	6.0	0.215	-2.323	-3.218	-2.271	0.012	-1.971	0.01	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.02	2.0	-0.007	-2.323	-6.534	-2.323	0.000	-2.074	0.02	6.0	0.215	-2.323	-3.218	-2.271	0.012	-1.971	0.02	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.03	2.0	-0.014	-2.323	-6.621	-2.323	0.000	-2.074	0.03	6.0	0.215	-2.323	-3.218	-2.271	0.012	-1.971	0.03	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.05	2.0	-0.023	-2.323	-6.720	-2.323	0.000	-2.074	0.05	6.0	0.215	-2.323	-3.218	-2.271	0.012	-1.971	0.05	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.10	2.0	-0.038	-2.323	-6.862	-2.323	0.000	-2.074	0.10	6.0	0.214	-2.323	-3.218	-2.271	0.012	-1.971	0.10	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.20	2.0	-0.095	-2.323	-6.989	-2.323	0.000	-2.074	0.20	6.0	0.213	-2.323	-3.218	-2.271	0.012	-1.971	0.20	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.30	2.0	-0.158	-2.323	-7.054	-2.323	0.000	-2.074	0.30	6.0	0.212	-2.323	-3.218	-2.271	0.012	-1.971	0.30	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.50	2.0	-0.299	-2.323	-7.125	-2.323	0.000	-2.074	0.50	6.0	0.202	-2.323	-3.218	-2.271	0.012	-1.971	0.50	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.70	2.0	-0.446	-2.323	-7.108	-2.323	0.000	-2.074	0.70	6.0	0.189	-2.323	-3.218	-2.271	0.012	-1.971	0.70	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
1.00	2.0	-0.506	-2.323	-7.108	-2.323	0.000	-2.074	1.00	6.0	0.161	-2.323	-3.218	-2.271	0.012	-1.971	1.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
2.00	2.0	-0.511	-2.323	-7.108	-2.323	0.000	-2.074	2.00	6.0	0.161	-2.323	-3.218	-2.271	0.012	-1.971	2.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
3.00	2.0	-0.511	-2.323	-7.108	-2.323	0.000	-2.074	3.00	6.0	0.161	-2.323	-3.218	-2.271	0.012	-1.971	3.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
5.00	2.0	-0.511	-2.323	-7.108	-2.323	0.000	-2.074	5.00	6.0	0.161	-2.323	-3.218	-2.271	0.012	-1.971	5.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
7.00	2.0	-0.511	-2.323	-7.108	-2.323	0.000	-2.074	7.00	6.0	0.161	-2.323	-3.218	-2.271	0.012	-1.971	7.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
10.00	2.0	-0.511	-2.323	-7.108	-2.323	0.000	-2.074	10.00	6.0	0.161	-2.323	-3.218	-2.271	0.012	-1.971	10.00	8.0	1.936	-2.323	-0.919	-0.902	0.220	-0.306
0.01	3.0	0.003	-2.323	-5.490	-2.323	0.000	-2.074	0.01	6.5	0.402	-2.323	-2.722	-2.177	0.037	-1.810	0.01	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.02	3.0	0.003	-2.323	-5.575	-2.323	0.000	-2.074	0.02	6.5	0.402	-2.323	-2.722	-2.177	0.037	-1.810	0.02	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.03	3.0	0.004	-2.323	-5.653	-2.323	0.000	-2.074	0.03	6.5	0.402	-2.323	-2.722	-2.177	0.037	-1.810	0.03	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.05	3.0	0.009	-2.323	-5.741	-2.323	0.000	-2.074	0.05	6.5	0.402	-2.323	-2.722	-2.177	0.037	-1.810	0.05	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.10	3.0	0.018	-2.323	-5.803	-2.323	0.000	-2.074	0.10	6.5	0.402	-2.323	-2.722	-2.177	0.037	-1.810	0.10	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.20	3.0	0.035	-2.323	-5.867	-2.323	0.000	-2.074	0.20	6.5	0.401	-2.323	-2.722	-2.177	0.037	-1.810	0.20	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.30	3.0	0.055	-2.323	-5.991	-2.323	0.000	-2.074	0.30	6.5	0.399	-2.323	-2.722	-2.177	0.037	-1.810	0.30	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.50	3.0	0.099	-2.323	-6.056	-2.323	0.000	-2.074	0.50	6.5	0.386	-2.323	-2.722	-2.177	0.037	-1.810	0.50	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.70	3.0	0.144	-2.323	-6.125	-2.323	0.000	-2.074	0.70	6.5	0.368	-2.323	-2.722	-2.177	0.037	-1.810	0.70	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
1.00	3.0	0.200	-2.323	-6.160	-2.323	0.000	-2.074	1.00	6.5	0.344	-2.323	-2.722	-2.177	0.037	-1.810	1.00	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
2.00	3.0	0.465	-2.323	-6.001	-2.323	0.000	-2.074	2.00	6.5	0.266	-2.323	-2.722	-2.177	0.037	-1.810	2.00	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
3.00	3.0	0.510	-2.323	-6.001	-2.323	0.000	-2.074	3.00	6.5	0.266	-2.323	-2.722	-2.177	0.037	-1.810	3.00	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
5.00	3.0	0.511	-2.323	-6.001	-2.323	0.000	-2.074	5.00	6.5	0.266	-2.323	-2.722	-2.177	0.037	-1.810	5.00	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
7.00	3.0	0.511	-2.323	-6.001	-2.323	0.000	-2.074	7.00	6.5	0.266	-2.323	-2.722	-2.177	0.037	-1.810	7.00	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
10.00	3.0	0.511	-2.323	-6.001	-2.323	0.000	-2.074	10.00	6.5	0.266	-2.323	-2.722	-2.177	0.037	-1.810	10.00	8.5	3.037	-2.323	-0.198	-0.195	0.268	0.453
0.01	4.0	0.012	-2.323	-4.820	-2.322	0.000	-2.071	0.01	7.0	0.711	-2.323	-2.177	-1.943	0.091	-1.477	0.01	9.0	4.671	-2.323	0.587	0.588	0.316	1.308
0.02	4.0	0.012	-2.323	-4.819	-2.322	0.000	-2.071	0.02	7.0	0.711	-2.323	-2.177	-1.943	0.091	-1.477	0.02	9.0	4.671	-2.323	0.587	0.588	0.316	1.308
0.03	4.0	0.011	-2.323	-4.836	-2.322	0.000	-2.071	0.03	7.0	0.711	-2.323	-2.177	-1.943	0.091	-1.477	0.03	9.0	4.671	-2.323	0.587	0.588	0.316	1.308
0.05	4.0	0.010	-2.323	-4.858	-2.322	0.000	-2.072	0.05	7.0	0.711	-2.323	-2.177	-1.943	0.091	-1.477	0.05	9.0	4.671	-2.323	0.587	0.588	0.316	1.308
0.10	4.0	0.009	-2.323	-4.879	-2.322	0.000	-2.072	0.10	7.0	0.711	-2.323	-2.177	-1.9										

