# THE ELEMENTAL COMPOSITION OF 4-30 MeV/nuc COSMIC RAY NUCLEI WITH 1 ≤ Z ≤ 8

R. A. Mewaldt, E. C. Stone, S. B. Vidor and R. E. Vogt

California Institute of Technology
Pasadena, California 91125

Recent observations of low energy cosmic rays have shown enhanced fluxes of nitrogen and oxygen relative to other elements in the ~ 8-30 MeV/nuc energy interval. We have extended the measurements of lithium through oxygen down to ~ 4 MeV/nuc with the Caltech Electron/Isotope Spectrometers on IMP-7 and -8 during solar quiet periods from October 1972 to September 1974. We find no evidence for significant enhancements of Li, Be, B, or C, which are found to have energy spectra consistent with those expected from the adiabatic deceleration of higher energy galactic cosmic rays. The He, N, and O fluxes are greatly enhanced when compared to the other elements, with relative abundances of O/He ~ 0.25, O/B ~ 100, and O/C ~ 30 at ~ 5 to 12.5 MeV/nuc.

1. Introduction. Recent observations of low energy cosmic rays have revealed anomalous enhancements of helium, nitrogen, and oxygen relative to other nuclei such as hydrogen, boron, and carbon (Garcia-Munoz et al., 1973; Hovestadt et al., 1973; McDonald et al., 1974). For example, at 10 MeV/nuc the oxygen flux is enhanced by a factor of ~ 30 above that expected from an extrapolation of the spectrum of 40 to 100 MeV/nuc galactic cosmic rays. A similar enhancement is observed in the low energy nitrogen, but not in the boron, carbon, magnesium, or silicon fluxes with energies down to ~ 8 MeV/nuc. In order to investigate possible enhancements of these elements at still lower energies, we have measured the fluxes of elements with 1 ≤ Z ≤ 8 in the energy region of ~ 4-30 MeV/nucleon. The implications of these measurements with respect to the origin of these nuclei are discussed.

2. Instrument. The elemental energy spectra were measured with the Caltech Electron-Isotope Spectrometers (EIS) aboard the IMP-7 and IMP-8 satellites. The IMP-8 EIS is schematically illustrated in *Figure 1*. (See Mewaldt et al., 1975 for an illustration of the IMP-7 EIS.) The telescope consists of a stack of fully depleted silicon surface-barrier detectors surrounded by a plastic scintillator anticoincidence cup. The detectors are nominally 1 mm thick, except D2, which is nominally 50 μm thick. For element identification

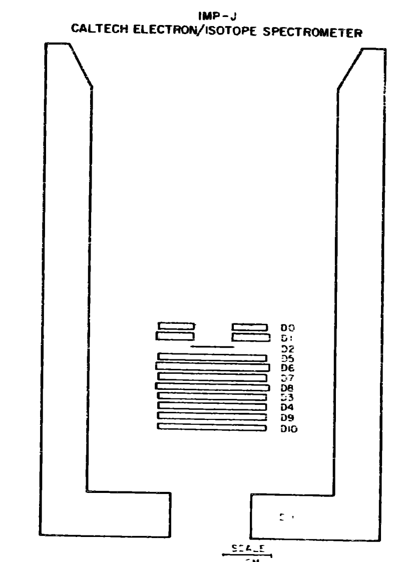


*Fig. 1. Schematic illustration of the IMP-8 EIS telescope.*

a $\Delta E$ vs. E technique was used in one of two analysis modes. The narrow geometry analysis mode, which was used to calculate the spectra of elements with $Z \geq 3$, requires that none of the annular detectors (D0, D1, D3, D4 on the IMP-7 EIS; D0 and D1 on the IMP-8 EIS) be triggered. For events that trigger only the detectors D2 and D5, the individual pulse heights are obtained from each detector. For narrow geometry events that penetrate past D5 into D6 or further, the energy loss in D5 and the residual energy loss in the remaining detectors is obtained, along with the identities of the detectors which were triggered. The hydrogen and helium spectra above 13 MeV/nuc were obtained from the wide geometry analysis mode, in which D0 serves as the $\Delta E$ detector.

