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INTEGRATED FLUX DISTRIBUTIONS IN NEUTRON CAPTURE IN STARS*

In stellar nucleosynthesis, neutron capture at a rate which is slow compared to that of the intervening beta-decays has been designated as the s-process. Since the early quantitative studies of the s-process by Clayton, Fowler, Hull, and Zimmerman (1961), considerable effort has been made to determine the possible distributions of neutron exposures which might have led to the observed relative solar-system abundances of those nuclei produced in the s-process. In particular, Seeger, Fowler, and Clayton (1965) presented families of curves corresponding to exposure distributions of the forms $\rho(\tau) \sim e^{-\tau/\tau_0}$ and $\rho(\tau) \sim \tau^{-n}$, both for $0 \leq \tau \leq \infty$. Here, τ is a parameter which measures the time integrated neutron flux to which seed nuclei are exposed. Nuclei of the iron group elements are taken to be the seed nuclei. Clayton (1964) called attention to the difference in slope between the best experimental values and the calculated values in Figure 1 of Seeger, Fowler, and Clayton (1965) in the mass region $60 < A < 90$, and suggested that a $\rho(\tau)$ which has a minimum near $\tau = 0.3$ [rather than a monotonic decreasing $\rho(\tau)$] may be required.

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However, a significant improvement over the curves given in Seeger, Fowler, and Clayton (1965) has been obtained by least-squares adjustment to a three-parameter family: $\rho(\tau) = (\tau/\tau_0)^{-\nu}$, $0 \leq \tau \leq \tau(\max)$, where $\tau(\max)$ is an upper limit to the integrated flux. The adjusted distribution is

$$\rho(\tau) = \left(\frac{\tau}{2.67}\right)^{-3.18} , \quad 0 \leq \tau \leq 1.35 , \tag{1}$$

with τ in units of 10^{27} neutrons/cm^2. The comparison of the resulting σN_s curve with experiment is shown in Figure 1. (These calculations are for cross sections corresponding to $kT = 30$ keV and for $N(\mathrm{Si}) = 10^6$; for other temperatures and abundance standards, scale factors may be applied.) The improvement in the sum of the squares of the errors of the logarithms over the best

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exponential or power law $\rho(\tau)$ without cut-off is a factor of 2.

From Table II or Figure 16 of Clayton, Fowler, Hull, and Zimmerman (1961), it is seen that the cut-off $\tau(\max) = 1.35$ corresponds to $n_c(\max) = 125$ neutrons per seed nucleus as the average number of neutrons captured by those of the seed nuclei exposed to the maximum integrated flux. This value is reasonable on the basis of possible sources of neutrons and iron-group abundances in stars. It implies that light nuclei such as C^{13}, Ne^{21}, and Ne^{22} on which exoergic (α,n) reactions occur are at most one-hundred times as abundant as the iron-group nuclei. It is also interesting to note that this value of n_c is adequate to produce the observed Pb abundance without appreciable cycling among the Pb isotopes having occurred.

Also from the calculations of Clayton, Fowler, Hull, and Zimmerman (1961), for $kT \sim 30$ keV we can approximate $n_c \sim 80\ \tau^{1.5}$ over the range $0 \leq \tau \leq 1.35$, in which case the exposure distribution can be expressed as

$$g(n_c) = \rho(\tau)\frac{d\tau}{dn_c} \sim \left(\frac{n_c}{40}\right)^{-2.5} \quad , \qquad 0 \leq n_c \leq 125 . \qquad (2)$$

Equations (1) and (2) can be used as empirical laws giving a good representation of the solar-system s-process abundances. In particular, form (2) will be independent of the neutron temperature. Integrals over $\rho(\tau)$ or $g(n_c)$ indicate that 10^{-3} of the iron-group nuclei ($N = 6.4 \times 10^5$ for $Si = 10^6$) have been exposed over the range $0.15 \leq \tau \leq 1.35$ or $5 \leq n_c \leq 125$. The divergence in integrations extended to $\tau = n_c = 0$ is not physically significant.