TABLE 7
DECAY RATES FOR $^3\text{S} \rightarrow ^3\text{P}$

T_0	$\log \rho/\mu_e$	U_F	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_0	$\log \rho/\mu_e$	U_F	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_0	$\log \rho/\mu_e$	U_F	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$
0.01	1.0	-0.003	-0.559	-6.007	-0.559	0.000	-0.182	0.01	5.0	0.053	-0.559	-2.729	-0.556	0.001	-0.175	0.01	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.02	1.0	-0.007	-0.559	-6.162	-0.559	0.000	-0.182	0.02	5.0	0.053	-0.559	-2.729	-0.556	0.001	-0.175	0.02	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.03	1.0	-0.013	-0.559	-6.249	-0.559	0.000	-0.182	0.03	5.0	0.053	-0.559	-2.729	-0.556	0.001	-0.175	0.03	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.05	1.0	-0.024	-0.559	-6.357	-0.559	0.000	-0.182	0.05	5.0	0.053	-0.559	-2.729	-0.556	0.001	-0.175	0.05	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.07	1.0	-0.037	-0.559	-6.430	-0.559	0.000	-0.182	0.07	5.0	0.053	-0.559	-2.729	-0.556	0.001	-0.175	0.07	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.10	1.0	-0.058	-0.559	-6.502	-0.559	0.000	-0.182	0.10	5.0	0.052	-0.559	-2.736	-0.556	0.001	-0.175	0.10	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.20	1.0	-0.134	-0.559	-6.634	-0.559	0.000	-0.182	0.20	5.0	0.047	-0.559	-2.750	-0.556	0.001	-0.176	0.20	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.30	1.0	-0.218	-0.559	-6.704	-0.559	0.000	-0.182	0.30	5.0	0.038	-0.559	-2.772	-0.557	0.001	-0.176	0.30	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.50	1.0	-0.398	-0.559	-6.778	-0.559	0.000	-0.182	0.50	5.0	0.011	-0.559	-2.811	-0.557	0.001	-0.176	0.50	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.70	1.0	-0.503	-0.559	-6.833	-0.559	0.000	-0.182	0.70	5.0	0.026	-0.559	-2.839	-0.557	0.001	-0.177	0.70	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
1.00	1.0	-0.511	-0.559	-6.899	-0.559	0.000	-0.182	1.00	5.0	0.098	-0.559	-2.867	-0.557	0.000	-0.177	1.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
2.00	1.0	-0.511	-0.559	-6.902	-0.559	0.000	-0.179	2.00	5.0	0.098	-0.559	-2.867	-0.557	0.000	-0.177	2.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
3.00	1.0	-0.511	-0.559	-6.902	-0.559	0.000	-0.179	3.00	5.0	0.098	-0.559	-2.867	-0.557	0.000	-0.177	3.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
5.00	1.0	-0.511	-0.559	-6.902	-0.559	0.000	-0.179	5.00	5.0	0.098	-0.559	-2.867	-0.557	0.000	-0.177	5.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
7.00	1.0	-0.511	-0.559	-6.902	-0.559	0.000	-0.179	7.00	5.0	0.098	-0.559	-2.867	-0.557	0.000	-0.177	7.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
10.00	1.0	-0.511	-0.559	-6.902	-0.559	0.000	-0.179	10.00	5.0	0.098	-0.559	-2.867	-0.557	0.000	-0.177	10.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.01	2.0	-0.001	-0.559	-5.028	-0.559	0.000	-0.182	0.01	6.0	0.215	-0.559	-1.891	-0.540	0.003	-0.139	0.01	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.02	2.0	-0.003	-0.559	-5.172	-0.559	0.000	-0.182	0.02	6.0	0.215	-0.559	-1.891	-0.540	0.003	-0.139	0.02	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.03	2.0	-0.007	-0.559	-5.259	-0.559	0.000	-0.182	0.03	6.0	0.215	-0.559	-1.891	-0.540	0.003	-0.139	0.03	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.05	2.0	-0.014	-0.559	-5.360	-0.559	0.000	-0.182	0.05	6.0	0.215	-0.559	-1.891	-0.540	0.003	-0.139	0.05	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.07	2.0	-0.023	-0.559	-5.430	-0.559	0.000	-0.182	0.07	6.0	0.215	-0.559	-1.891	-0.540	0.003	-0.139	0.07	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.10	2.0	-0.038	-0.559	-5.502	-0.559	0.000	-0.182	0.10	6.0	0.214	-0.559	-1.891	-0.540	0.003	-0.139	0.10	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.20	2.0	-0.095	-0.559	-5.634	-0.559	0.000	-0.182	0.20	6.0	0.211	-0.559	-1.891	-0.540	0.003	-0.139	0.20	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.30	2.0	-0.158	-0.559	-5.703	-0.559	0.000	-0.182	0.30	6.0	0.202	-0.559	-1.891	-0.540	0.003	-0.139	0.30	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.50	2.0	-0.299	-0.559	-5.780	-0.559	0.000	-0.182	0.50	6.0	0.202	-0.559	-1.891	-0.540	0.003	-0.139	0.50	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.70	2.0	-0.446	-0.559	-5.770	-0.559	0.000	-0.182	0.70	6.0	0.189	-0.559	-1.891	-0.540	0.003	-0.139	0.70	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
1.00	2.0	-0.506	-0.559	-5.881	-0.559	0.000	-0.182	1.00	6.0	0.161	-0.559	-1.891	-0.540	0.003	-0.139	1.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
2.00	2.0	-0.511	-0.559	-5.899	-0.559	0.000	-0.179	2.00	6.0	0.001	-0.559	-1.891	-0.540	0.003	-0.139	2.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
3.00	2.0	-0.511	-0.559	-5.899	-0.559	0.000	-0.179	3.00	6.0	0.001	-0.559	-1.891	-0.540	0.003	-0.139	3.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
5.00	2.0	-0.511	-0.559	-5.899	-0.559	0.000	-0.179	5.00	6.0	0.001	-0.559	-1.891	-0.540	0.003	-0.139	5.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
7.00	2.0	-0.511	-0.559	-5.899	-0.559	0.000	-0.179	7.00	6.0	0.001	-0.559	-1.891	-0.540	0.003	-0.139	7.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
10.00	2.0	-0.511	-0.559	-5.899	-0.559	0.000	-0.179	10.00	6.0	0.001	-0.559	-1.891	-0.540	0.003	-0.139	10.00	8.0	1.936	-0.559	0.213	0.281	0.084	1.033
0.01	3.0	0.003	-0.559	-4.127	-0.559	0.000	-0.181	0.01	6.5	0.402	-0.559	-1.418	-0.503	0.006	-0.064	0.01	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.02	3.0	0.002	-0.559	-4.212	-0.559	0.000	-0.181	0.02	6.5	0.402	-0.559	-1.418	-0.503	0.006	-0.064	0.02	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.03	3.0	0.000	-0.559	-4.291	-0.559	0.000	-0.181	0.03	6.5	0.402	-0.559	-1.418	-0.503	0.006	-0.064	0.03	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.05	3.0	0.004	-0.559	-4.379	-0.559	0.000	-0.181	0.05	6.5	0.402	-0.559	-1.418	-0.503	0.006	-0.064	0.05	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.07	3.0	0.009	-0.559	-4.442	-0.559	0.000	-0.182	0.07	6.5	0.402	-0.559	-1.419	-0.503	0.006	-0.064	0.07	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.10	3.0	0.018	-0.559	-4.508	-0.559	0.000	-0.182	0.10	6.5	0.402	-0.559	-1.419	-0.503	0.006	-0.064	0.10	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.20	3.0	0.055	-0.559	-4.635	-0.559	0.000	-0.182	0.20	6.5	0.401	-0.559	-1.419	-0.503	0.006	-0.064	0.20	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.30	3.0	0.099	-0.559	-4.704	-0.559	0.000	-0.182	0.30	6.5	0.399	-0.559	-1.419	-0.503	0.006	-0.064	0.30	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.50	3.0	0.200	-0.559	-4.781	-0.559	0.000	-0.182	0.50	6.5	0.394	-0.559	-1.419	-0.503	0.006	-0.064	0.50	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.70	3.0	0.314	-0.559	-4.823	-0.559	0.000	-0.182	0.70	6.5	0.386	-0.559	-1.419	-0.503	0.006	-0.064	0.70	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
1.00	3.0	0.465	-0.559	-4.875	-0.559	0.000	-0.182	1.00	6.5	0.386	-0.559	-1.419	-0.503	0.006	-0.064	1.00	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
2.00	3.0	0.510	-0.559	-4.895	-0.559	0.000	-0.179	2.00	6.5	0.266	-0.559	-1.402	-0.503	0.007	-0.062	2.00	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
3.00	3.0	0.511	-0.559	-4.895	-0.559	0.000	-0.179	3.00	6.5	0.266	-0.559	-1.402	-0.503	0.007	-0.062	3.00	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
5.00	3.0	0.511	-0.559	-4.895	-0.559	0.000	-0.179	5.00	6.5	0.266	-0.559	-1.402	-0.503	0.007	-0.062	5.00	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
7.00	3.0	0.511	-0.559	-4.895	-0.559	0.000	-0.179	7.00	6.5	0.266	-0.559	-1.402	-0.503	0.007	-0.062	7.00	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
10.00	3.0	0.511	-0.559	-4.895	-0.559	0.000	-0.179	10.00	6.5	0.266	-0.559	-1.402	-0.503	0.007	-0.062	10.00	8.5	3.037	-0.559	0.835	0.852	0.133	1.677
0.01	4.0	0.012	-0.559	-3.459	-0.559	0.001	-0.180	0.01	7.0	0.711	-0.559	-0.912	-0.400	0.017	0.126	0.01	9.0	4.671	-0.559	1.500	1.503	0.186	2.397
0.02	4.0	0.012	-0.559	-3.459	-0.559	0.001	-0.180	0.02	7.0	0.711	-0.559	-0.912	-0.400	0.017	0.126	0.02	9.0	4.671	-0.559	1.500	1.503	0.186	2.397
0.03	4.0	0.012	-0.559	-3.459	-0.559	0.001	-0.180	0.03	7.0	0.711	-0.559	-0.912	-										

