COSMIC RAY CHARGE AND ENERGY SPECTRUM MEASUREMENTS USING A NEW LARGE AREA CERENKOV x dE/dx TELESCOPE

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1. Introduction. A detailed study of the energy spectra and relative abundance of $Z = 4 - 14$ nuclei contains valuable information relating to the acceleration and propagation of cosmic rays in the galaxy. Nuclei such as C, O, Ne, Mg and Si are mainly source nuclei and possible differences in their spectra at both high and low energies are sensitive measures of cosmic ray source spectra and propagation effects. Nuclei such as Be, B and N are mainly produced by interstellar fragmentation and their relative abundances provide a direct measure of the interstellar path length as a function of energy.

The most precise and complete study of the relative abundances of these nuclei is from the French-Danish experiment on board HEAO-3. This experiment, which flew in 1979-80, measured nuclei with $Z = 4 - 30$, over the energy range ~ 1 - 15 GeV/nuc. Engelmann et al., 1983. Absolute intensities were not reported in this experiment and a possible energy dependent bias in the flash tube efficiency for lower Z nuclei could affect the B/C ratio.

We have flown in September, 1981, a new $0.5 m^2$ ster cosmic ray telescope to study the charge composition and energy spectrum of cosmic ray nuclei between 0.3 and 4 GeV/nuc. A high resolution Cerenkov counter, and three dE/dx measuring scintillation counters, including two position scintillators were contained in the telescope used for the charge and energy spectrum measurements. The analysis procedures did not require any large charge or energy dependent corrections, and absolute fluxes could be obtained to an accuracy ~ 5%. The spectral measurements made in 1981, at a time of extreme solar modulation, could be compared with measurements with a similar telescope made by our group in 1977, at a time of minimum modulation and can be used to derive absolute intensity values for the HEAO measurements made in 1979-80. Using both data sets precise energy spectra and abundance ratios can be derived over the entire energy range from 0.3 to greater than 15 GeV/nuc.

1. Instrumentation & Data Analysis. The telescope used in these studies is shown in Figure 1a. The registration of an event is accomplished by a coincidence between PS1 & PS2, defining a geometry factor of $0.46 \pm 0.01\ m^2$-ster. The total live time is 95,800 sec. including a measured data analysis and transmission efficiency of 0.93 ± 0.01, giving an $A \Omega t$ of $44{,}050 m^2$-ster-sec. To obtain absolute intensities at the instrument the observed events need only be divided by $A \Omega t$. All events are initially accepted for analysis, however consistency criteria are placed on the relative outputs of the three separate dE/dx counters to remove nuclear interactions etc. in the telescope. Matrices of C1 vs. the avg. of the three S counters, subject to these criteria, exhibit clearly defined charge lines as shown in Figure 1b and these matrices are directly used to obtain the various charge abundances. The major source of charge dependent uncertainity in the absolute abundances, and in the ratios we derive, comes from the

above consistency criterion correction which varies from 1.217 for B to 1.086 for S. Finally to correct the intensities to the top of the atmosphere one must consider the 7.1 g/cm^2 of material in the telescope and gondola and the 3.6 g/cm^2 of residual atmosphere. This correction amounts to a factor of 1.596 for Oxygen nuclei with an uncertainty of ± 5%. This correction ranges from 1.332 for B to 1.887 for S, and the relative uncertainty in the ratios of this correction is less than 3%.

For each charge we have constructed a histogram of events in the C dimension from the matrices as illustrated in Figure 1b. Histograms for Be through O nuclei are shown in Figure 2. This distribution of events vs. C/C_{max} may be transformed into an energy spectrum using deconvolution procedures similar to those discussed by Lezniak, 1975. In this approach there are several key steps. First the $\beta = 1$ point must be determined for each charge to an accureacy of < 1%. Second the resolution function for $\beta = 1$ particles for each charge must be determined and finally an appropriate Cerenkov relation modified for residual scintillation and knock-on electrons must be used to transform from Cerenkov output to energy. Space does not permit these procedures to be discussed in detail, however there are many tests that can be used to verify their accuracy. When one is comparing ratios of adjacent charges, for example, it is useful to form ratios of events vs. C/C_{max} such as shown in Figure 3 for B/C. The instrumental effects that could change this ratio are easily identified (e.g. the increase above $C/C_{max} = 1.0$ is caused by the different resolution for B and C nuclei) and most of the change that is observed is believed to be due to a real change in the B/C ratio with energy.

3. Data and Discussion. In Figure 4 we show the B/C ratio derived from this measurement and that observed by Engelmann et al., 1983. In general, there is quite good agreement, but below ~ 3 GeV/nuc our values of this ratio are lower by ~ 5-10%. Some of this difference may be due to the larger solar modulation at the time of our measurement but we believe there is also a significant difference in the two results in this energy range. Since this ratio is used by most workers to derive the amount of interstellar material traversed as well as its energy dependence, this result will lead to modifications of these conclusions. In Figure 5 we show that N/O ratio derived from this measurement and that reported by Engelmann et al., 1983. Here the agreement is excellent. We are not aware of any charge or energy dependent effects in our analysis that could produce differences of > 1-2% in our relative B/C and N/O ratios and this N/O measurement therefore seems to support the suggestion of a systematic effect in the B/C ratio.