PHILIP A. SEEGER

WILLIAM A. FOWLER

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Los Alamos Scientific Laboratory,
University of California

and

California Institute of Technology

REFERENCES

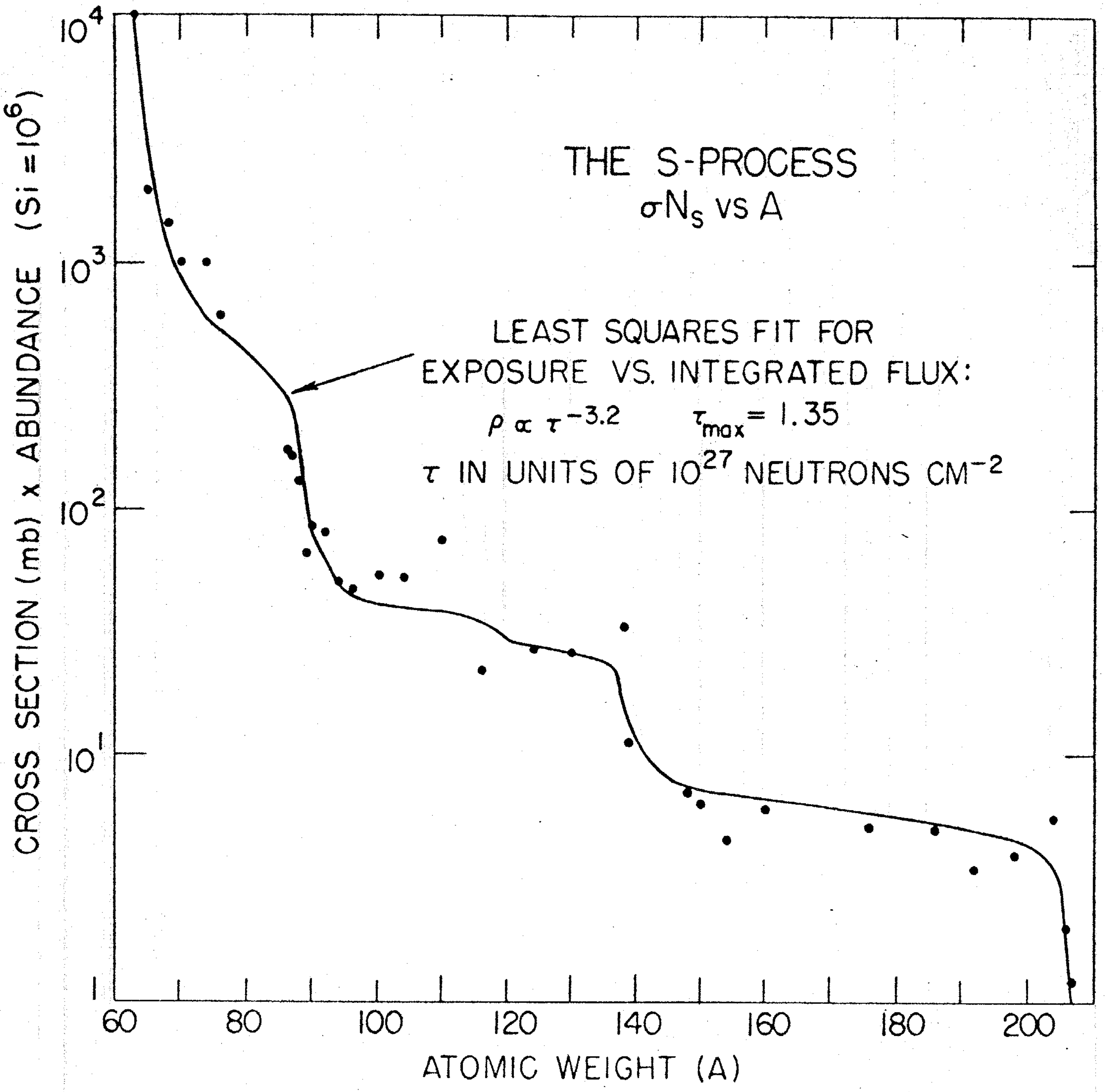
Clayton, D. D. 1965, J. Geophys. Res., 69, 5081.

Clayton, D. D., Fowler, W. A., Hull, T. C., and Zimmerman, B. A. 1961, Ann. Phys., 12, 331.

Seeger, P. A., Fowler, W. A., and Clayton, D. D. 1965, Ap. J. Suppl., 97, 121.

FIGURE CAPTION

Fig. 1. Neutron Capture Cross Section (σ) at 30 keV times the solar system abundance attributable to the s-process (N_s). See Seeger, Fowler, and Clayton (1965) for details of experimental points. The solid curve is that calculated for exposures to integrated neutron flux given by equation (1).


THE S-PROCESS
σN_s vs A
LEAST SQUARES FIT FOR
EXPOSURE VS. INTEGRATED FLUX:
$\rho \propto \tau^{-3.2}$ $\tau_{max} = 1.35$
τ IN UNITS OF 10^{27} NEUTRONS CM^{-2}
CROSS SECTION (mb) x ABUNDANCE (Si $=10^6$)
10^4
10^3
10^2
10^1
1
60
80
100
120
140
160
180
200
ATOMIC WEIGHT (A)