The decay $^{31}\text{S} \rightarrow ^{31}\text{P}$ (Table 7) is a self-mirror system, with the result that all transitions along the diagonal ($1 \rightarrow 1$, $2 \rightarrow 2$, $3 \rightarrow 3$, etc.) have fast Fermi components. With its Gamow-Teller component included, the ground state to ground state transition has $\log ft = 3.69$ and $Q_n = 4.88$ MeV of available electron-capture phase space, yielding a very fast rate even at low temperatures (Fig. 4). The first excited state in ^{31}S lies at an excitation energy of 1.25 MeV, so that the ground state transition dominates the low density rate at all but the highest temperatures considered. However, at high temperature and density a large number of relatively fast Gamow-Teller electron capture channels open up. For instance, the $1 \rightarrow 15$ decay has $\log ft = 4.29$; $1 \rightarrow 17$, $\log ft = 4.028$; and $1 \rightarrow 20$, $\log ft = 4.30$ (all determined from calculations of Wildenthal [1979]). The diagonal Fermi transitions dominate the positron emission rate with the result that our $^{31}\text{S} \rightarrow ^{31}\text{P}$ rate agrees very well with that given by the parametrized fit of Hansen (1966). However, at higher densities, where electron capture dominates the total weak destruction rate, our rates are somewhat faster than those of Hansen. At $T_9 = 2$ and $\rho/\mu_e = 10^8$, our rate is within a factor of 2 of the Hansen value, but at $T_9 = 10$ and $\rho/\mu_e = 10^6$ we are roughly 60 times faster, and at $T_9 = 10$ and $\rho/\mu_e = 10^9$ we are 4 times faster with an uncertainty of a factor of 2.5.

The decay $^{32}\text{S} \rightarrow ^{32}\text{P}$ (Table 8) is extremely slow at any but the highest temperatures and densities considered, but as a result of the large abundance of ^{32}S at the end of oxygen burning it becomes an important neutronizer. The slow nature of the rate is a reflection of the fact that ^{32}S is stable in the laboratory ($Q_n = -2.221$ MeV) and of the very small matrix element for the ground state to ground state transition ($\log ft = 7.42$). Furthermore, the first excited state of ^{32}S lies at 2.23 MeV, although the transition from this state to the ground state of ^{32}P ($2 \rightarrow 1$) has a somewhat faster than average matrix element ($\log ft = 4.74$ as determined by mirror symmetry from the $^{32}\text{Cl} \rightarrow ^{32}\text{S}$ positron decay). At lower temperatures the positron emission rate is very slow, since there is no contribution from the ground state, but a very steep temperature dependence develops as the first excited state begins to become populated around $T_9 = 3.0$. This results in positron emission rates 100 times faster than Hansen's at $T_9 = 3$. The electron capture rates at intermediate temperatures and higher densities are influenced by several relatively fast Gamow-Teller transitions upward from the ground state of ^{32}Si (Fig. 5): transition $1 \rightarrow 4$, $\log ft = 3.99$; $1 \rightarrow 9$, $\log ft = 4.20$; $1 \rightarrow 20$, $\log ft = 4.17$, all accessible for Fermi energies larger than 1 MeV; and finally, transition $1 \rightarrow 25$, $\log ft = 3.56$, accessible

FIG. 4

FIG. 5

FIG. 4.—Total decay rate for $^{31}\text{S} \rightarrow ^{31}\text{P}$; $\log \Sigma$ from Table 7. This self-mirror system is dominated by the large number of fast Fermi transitions (cf., § III), and shows no dramatic temperature or density dependence. Electron capture dominates above $\log \rho/\mu_e = 6.0$.

FIG. 5.—Total decay rate for $^{32}\text{S} \rightarrow ^{32}\text{P}$; $\log \Sigma$ from Table 8. Since ^{32}S is stable in the laboratory, the rate of this decay is very slow at low densities until the temperature is high enough for significant thermal population of parent excited states. However, at $\log \rho/\mu_e \gtrsim 8.0$, U_F is large enough to allow upward transitions from the ground state, and a dramatic change in the low-temperature rate is observed.