3. Observations. To obtain the solar quiet time spectra of the low energy cosmic rays, restrictions had to be placed on solar particle activity. For hydrogen and helium, the fluxes were calculated for a period of 35 (nonconsecutive) days during which the fluxes were near the lowest level for a two year period. At energies above ~ 4 MeV/nuc, the fluxes of elements with $3 \leq Z \leq 8$ are much less sensitive to small variations in solar activity (see Mewaldt et al., 1975), and therefore a total of 482 days were used to compute the $3 \leq Z \leq 8$ fluxes. Combining data from the IMP-7 and IMP-8 instruments, the resulting quiet time spectra are shown in *Figure 2* for the period from October 1972 - September 1974. Also shown are higher energy spectra of other experimenters. The turnups below ~ 5-8 MeV/nuc in the hydrogen and helium spectra are likely of solar origin. In the energy region ~ 10-40 MeV/nuc, the hydrogen and carbon fluxes are consistent with a $j \propto T$ relation, where j is the differential flux and T is the kinetic energy per nucleon. This simple linear relationship can be explained with conventional modulation theory by the adiabatic deceleration of galactic cosmic rays in the heliosphere (Goldstein et al., 1970). By contrast, the nitrogen and oxygen fluxes increase rapidly at energies below 30 MeV/nuc. The helium flux is relatively energy independent from 5-40 MeV/nuc. In this respect the helium flux is also anomalous since, at low energies, it is significantly above a $j \propto T$ extrapolation. At energies of overlap, the present observations are consistent with those of other experimenters (Garcia-Munoz et al., 1973; Hovestadt et al., 1973; Chan and Price, 1974; McDonald et al., 1974).

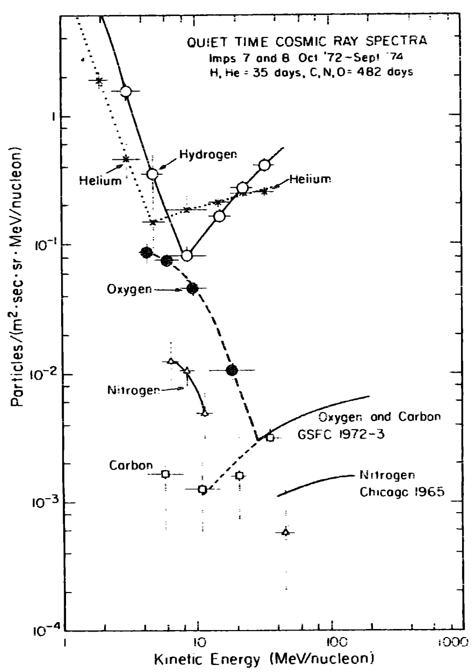


*Fig. 2. Quiet time spectra. The smooth curves are meant to aid the eye and are not best fits to the data.*

In *Figure 3* the observed fluxes of elements with $3 \leq Z \leq 7$ are compared with two spectral types: 1) a flux proportional

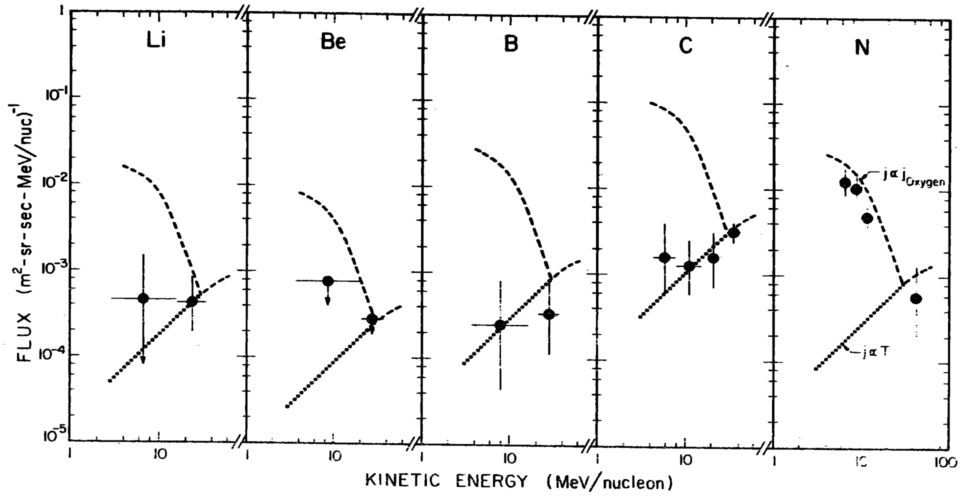


*Fig. 3. Quiet time fluxes from 10/72 to 9/74. The curves are normalized at 30 MeV/nuc to the high energy cosmic ray abundances relative to oxygen. The shape of the $j_{oxygen}$ curve is from Figure 2.*

to the observed low energy oxygen flux and 2) a flux proportional to kinetic energy. The high energy abundances relative to oxygen are used to normalize the smooth curves at 30 MeV/nuc. We find that even at the lowest energies only the nitrogen flux is seen to exhibit an enhancement similar to oxygen. There is no similar enhancement of the $3 \leq Z \leq 6$ fluxes, which are consistent with $j \propto T$, although, due to limited statistics, fluxes that are independent of energy (flat spectra) cannot be ruled out.