In Figure 6 we show the Oxygen spectrum derived from this work as well as the spectrum previously reported from a 1977 balloon flight with a similar type of instrument (Webber et al., 1979). The earlier reported spectra have been modified slightly as a result of using improved data analysis procedures compatible with the analysis of the 1981 balloon flight data. It is seen that the intensity in 1981 is a factor ~ 2 lower at 1 GeV/nuc than in 1977. This is compatible with the Mt. Washington neutron monitor rates on the dates of the two measurements, which were 2365 in 1977 and 2118 in 1981 for a decrease of 10.5%. At the time of the HEAO measurement in 1979-80 we obtain an average neutron monitor rate = 2190, and the HEAO spectrum, normalized accordingly, is shown in Figure 6. This spectrum is ~ 30% lower than that utilized by Engelmann et al., 1984 where they normalized to intensity measurements made at 10 GeV/nuc. However with this new normalization, which essentially fits data between ~ 0.7 and 4.0 GeV/nuc, the HEAO intensities above ~ 10 GeV/nuc are now ~ 30% lower than the average reported intensities from several observers. This suggests possible systematic differences between the high and low energy spectra ~ 30%, which could distort the spectral shape of the derived interstellar energy spectrum in this energy range.

In Table I we present integral intensities of various nuclei > 400 MeV/nuc and 4 GeV/nuc obtained in 1981, that may be used to compare with earlier values reported in the literature.

4. Acknowledgements. This work was supported by a NASA Grant #NGR-30-002-052.

5. References.

Engelmann, J. J., et al., Proc. 18th ICRC, 2, 17, 1983.
Engelmann, J. J. et al., Astron. Astrophys., in press, 1985.
Lezniak, J. A., Nuc. Inst. & Methods, 126, 129, 1975.
Webber, W. R., & Yushak, S. M. Proc. 16th ICRC, 1, 383, 1979.

6. Figure Captions.

Figure 1a, b. Outline drawing of telescope and matrix of C, N, O events.
Figure 2. Cerenkov distributions for Be-O nuclei. Estimated resolution for $\beta = 1$ particles is shown.
Figure 3. Ratio of B/C events as a function of C/C_{max}.
Figure 4. Observed B/C ratio at top of atmosphere in 1981. HEAO data from Engelmann et al., 1983 also shown.
Figure 5. Observed N/O ratio + HEAO data.
Figure 6. Observed Oxygen spectra in 1977 and 1981 ($xE^{2.5}$) along with normalized HEAO spectrum.