TABLE 8
DECAY RATES FOR $^{32}\text{S} \rightarrow ^{32}\text{P}$

T_g	$\log \rho/\mu_e$	U_T	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_g	$\log \rho/\mu_e$	U_T	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_g	$\log \rho/\mu_e$	U_T	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_g	$\log \rho/\mu_e$	U_T	$\log \beta^*$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$
0.01	1.0	-0.003	-99.999	-99.999	-99.999	0.000	-99.999	0.01	5.0	0.053	-99.999	-99.999	-99.999	0.000	-99.999	0.01	8.0	1.936	-99.999	-7.608	-7.608	0.000	-8.378	0.01	8.0	1.936	-99.999	-7.608	-7.608	0.000	-8.378
0.02	1.0	-0.007	-99.999	-99.999	-99.999	0.000	-99.999	0.02	5.0	0.053	-99.999	-99.999	-99.999	0.000	-99.999	0.02	8.0	1.936	-99.999	-7.611	-7.611	0.000	-8.378	0.02	8.0	1.936	-99.999	-7.611	-7.611	0.000	-8.378
0.03	1.0	-0.013	-99.999	-99.999	-99.999	0.000	-99.999	0.03	5.0	0.053	-99.999	-99.999	-99.999	0.000	-99.999	0.03	8.0	1.936	-99.999	-7.610	-7.610	0.000	-8.377	0.03	8.0	1.936	-99.999	-7.610	-7.610	0.000	-8.377
0.05	1.0	-0.024	-99.999	-99.999	-99.999	0.000	-99.999	0.05	5.0	0.053	-99.999	-99.999	-99.999	0.000	-99.999	0.05	8.0	1.936	-99.999	-7.607	-7.607	0.000	-8.372	0.05	8.0	1.936	-99.999	-7.607	-7.607	0.000	-8.372
0.07	1.0	-0.037	-99.999	-99.999	-99.999	0.000	-99.999	0.07	5.0	0.053	-99.999	-99.999	-99.999	0.000	-99.999	0.07	8.0	1.936	-99.999	-7.604	-7.604	0.000	-8.365	0.07	8.0	1.936	-99.999	-7.604	-7.604	0.000	-8.365
0.10	1.0	-0.058	-99.999	-99.999	-99.999	0.000	-99.999	0.10	5.0	0.052	-99.999	-99.999	-99.999	0.000	-99.999	0.10	8.0	1.935	-99.999	-7.586	-7.586	0.000	-8.329	0.10	8.0	1.935	-99.999	-7.586	-7.586	0.000	-8.329
0.20	1.0	-0.134	-99.999	-99.999	-99.999	0.000	-99.999	0.20	5.0	0.047	-99.999	-99.999	-99.999	0.000	-99.999	0.20	8.0	1.935	-99.999	-7.556	-7.556	0.000	-8.272	0.20	8.0	1.935	-99.999	-7.556	-7.556	0.000	-8.272
0.30	1.0	-0.218	-99.999	-99.999	-99.999	0.000	-99.999	0.30	5.0	0.038	-99.999	-99.999	-99.999	0.000	-99.999	0.30	8.0	1.933	-99.999	-7.471	-7.471	0.000	-8.117	0.30	8.0	1.933	-99.999	-7.471	-7.471	0.000	-8.117
0.50	1.0	-0.398	-99.999	-99.999	-99.999	0.000	-99.999	0.50	5.0	0.011	-99.999	-99.999	-99.999	0.000	-99.999	0.50	8.0	1.931	-99.999	-7.367	-7.367	0.000	-7.937	0.50	8.0	1.931	-99.999	-7.367	-7.367	0.000	-7.937
0.70	1.0	-0.503	-99.999	-99.999	-99.999	0.000	-99.999	0.70	5.0	-0.026	-99.999	-99.999	-99.999	0.000	-99.999	0.70	8.0	1.925	-99.999	-7.180	-7.180	0.009	-7.654	0.70	8.0	1.925	-99.999	-7.180	-7.180	0.009	-7.654
1.00	1.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	1.00	5.0	-0.098	-99.999	-99.999	-99.999	0.001	-99.999	1.00	8.0	1.844	-99.999	-6.312	-6.312	0.358	-4.231	1.00	8.0	1.844	-99.999	-6.312	-6.312	0.358	-4.231
2.00	1.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	2.00	5.0	-0.375	-99.999	-99.999	-99.999	0.001	-99.999	2.00	8.0	1.681	-99.999	-2.876	-2.876	2.062	-0.541	2.00	8.0	1.681	-99.999	-2.876	-2.062	0.541	-0.541
3.00	1.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	3.00	5.0	-0.476	-99.999	-99.999	-99.999	0.001	-99.999	3.00	8.0	1.441	-99.999	-1.269	-1.269	0.622	-0.713	3.00	8.0	1.441	-99.999	-1.269	-0.622	0.713	-0.713
5.00	1.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	5.00	5.0	-0.507	-99.999	-99.999	-99.999	0.001	-99.999	5.00	8.0	1.082	-99.999	-0.624	-0.624	0.705	-0.988	5.00	8.0	1.082	-99.999	-0.624	-0.705	0.988	-0.988
10.00	1.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	10.00	5.0	-0.509	-99.999	-99.999	-99.999	0.001	-99.999	10.00	8.0	0.982	-99.999	-0.624	-0.624	0.705	-0.988	10.00	8.0	0.982	-99.999	-0.624	-0.705	0.988	-0.988
0.01	2.0	-0.001	-99.999	-99.999	-99.999	0.000	-99.999	0.01	6.0	0.215	-99.999	-99.999	-99.999	0.000	-99.999	0.01	8.0	1.936	-99.999	-7.608	-7.608	0.000	-8.378	0.01	8.0	1.936	-99.999	-7.608	-7.608	0.000	-8.378
0.02	2.0	-0.003	-99.999	-99.999	-99.999	0.000	-99.999	0.02	6.0	0.215	-99.999	-99.999	-99.999	0.000	-99.999	0.02	8.0	1.936	-99.999	-7.611	-7.611	0.000	-8.378	0.02	8.0	1.936	-99.999	-7.611	-7.611	0.000	-8.378
0.03	2.0	-0.007	-99.999	-99.999	-99.999	0.000	-99.999	0.03	6.0	0.215	-99.999	-99.999	-99.999	0.000	-99.999	0.03	8.0	1.936	-99.999	-7.610	-7.610	0.000	-8.377	0.03	8.0	1.936	-99.999	-7.610	-7.610	0.000	-8.377
0.05	2.0	-0.014	-99.999	-99.999	-99.999	0.000	-99.999	0.05	6.0	0.215	-99.999	-99.999	-99.999	0.000	-99.999	0.05	8.0	1.936	-99.999	-7.607	-7.607	0.000	-8.372	0.05	8.0	1.936	-99.999	-7.607	-7.607	0.000	-8.372
0.07	2.0	-0.023	-99.999	-99.999	-99.999	0.000	-99.999	0.07	6.0	0.215	-99.999	-99.999	-99.999	0.000	-99.999	0.07	8.0	1.936	-99.999	-7.604	-7.604	0.000	-8.365	0.07	8.0	1.936	-99.999	-7.604	-7.604	0.000	-8.365
0.10	2.0	-0.038	-99.999	-99.999	-99.999	0.000	-99.999	0.10	6.0	0.214	-99.999	-99.999	-99.999	0.000	-99.999	0.10	8.0	1.935	-99.999	-7.586	-7.586	0.000	-8.329	0.10	8.0	1.935	-99.999	-7.586	-7.586	0.000	-8.329
0.20	2.0	-0.095	-99.999	-99.999	-99.999	0.000	-99.999	0.20	6.0	0.213	-99.999	-99.999	-99.999	0.000	-99.999	0.20	8.0	1.935	-99.999	-7.556	-7.556	0.000	-8.272	0.20	8.0	1.935	-99.999	-7.556	-7.556	0.000	-8.272
0.30	2.0	-0.158	-99.999	-99.999	-99.999	0.000	-99.999	0.30	6.0	0.211	-99.999	-99.999	-99.999	0.000	-99.999	0.30	8.0	1.933	-99.999	-7.471	-7.471	0.000	-8.117	0.30	8.0	1.933	-99.999	-7.471	-7.471	0.000	-8.117
0.50	2.0	-0.299	-99.999	-99.999	-99.999	0.000	-99.999	0.50	6.0	0.202	-99.999	-99.999	-99.999	0.000	-99.999	0.50	8.0	1.931	-99.999	-7.367	-7.367	0.000	-7.937	0.50	8.0	1.931	-99.999	-7.367	-7.367	0.000	-7.937
0.70	2.0	-0.446	-99.999	-99.999	-99.999	0.000	-99.999	0.70	6.0	0.189	-99.999	-99.999	-99.999	0.000	-99.999	0.70	8.0	1.925	-99.999	-7.180	-7.180	0.009	-7.654	0.70	8.0	1.925	-99.999	-7.180	-7.180	0.009	-7.654
1.00	2.0	-0.506	-99.999	-99.999	-99.999	0.001	-99.999	1.00	6.0	0.161	-99.999	-99.999	-99.999	0.001	-99.999	1.00	8.0	1.844	-99.999	-6.312	-6.312	0.358	-4.231	1.00	8.0	1.844	-99.999	-6.312	-6.312	0.358	-4.231
2.00	2.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	2.00	6.0	0.101	-99.999	-99.999	-99.999	0.001	-99.999	2.00	8.0	1.681	-99.999	-2.876	-2.876	2.062	-0.541	2.00	8.0	1.681	-99.999	-2.876	-2.062	0.541	-0.541
3.00	2.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	3.00	6.0	-0.212	-99.999	-99.999	-99.999	0.001	-99.999	3.00	8.0	1.441	-99.999	-1.269	-1.269	0.622	-0.713	3.00	8.0	1.441	-99.999	-1.269	-0.622	0.713	-0.713
5.00	2.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	5.00	6.0	-0.420	-99.999	-99.999	-99.999	0.001	-99.999	5.00	8.0	1.082	-99.999	-0.624	-0.624	0.705	-0.988	5.00	8.0	1.082	-99.999	-0.624	-0.705	0.988	-0.988
10.00	2.0	-0.511	-99.999	-99.999	-99.999	0.001	-99.999	10.00	6.0	-0.469	-99.999	-99.999	-99.999	0.001	-99.999	10.00	8.0	0.982	-99.999	-0.624	-0.624	0.705	-0.988	10.00	8.0	0.982	-99.999	-0.624	-0.705	0.988	-0.988
0.01	3.0	0.003	-99.999	-99.999	-99.999	0.000	-99.999	0.01	6.5	0.402	-99.999	-99.999	-99.999	0.000	-99.999	0.01	8.5	3.037	-99.999	-4.109	-4.109	0.369	-4.729	0.01	8.5	3.037	-99.999	-4.109	-0.369	4.729	-4.729
0.02	3.0	0.002	-99.999	-99.999	-99.999	0.000	-99.999	0.02	6.5	0.402	-99.999	-99.999	-99.999	0.000	-99.999	0.02	8.5	3.038	-99.999	-4.102	-4.102	0.368	-4.723	0.02	8.5	3.038	-99.999	-4.102	-0.368	4.723	-4.723
0.03	3.0	0.000	-99.999	-99.999	-99.999	0.000	-99.999	0.03	6.5	0.402	-99.999	-99.999	-99.999	0.000	-99.999	0.03	8.5	3.038	-99.999	-4.104	-4.104	0.368	-4.726	0.03	8.5	3.038	-99.999	-4.104	-0.368	4.726	-4.726
0.05	3.0	-0.004	-99.999	-99.999	-99.999	0.000	-99.999	0.05	6.5	0.402	-99.999	-99.999	-99.999	0.000	-99.999	0.05	8.5	3.038	-99.999	-4.103	-4.103	0.369	-4.724	0.05	8.5	3.038	-99.999	-4.103	-0.369	4.724	-4.724
0.07	3.0	-0.009	-99.999	-99.999	-99.999	0.000	-99.999	0.07	6.5	0.402	-99.999	-99.999	-99.999	0.000	-99.999	0.07	8.5	3.038	-99.999	-4.101	-4.101	0.369	-4.721	0.07	8.5	3.038	-99.999	-4.101	-0.369	4.721	-4.721
0.10	3.0	-0.018	-99.999	-99.999	-99.999	0.000	-99.999	0.10	6.5	0.402	-99.999	-99.999	-99.999	0.000	-99.999	0.10	8.5	3.038	-99.999	-4.098	-4.098	0.372	-4.685	0.10	8.5	3.038	-99.999	-4.098	-0.372	4.685	-4.685
0.20	3.0	-0.055	-99.999	-99.999	-99.999	0.000	-99.999	0.20	6.5	0.399	-99.999	-99.999	-99.999	0.000	-99.999	0.20	8.5	3.037	-99.999	-4.079	-4.079	0.373	-4.637	0.20	8.5	3.037	-99.999	-4.079	-0.373	4.637	-4.637
0.30	3.0	-0.090	-99.999	-99.999	-99.																										