4. Discussion. The present results, which extend earlier observations to lower energies, confirm the anomalous characteristics of the elemental abundances over the entire 4 to 30 MeV/nuc energy interval. The elemental composition at ~ 5 to 12.5 MeV/nuc relative to oxygen is summarized in *Figure 4*. The comparison of the composition of the low energy fluxes with that of higher energy galactic cosmic rays (Webber et al., 1972; Shapiro et al., 1973; Webber and Lezniak, 1974) shown in *Figure 4* illustrate the marked enhancement of nitrogen and oxygen. For example, at ~ 5 to 12.5 MeV/nuc the relative abundances are O/He ~ 0.25,

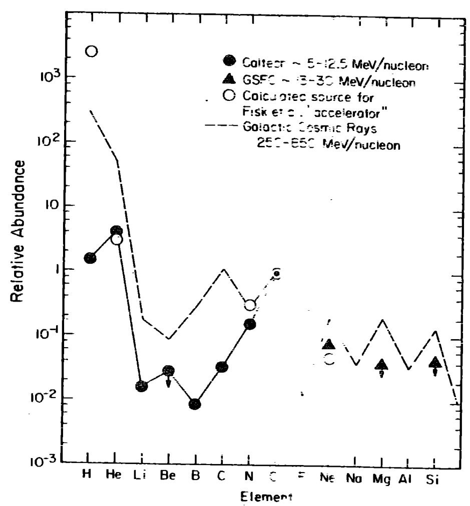


*Fig. 4. Comparison of observed abundances with the abundances of higher energy cosmic rays and the "source" abundances associated with the model of Fisk et al. (1974).*

O/B ~ 100, and O/C ~ 30. These ratios are strongly energy dependent as can be determined from the spectra in *Figures 2* and *3*.

Consideration of the spectral differences of the various elemental fluxes leads to the identification of at least two distinct particle populations at low energies. The low energy fluxes of H, Li, Be, B, and C are consistent with $j \propto T$, as would result from adiabatic deceleration of higher energy galactic cosmic rays by the solar wind. The low energy He, N, and O fluxes, however, may be part of an additional low energy component which has an elemental composition markedly different from that of higher energy cosmic rays.

Fisk et al. (1974) have suggested that the low energy anomalous component of the cosmic rays originates from neutral interstellar particles that penetrate the heliosphere, are singly ionized, and are then accelerated to several MeV/nuc. According to this model, only those elements which are abundant in the neutral state in the interstellar medium (e.g., H, He, N, O, Ne) and penetrate the heliosphere can be accelerated. *Figure 4* compares the relative abundances of the low energy cosmic rays with the estimated source abundances for the proposed accelerator. To estimate these source abundances, the interstellar abundances, adopted from the solar system abundances (Cameron, 1973), were multiplied by the areas corresponding to the approximate radial distances from the sun at which the different elements are ionized (Axford, 1972). Only those elements which exist in the interstellar medium primarily in the neutral state (Rogerson et al., 1973) were considered, and no correction was made for the partial ionization of some of these elements.

Notice that there is qualitative agreement between the observed helium, nitrogen, oxygen, and neon fluxes and the relative source composition. However, the observed hydrogen flux is ~ $10^3$ times lower than the source hydrogen. In order to make a more quantitative comparison of the observed fluxes with the fluxes expected from the model of Fisk et al. (1974), the relative acceleration efficiencies and solar modulation effects for the different elements must be considered.

It is also possible that the low energy cosmic rays originate from a galactic source. In this case, the nucleosynthesis process or the acceleration mechanism must be able to enhance nitrogen and oxygen relative to carbon (see, e.g., Hoyle and Clayton, 1974). The particles from such a source cannot, however, propagate through much interstellar material if they have energies typical of the particles observed at 1 AU. For example, 10 MeV/nuc oxygen has a range of ~ 0.015 g/cm$^2$ in the interstellar medium. The absence of significantly enhanced secondary nuclei such as Li, Be, and B (and in this case C) is consistent with such a short interstellar pathlength.

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## 6. References.

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