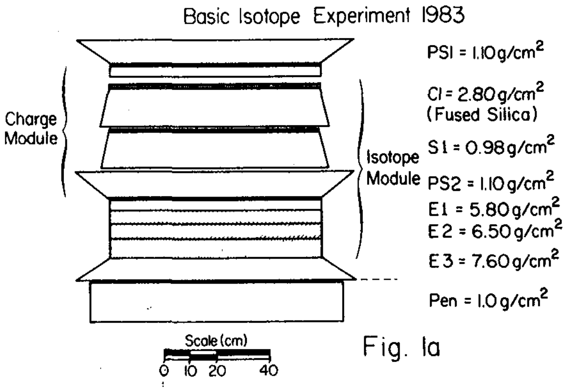


Fig. 1a

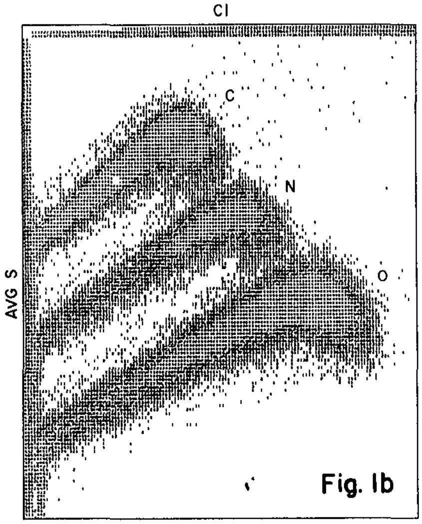


Fig. 1b

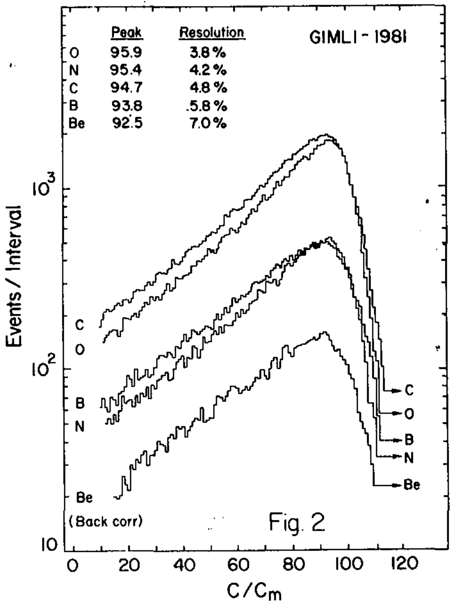
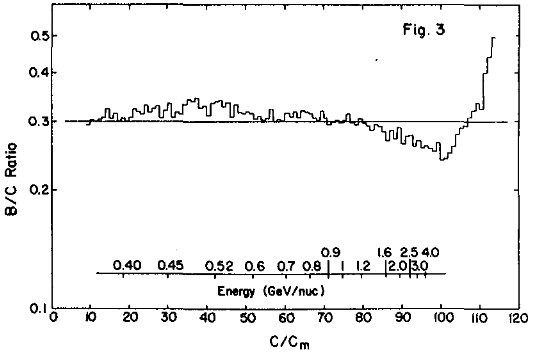


Fig. 2



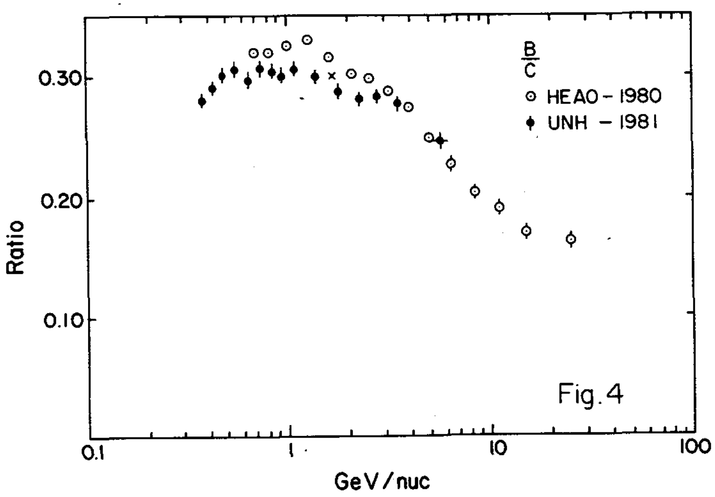


Fig. 4

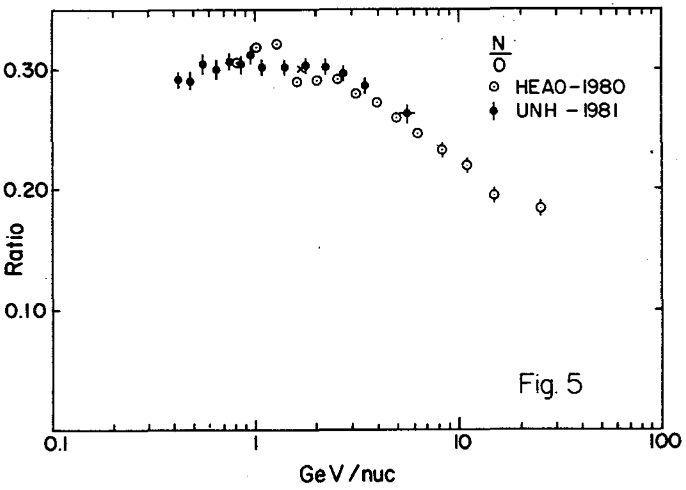


Fig. 5

Table I

Absolute Intensities
At Top of Atmosphere
Aug. 27-28, 1981
Balloon Flight

	> 400 MeV/nuc	> 4.0 GeV/nuc
Be	9258c[a] → 0.314p[b]	2,328c → 0.0764p
B	28,824c → 0.937p	7,140c → 0.215p
C	100,860c → 3.28p	28,020c → 0.876p
N	26,526c → 0.898p	6,960c → 0.224p
O	89,184c → 3.03p	26,105c → 0.845p
Ne	14,436c → 0.498p	4,241c → 0.143p
Mg	17,604c → 0.632p	5,304c → 0.186p
Si	13,056c → 0.487p	3,876c → 0.144p
S	2,832c → 0.109p	862c → 0.0327p

[a] Number of events observed after selection criteria

[b] Intensity at top of atmosphere in particles/m^2 ster-sec. ≡ peters

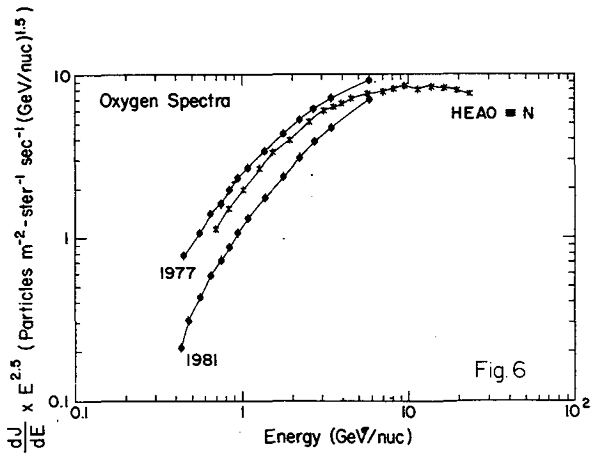


Fig. 6