only for Fermi energies near 5 MeV ($\rho/\mu_e \approx 10^9$). This structure contributes to our rates being 10 times faster than Hansen's at $T_9=2$, $\rho/\mu_e=10^6$, 10 times slower at $\rho/\mu_e=10^8$ and the same temperature, and then, as the $1 \rightarrow 25$ transition becomes accessible, 200 times faster at $\rho/\mu_e=10^9$. At $T_9=10$ and densities between $\rho/\mu_e=10^6$ and 10^9 , our rates are between a factor of 15 and 60 times faster than Hansen's, with matrix element induced uncertainties between factors of 2.5 and 5.

The decay $^{33}\text{S} \rightarrow ^{33}\text{P}$ (Table 9) is again characterized by a relatively slow rate and a large abundance of laboratory stable ^{33}S in the presupernova neutronization regime, but here the nuclear Q_n -value is only -0.76 MeV. The ground state to ground state decay is measured to have the relatively slow matrix element $\log ft=5.33$. However, here the first excited state of parent ^{33}S is at only 0.841 MeV and is accompanied by the relatively fast $2 \rightarrow 1$ transition of $\log ft=4.44$ (determined from the mirror positron decay $^{33}\text{Ar} \rightarrow ^{33}\text{Cl}$, and determined from calculations by Wildenthal to be $\log ft=4.32$). Again, the positron decay rate is very slow until the first excited state begins to become thermally populated at around $T_9 \approx 0.5$, at which point it rises steeply. This rate is much slower than Hansen's until about $T_9 \approx 0.5-1$, at which point it rises to become 100 times faster between $T_9 \approx 2$ and 6, and then begins to converge on the Hansen rate at $T_9=10$ as the fast $2 \rightarrow 1$ decay becomes relatively less important than the Fermi and Gamow-Teller transition from the analogue of the daughter ground state at 5.47 MeV ($30 \rightarrow 1$, $\log ft=3.34$.) The electron capture rates are influenced by many average Gamow-Teller channels, with only a few fast channels available, and these at only very high daughter excitation energy ($1 \rightarrow 9$, $\log ft=4.17$, 4.19 MeV excitation; $1 \rightarrow 1$, $\log ft=4.48$, 4.86 MeV excitation). Consequently, our rates agree well with those of Hansen at $T_9=2$, and are faster by a factor of 5 at $T_9=10$, where many unmeasured and uncalculated Gamow-Teller channels contribute; the factor of 5 reflects the difference between Hansen's average $\log ft=5.7$ and our average $\log ft=5.0$, and at $T_9=10.0$, $\rho/\mu_e=10^9$, for instance, the uncertainty is about a factor of 7, reflecting the order of magnitude uncertainty assigned to the average Gamow-Teller value. The total rate for the $^{33}\text{S} \rightarrow ^{33}\text{P}$ decay is shown in Figure 6.

Finally, the $^{35}\text{Cl} \rightarrow ^{35}\text{S}$ decay (Table 10) again reflects the slow decay of a relatively abundant laboratory-stable species. Here the ground state to ground state matrix element is measured to be $\log ft=5.01$ and the nuclear Q -value is only -0.68 MeV. The first excited state of parent ^{35}Cl is at 1.219 MeV, and its population begins to affect the rate at intermediate temperatures (Fig. 7). The transition from the first excited state to the ground state of ^{35}S ($2 \rightarrow 1$) is determined from calculations by Wildenthal to be a very slow $\log ft=6.43$, but the $2 \rightarrow 2$ transition is calculated to

FIG. 6

FIG. 7

FIG. 6.—Total decay rate for $^{33}\text{S} \rightarrow ^{33}\text{P}$; $\log \Sigma$ from Table 9. As in Fig. 5, but in stable ^{33}S lower temperatures are required for significant population of low-lying parent levels, and upward transitions from the ground state begin to be important for $\log \rho/\mu_e \geq 6.5$.

FIG. 7.—Total decay rate for $^{35}\text{Cl} \rightarrow ^{35}\text{S}$; $\log \Sigma$ from Table 10. As in Figs. 5 and 6, except that still lower temperatures and densities are sufficient to achieve a significant weak interaction rate for the decay of laboratory-stable ^{35}Cl .

TABLE 9
DECAY RATES FOR $^{33}\text{S} \rightarrow ^{33}\text{P}$

T_9	$\log \rho/\mu_e$	U_T	$\log \beta^+$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_9	$\log \rho/\mu_e$	U_T	$\log \beta^+$	$\log \varepsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$
0.01	1.0	-0.003	-99.999	-99.999	-99.999	0.000	-99.999	0.01	1.0	0.053	-99.999	-99.999	-99.999	0.000	-99.999
0.02	1.0	-0.007	-99.999	-76.751	-76.751	0.000	-79.035	0.02	1.0	0.053	-99.999	-99.999	-99.999	0.000	-79.035
0.03	1.0	-0.013	-99.999	-55.569	-55.569	0.000	-57.676	0.03	1.0	0.053	-99.999	-99.999	-99.999	0.000	-57.676
0.05	1.0	-0.024	-99.999	-38.500	-38.500	0.000	-40.383	0.05	1.0	0.053	-99.999	-99.999	-99.999	0.000	-40.383
0.07	1.0	-0.037	-99.999	-31.109	-31.109	0.000	-32.843	0.07	1.0	0.053	-99.999	-99.999	-99.999	0.000	-32.843
0.10	1.0	-0.058	-99.999	-25.491	-25.491	0.000	-27.067	0.10	1.0	0.053	-99.999	-99.999	-99.999	0.000	-27.067
0.20	1.0	-0.134	-63.543	-18.744	-18.744	0.000	-20.009	0.20	1.0	0.047	-63.543	-14.177	-14.177	0.000	-15.441
0.30	1.0	-0.218	-44.118	-16.369	-16.369	0.000	-17.449	0.30	1.0	0.038	-44.118	-12.065	-12.065	0.000	-13.144
0.50	1.0	-0.398	-28.578	-14.324	-14.324	0.000	-15.165	0.50	1.0	0.011	-28.578	-10.195	-10.195	0.000	-11.316
0.70	1.0	-0.501	-21.919	-12.716	-12.716	0.000	-13.393	0.70	1.0	0.026	-21.919	-9.282	-9.282	0.000	-9.960
1.00	1.0	-0.511	-16.924	-10.568	-10.568	0.000	-11.485	1.00	1.0	-0.388	-16.924	-8.084	-8.084	0.000	-8.967
2.00	1.0	-0.511	-11.097	-7.386	-7.386	0.003	-7.087	2.00	1.0	-0.383	-11.093	-7.084	-7.084	0.002	-7.164
3.00	1.0	-0.511	-8.985	-5.913	-5.913	0.040	-5.821	3.00	1.0	-0.476	-8.983	-5.954	-5.954	0.039	-5.792
5.00	1.0	-0.511	-6.067	-4.263	-4.263	0.290	-3.941	5.00	1.0	-0.502	-6.066	-5.257	-5.257	0.932	-2.895
7.00	1.0	-0.511	-4.569	-3.213	-3.194	0.556	-2.730	7.00	1.0	-0.507	-4.569	-3.192	-3.192	0.557	-2.737
10.00	1.0	-0.511	-3.477	-2.116	-2.098	0.795	-1.465	10.00	1.0	-0.509	-3.477	-2.115	-2.087	0.795	-1.464
0.01	2.0	-0.001	-99.999	-99.999	-99.999	0.000	-99.999	0.01	2.0	0.215	-99.999	-30.383	-30.383	0.000	-32.969
0.02	2.0	-0.003	-99.999	-75.734	-75.734	0.000	-78.018	0.02	2.0	0.215	-99.999	-20.813	-20.813	0.000	-23.097
0.03	2.0	-0.007	-99.999	-54.565	-54.565	0.000	-56.672	0.03	2.0	0.215	-99.999	-17.393	-17.393	0.000	-19.500
0.05	2.0	-0.014	-99.999	-37.496	-37.496	0.000	-39.376	0.05	2.0	0.215	-99.999	-14.410	-14.410	0.000	-16.293
0.07	2.0	-0.023	-99.999	-30.105	-30.105	0.000	-31.839	0.07	2.0	0.215	-99.999	-12.975	-12.975	0.000	-14.709
0.10	2.0	-0.038	-99.999	-24.489	-24.489	0.000	-26.066	0.10	2.0	0.215	-99.999	-11.783	-11.783	0.000	-13.359
0.20	2.0	-0.095	-63.543	-17.744	-17.744	0.000	-19.008	0.20	2.0	0.214	-63.543	-9.998	-9.998	0.000	-11.259
0.30	2.0	-0.158	-44.118	-15.368	-15.368	0.000	-16.448	0.30	2.0	0.211	-44.118	-8.182	-8.182	0.000	-10.256
0.50	2.0	-0.299	-28.578	-13.326	-13.326	0.000	-14.167	0.50	2.0	0.202	-28.578	-8.287	-8.287	0.000	-9.122
0.70	2.0	-0.446	-16.924	-12.303	-12.303	0.000	-12.980	0.70	2.0	0.189	-21.919	-7.747	-7.747	0.000	-8.420
1.00	2.0	-0.506	-11.924	-10.547	-10.547	0.000	-11.034	1.00	2.0	0.161	-16.924	-7.205	-7.205	0.000	-7.695
2.00	2.0	-0.511	-11.097	-7.386	-7.386	0.003	-7.486	2.00	2.0	-0.212	-11.094	-6.119	-6.119	0.003	-6.216
3.00	2.0	-0.511	-8.985	-5.913	-5.913	0.040	-5.826	3.00	2.0	-0.212	-8.977	-5.420	-5.420	0.039	-5.325
5.00	2.0	-0.511	-6.067	-4.263	-4.263	0.290	-3.941	5.00	2.0	-0.469	-6.065	-4.173	-4.167	0.288	-3.851
7.00	2.0	-0.511	-4.569	-3.213	-3.194	0.556	-2.730	7.00	2.0	-0.469	-4.568	-3.183	-3.166	0.557	-2.701
10.00	2.0	-0.511	-3.477	-2.116	-2.098	0.795	-1.465	10.00	2.0	-0.481	-3.476	-2.107	-2.088	0.795	-1.456
0.01	3.0	0.003	-99.999	-99.999	-99.999	0.000	-99.999	0.01	3.0	0.402	-99.999	-6.942	-6.942	0.000	-7.874
0.02	3.0	0.002	-99.999	-74.510	-74.510	0.000	-76.794	0.02	3.0	0.402	-99.999	-6.942	-6.942	0.000	-7.874
0.03	3.0	0.000	-99.999	-53.458	-53.458	0.000	-55.564	0.03	3.0	0.402	-99.999	-6.941	-6.941	0.000	-7.871
0.05	3.0	0.004	-99.999	-36.450	-36.450	0.000	-38.333	0.05	3.0	0.402	-99.999	-6.938	-6.938	0.000	-7.866
0.07	3.0	0.009	-99.999	-29.078	-29.078	0.000	-30.812	0.07	3.0	0.402	-99.999	-6.930	-6.930	0.000	-7.848
0.10	3.0	0.018	-99.999	-23.472	-23.472	0.000	-25.048	0.10	3.0	0.402	-99.999	-6.930	-6.930	0.000	-7.848
0.20	3.0	0.055	-63.543	-16.738	-16.738	0.000	-18.003	0.20	3.0	0.401	-63.543	-6.889	-6.889	0.000	-7.770
0.30	3.0	0.099	-44.118	-14.366	-14.366	0.000	-15.445	0.30	3.0	0.394	-44.118	-6.877	-6.877	0.000	-7.655
0.50	3.0	0.200	-28.578	-12.325	-12.325	0.000	-13.166	0.50	3.0	0.386	-28.578	-6.868	-6.868	0.000	-7.380
0.70	3.0	0.314	-21.919	-11.354	-11.354	0.000	-12.032	0.70	3.0	0.368	-21.919	-6.498	-6.498	0.000	-7.100
1.00	3.0	0.465	-16.924	-10.341	-10.341	0.000	-10.828	1.00	3.0	0.368	-16.924	-6.498	-6.498	0.000	-7.100
2.00	3.0	0.510	-11.097	-7.383	-7.383	0.003	-7.483	2.00	3.0	0.266	-11.093	-5.499	-5.499	0.003	-6.706
3.00	3.0	0.511	-8.985	-5.912	-5.912	0.039	-5.820	3.00	3.0	0.266	-11.093	-5.499	-5.499	0.039	-5.588
5.00	3.0	0.511	-6.067	-4.263	-4.263	0.290	-3.941	5.00	3.0	0.101	-8.975	-4.917	-4.917	0.039	-4.815
7.00	3.0	0.511	-4.569	-3.213	-3.194	0.556	-2.730	7.00	3.0	-0.234	-6.062	-3.990	-3.986	0.285	-3.669
10.00	3.0	0.511	-3.477	-2.116	-2.098	0.795	-1.465	10.00	3.0	-0.377	-4.566	-3.119	-3.104	0.557	-2.638
0.01	4.0	0.012	-99.999	-99.999	-99.999	0.000	-99.999	0.01	4.0	0.449	-3.475	-2.086	-2.068	0.796	-1.435
0.02	4.0	0.012	-99.999	-71.935	-71.935	0.000	-74.219	0.02	4.0	0.711	-99.999	-5.274	-5.274	0.000	-5.716
0.03	4.0	0.011	-99.999	-51.560	-51.560	0.000	-53.667	0.03	4.0	0.711	-99.999	-5.274	-5.274	0.000	-5.716
0.05	4.0	0.010	-99.999	-35.013	-35.013	0.000	-37.896	0.05	4.0	0.711	-99.999	-5.274	-5.274	0.000	-5.715
0.07	4.0	0.009	-99.999	-27.801	-27.801	0.000	-29.536	0.07	4.0	0.711	-99.999	-5.274	-5.274	0.000	-5.714
0.10	4.0	0.005	-99.999	-22.316	-22.316	0.000	-23.892	0.10	4.0	0.711	-99.999	-5.274	-5.274	0.000	-5.711
0.20	4.0	0.013	-63.543	-15.683	-15.683	0.000	-16.948	0.20	4.0	0.711	-63.543	-5.266	-5.266	0.000	-5.701
0.30	4.0	0.037	-44.118	-13.337	-13.337	0.000	-14.147	0.30	4.0	0.710	-44.118	-5.257	-5.257	0.000	-5.683
0.50	4.0	0.100	-28.578	-11.313	-11.313	0.000	-12.154	0.50	4.0	0.710	-28.578	-5.250	-5.250	0.000	-5.632
0.70	4.0	0.174	-21.924	-10.348	-10.348	0.000	-11.026	0.70	4.0	0.701	-21.919	-5.193	-5.193	0.000	-5.563
1.00	4.0	0.302	-16.924	-9.519	-9.519	0.000	-10.006	1.00	4.0	0.689	-16.924	-5.119	-5.119	0.000	-5.429
2.00	4.0	0.497	-11.097	-7.351	-7.351	0.040	-7.452	2.00	4.0	0.622	-11.093	-4.742	-4.742	0.003	-4.800
3.00	4.0	0.507	-8.984	-5.907	-5.907	0.291	-5.815	3.00	4.0	0.622	-8.974	-4.300	-4.300	0.042	-4.178
5.00	4.0	0.511	-6.067	-4.262	-4.256	0.556	-3.940	5.00	4.0	0.510	-6.062	-3.981	-3.981	0.558	-3.257
7.00	4.0	0.511	-4.569	-3.213	-3.194	0.556	-2.730	7.00	4.0	0.187	-4.561	-3.929	-3.919	0.558	-2.701
10.00	4.0	0.511	-3.477	-2.116	-2.098	0.795	-1.465	10.00	4.0	-0.315	-3.470	-2.020	-2.005	0.798	-1.370

TABLE 10
DECAY RATES FOR $^{35}\text{Cl} \rightarrow ^{35}\text{S}$

T_0	$\log \rho/\mu_0$	U_T	$\log \beta^+$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_0	$\log \rho/\mu_0$	U_T	$\log \beta^+$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$	T_0	$\log \rho/\mu_0$	U_T	$\log \beta^+$	$\log \epsilon^-$	$\log \Sigma$	$\log \Delta$	$\log \nu$
0.01	1.0	-0.003	-99.999	-98.605	-98.605	0.000	-99.999	0.01	5.0	0.053	-99.999	-70.429	-70.429	0.000	-73.015	0.01	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
0.02	1.0	-0.007	-99.999	-55.976	-55.976	0.000	-58.259	0.02	5.0	0.053	-99.999	-70.429	-70.429	0.000	-43.013	0.02	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
0.03	1.0	-0.013	-99.999	-41.648	-41.648	0.000	-43.759	0.03	5.0	0.053	-99.999	-70.429	-70.429	0.000	-32.705	0.03	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
0.05	1.0	-0.027	-99.999	-25.018	-25.018	0.000	-26.742	0.05	5.0	0.053	-99.999	-70.429	-70.429	0.000	-24.129	0.05	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
0.07	1.0	-0.037	-99.999	-20.081	-20.081	0.000	-21.942	0.07	5.0	0.053	-99.999	-70.429	-70.429	0.000	-20.279	0.07	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
0.10	1.0	-0.056	-74.322	-15.161	-15.161	0.000	-16.723	0.10	5.0	0.053	-99.999	-70.429	-70.429	0.000	-17.216	0.10	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
0.20	1.0	-0.134	-43.596	-16.464	-16.464	0.000	-17.723	0.20	5.0	0.053	-99.999	-70.429	-70.429	0.000	-17.216	0.20	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
0.30	1.0	-0.218	-33.346	-13.769	-13.769	0.000	-15.868	0.30	5.0	0.053	-99.999	-70.429	-70.429	0.000	-17.216	0.30	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
0.50	1.0	-0.386	-23.234	-13.263	-13.263	0.000	-15.868	0.50	5.0	0.053	-99.999	-70.429	-70.429	0.000	-17.216	0.50	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
1.00	1.0	-0.503	-16.161	-11.863	-11.863	0.000	-12.358	1.00	5.0	0.053	-99.999	-70.429	-70.429	0.000	-17.216	1.00	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
2.00	1.0	-0.511	-14.352	-9.918	-9.918	0.000	-9.721	2.00	5.0	0.053	-99.999	-70.429	-70.429	0.000	-17.216	2.00	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
3.00	1.0	-0.511	-14.352	-9.918	-9.918	0.000	-9.721	3.00	5.0	0.053	-99.999	-70.429	-70.429	0.000	-17.216	3.00	7.5	1.197	-99.999	-3.644	-3.644	0.000	-3.727
5.00	1.0	-0.511	-7.812	-5.737	-5.737	0.036	-5.886	5.00	5.0	0.053	-99.999	-70.429	-70.429	0.036	-5.886	5.00	7.5	1.197	-99.999	-3.644	-3.644	0.036	-5.886
7.00	1.0	-0.511	-5.557	-4.236	-4.236	0.172	-4.665	7.00	5.0	0.053	-99.999	-70.429	-70.429	0.172	-4.665	7.00	7.5	1.197	-99.999	-3.644	-3.644	0.172	-4.665
10.00	1.0	-0.511	-4.207	-3.214	-3.214	0.679	-2.665	10.00	5.0	0.053	-99.999	-70.429	-70.429	0.679	-2.665	10.00	7.5	1.197	-99.999	-3.644	-3.644	0.679	-2.665
0.01	2.0	-0.001	-99.999	-97.548	-97.548	0.000	-99.999	0.01	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.01	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
0.02	2.0	-0.003	-99.999	-54.958	-54.958	0.000	-57.242	0.02	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.02	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
0.03	2.0	-0.007	-99.999	-40.643	-40.643	0.000	-43.749	0.03	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.03	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
0.05	2.0	-0.014	-99.999	-29.057	-29.057	0.000	-30.738	0.05	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.05	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
0.07	2.0	-0.023	-99.999	-24.014	-24.014	0.000	-25.733	0.07	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.07	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
0.10	2.0	-0.038	-74.322	-20.159	-20.159	0.000	-21.733	0.10	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.10	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
0.20	2.0	-0.095	-43.596	-15.484	-15.484	0.000	-16.723	0.20	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.20	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
0.30	2.0	-0.158	-33.346	-13.768	-13.768	0.000	-14.843	0.30	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.30	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
0.50	2.0	-0.298	-23.234	-12.265	-12.265	0.000	-13.100	0.50	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	0.50	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
1.00	2.0	-0.446	-18.161	-11.870	-11.870	0.000	-12.145	1.00	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	1.00	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
2.00	2.0	-0.506	-14.352	-9.886	-9.886	0.000	-10.145	2.00	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	2.00	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
3.00	2.0	-0.511	-14.352	-9.886	-9.886	0.000	-10.145	3.00	6.0	0.215	-99.999	-8.352	-8.352	0.000	-9.797	3.00	8.0	1.936	-99.999	-2.647	-2.647	0.001	-2.481
5.00	2.0	-0.511	-7.812	-5.737	-5.737	0.036	-5.703	5.00	6.0	0.215	-99.999	-8.352	-8.352	0.036	-5.703	5.00	8.0	1.936	-99.999	-2.647	-2.647	0.036	-5.703
7.00	2.0	-0.511	-5.557	-4.236	-4.236	0.172	-4.665	7.00	6.0	0.215	-99.999	-8.352	-8.352	0.172	-4.665	7.00	8.0	1.936	-99.999	-2.647	-2.647	0.172	-4.665
10.00	2.0	-0.511	-4.207	-3.214	-3.214	0.679	-2.665	10.00	6.0	0.215	-99.999	-8.352	-8.352	0.679	-2.665	10.00	8.0	1.936	-99.999	-2.647	-2.647	0.679	-2.665
0.01	3.0	-0.003	-99.999	-95.926	-95.926	0.000	-98.512	0.01	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.01	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
0.02	3.0	-0.007	-99.999	-53.726	-53.726	0.000	-56.012	0.02	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.02	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
0.03	3.0	-0.013	-99.999	-39.539	-39.539	0.000	-41.842	0.03	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.03	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
0.05	3.0	-0.027	-99.999	-28.019	-28.019	0.000	-29.892	0.05	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.05	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
0.07	3.0	-0.037	-99.999	-22.987	-22.987	0.000	-24.716	0.07	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.07	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
0.10	3.0	-0.056	-74.322	-19.142	-19.142	0.000	-20.716	0.10	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.10	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
0.20	3.0	-0.134	-43.596	-14.456	-14.456	0.000	-15.719	0.20	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.20	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
0.30	3.0	-0.218	-33.346	-12.763	-12.763	0.000	-13.840	0.30	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.30	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
0.50	3.0	-0.386	-23.234	-11.264	-11.264	0.000	-12.099	0.50	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	0.50	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
1.00	3.0	-0.503	-16.161	-10.522	-10.522	0.000	-11.196	1.00	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	1.00	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
2.00	3.0	-0.511	-14.352	-9.680	-9.680	0.000	-10.192	2.00	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	2.00	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
3.00	3.0	-0.511	-14.352	-9.680	-9.680	0.000	-10.192	3.00	6.5	0.402	-99.999	-6.074	-6.074	0.000	-6.815	3.00	8.5	3.036	-99.999	-1.677	-1.677	0.046	-1.326
5.00	3.0	-0.511	-7.812	-5.737	-5.737	0.036	-5.702	5.00	6.5	0.402	-99.999	-6.074	-6.074	0.036	-5.702	5.00	8.5	3.036	-99.999	-1.677	-1.677	0.036	-5.702
7.00	3.0	-0.511	-5.557	-4.236	-4.236	0.172	-4.665	7.00	6.5	0.402	-99.999	-6.074	-6.074	0.172	-4.665	7.00	8.5	3.036	-99.999	-1.677	-1.677	0.172	-4.665
10.00	3.0	-0.511	-4.207	-3.214	-3.214	0.679	-2.665	10.00	6.5	0.402	-99.999	-6.074	-6.074	0.679	-2.665	10.00	8.5	3.036	-99.999	-1.677	-1.677	0.679	-2.665
0.01	4.0	-0.012	-99.999	-91.290	-91.290	0.000	-93.876	0.01	7.0	0.711	-99.999	-4.745	-4.745	0.000	-5.113	0.01	9.0	4.671	-99.999	-0.644	-0.644	0.263	-0.153
0.02	4.0	-0.012	-99.999	-51.160	-51.160	0.000	-53.443	0.02	7.0	0.711	-99.999	-4.745	-4.745	0.000	-5.113	0.02	9.0	4.671	-99.999	-0.644	-0.644	0.263	-0.153
0.03	4.0	-0.012	-99.999	-37.639	-37.639	0.000	-39.745	0.03	7.0	0.711	-99.999	-4.745	-4.745	0.000	-5.113	0.03	9.0	4.671	-99.999	-0.644	-0.644	0.263	-0.153
0.05	4.0	-0.010	-99.999	-26.574	-26.574	0.000	-28.443	0.05	7.0	0.711	-99.999	-4.745	-4.745	0.000	-5.113	0.05	9.0	4.671	-99.999	-0.644	-0.644	0.263	-0.153
0.07	4.0	-0.009	-99.999	-21.711	-21.711	0.000	-23.																

have $\log ft = 4.46$. The analog of the ^{35}S ground state lies at the very high excitation energy of 5.65 MeV and the Fermi transition from this state (with an average Gamow-Teller component of $\log ft = 5.0$) has $\log ft = 3.30$. The result is that the rates again exhibit a steep temperature dependence which tracks the Hansen parametrized fits well for both positron emission and electron capture until relatively high temperatures. At a temperature of $T_9 = 10$ and $\rho/\mu_e = 10^6$, our rates are a factor of 6 faster than Hansen's, dropping to a factor of 3 faster at $\rho/\mu_e = 10^8$. At the most extreme temperature and density point considered ($T_9 = 10$ and $\rho/\mu_e = 10^9$), our rates are almost six orders of magnitude faster than Hansen's, with a rate uncertainty well over an order of magnitude, indicating the importance of unknown high lying Gamow-Teller strength at these conditions.

In conclusion, the nuclear weak interaction rates of the decays $^{26}\text{Al} \rightarrow ^{26}\text{Mg}$, $^{30}\text{P} \rightarrow ^{30}\text{Si}$, $^{31}\text{S} \rightarrow ^{31}\text{P}$, $^{32}\text{S} \rightarrow ^{32}\text{P}$, $^{33}\text{S} \rightarrow ^{33}\text{P}$, and $^{35}\text{Cl} \rightarrow ^{35}\text{S}$ become sensitive functions of temperature and density in the stellar environment. These rates are for the most part determined by experimentally measured matrix elements and matrix elements derived from isospin symmetry, but where unmeasured Gamow-Teller transitions are important the rates can be computed with some confidence utilizing the detailed shell model calculations and nuclear systematics considered here. Our rates roughly agree with those of Hansen (1966) over a large range of conditions, but potentially important differences in the rates exist at temperatures and densities relevant for the production and destruction of ^{26}Al and for the neutronization-neutrino loss problem of presupernova evolution. Uncertainties in the rates have been estimated as a function of temperature and density, and the improved rates are presented in a form which should make them convenient to incorporate into detailed nucleosynthesis calculations involving these key species.

We are grateful to professor B. H. Wildenthal for providing us with nuclear matrix elements derived from the detailed nuclear shell model calculations into which he and his colleagues have put so much effort over the years, to H. S. Wilson and R. W. Kavanagh for making available to us their unpublished $\log ft$ measurements, to S. E. Koonin for helpful discussions on many aspects of the problem, and to S. E. Woosley and T. Weaver for many interesting discussions on the effects of weak-interaction processes in the late stages of presupernova stellar evolution, and especially for providing a list of the weak decays of great importance to the supernova problem.

REFERENCES

- Arnett, W. D., and Wefel, J. P. 1978, *Ap. J. (Letters)*, **224**, L139.
 Arnould, M., Hillebrandt, W., and Thielemann, F. K. 1978, Max-Planck-Institut, preprint.
 Bahcall, J. N. 1961, *Phys. Rev.*, **124**, 495.
 ———. 1962a, *Phys. Rev.*, **126**, 1143.
 ———. 1962b, *Phys. Rev.*, **128**, 1297.
 ———. 1962c, *Ap. J.*, **136**, 445.
 ———. 1964, *Ap. J.*, **139**, 318.
 Bethe, H. A., Brown, G. E., Applegate, J., and Lattimer, J. M. 1979, *Nucl. Phys. A*.
 Brown, B. A., Chung, W., and Wildenthal, B. H. 1978, *Phys. Rev. Letters*, **40**, 1631.
 Cameron, A. G. W. 1959, *Ap. J.*, **130**, 453.
 Chung, W. 1976, Ph.D. thesis, Michigan State University.
 Egawa, Y., Koichi, Y., and Yamada, M. 1975, *Progr. Theor. Phys.*, **54**, 1339.
 Endt, P. M., and van der Leun, C. 1973, *Nucl. Phys.*, **214A**, 1.
 ———. 1978, *Nucl. Phys.*, **310A**, 1.
 Fowler, W. A., and Hoyle, F. 1964, *Ap. J. Suppl.*, **9**, 201.
 Gove, N. B., and Martin, M. J. 1971, *Nuclear Data Tables*, **10**, 205.
 Gray, C. M., and Compston, W. 1974, *Nature*, **251**, 495.
 Hansen, C. J. 1966, Ph.D. thesis, Yale University.
 Iben, I. 1978, *Ap. J.*, **219**, 213.
 Lee, T., and Papanastassiou, D. A. 1974, *Geophys. Res. Letters*, **1**, 225.
 Lee, T., Papanastassiou, D. A., and Wasserburg, G. J. 1976, *Geophys. Res. Letters*, **3**, 109.
 Mazurek, T. J., Truran, J. W., and Cameron, A. G. W. 1974, *Ap. Space Sci.*, **27**, 261.
 Peterson, V. L., and Bahcall, J. N. 1963, *Ap. J.*, **138**, 437.
 Takahashi, K. 1971, *Progr. Theor. Phys.*, **45**, 1466.
 Takahashi, K., and Yamada, J. 1969, *Progr. Theor. Phys.*, **41**, 1470.
 Takahashi, K., Yamada, M., and Kondoh, T. 1973, *Atomic Data and Nuclear Data Tables*, **12**, 101.
 Takahashi, K., El Eid, M. F., and Hillebrandt, W. 1978, *Astr. Ap.*, **67**, 185.
 Truran, J. W., and Cameron, A. G. W. 1978, *Ap. J.*, **219**, 226.
 Tubbs, D. L., and Koonin, S. E. 1979, *Ap. J. (Letters)*, **232**, L59.
 Ward, R. A., and Fowler, W. A. 1979, preprint.
 Weaver, T. A., Woosley, S. E., and Zimmerman, G. B. 1978, *Ap. J.*, **225**, 1021.
 Weaver, T. A., and Woosley, S. E. 1979, private communication.
 Wildenthal, B. H. 1977, *Elementary Modes of Excitation in Nuclei*, vol. **69**, (Corso: Soc. Italiana di Fisica-Bologna-Italy).
 ———. 1979, private communication.
 Wilson, H. S., and Kavanagh, R. W. 1978, private communication.
 Woosley, S. E., Arnett, W. D., and Clayton, D. D. 1972, *Ap. J.*, **175**, 731.

GEORGE M. FULLER and WILLIAM A. FOWLER: W. K. Kellogg Radiation Laboratory 106-38, California Institute of Technology, Pasadena, CA 91125

MICHAEL J. NEWMAN: T-DOT, Mail Stop 288, Los Alamos Scientific Laboratory, University of California, P.O. Box 1663, Los Alamos, NM 87545