CHARGE COMPOSITION AND ENERGY SPECTRA OF PRIMARY COSMIC RAY NUCLEI BETWEEN 5 and 100 GEV PER NUCLEON

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A large area scintillation-Cerenkov cosmic ray telescope designed to measure the charge composition of cosmic ray nuclei with $Z > 2$ was recently flown in two balloon flights launched from Palestine, Texas for a total of 55 hours under about 4 g/cm^2 of residual atmosphere. Nuclear charges are determined by two scintillation counters, which, in combination with an annular guard counter, have a geometric factor of 910 cm^2 sr. Three gas Cerenkov counters with different indices of refraction, and thus sensitive in different energy regions, measure the energy of cosmic ray nuclei between 5 and 100 GeV per nucleon. The gases used for that purpose were ethylene at 18.6 atmospheres, and isobutane, Freon-12, and CO_2 at 1 atmosphere pressure. Our first results deal with the energy dependence of the abundance ratio N/(C + O).

I. Introduction. In the past few years, it has been established that above several GeV per nucleon the nuclear composition of cosmic rays is quite different than at lower energies (Juliusson et al., 1972; Smith et al., 1973; Ormes and Balasubrahmanyan, 1973). These results have caused a re-examination of the models of galactic cosmic ray origin and propagation. The problems involved in performing experiments at high energies have so far limited the amount of astrophysical information that can be extracted from these data. The very low flux of high energy nuclei with charge greater than two makes the collection of a statistically significant number of particles very difficult. Also experimental techniques new to cosmic ray physics have had to be introduced to make these energy measurements in the GeV regime. We have recently made two balloon flights with an instrument capable of measuring the charge composition and energy spectra of cosmic ray nuclei with energies from 5 to 100 GeV per nucleon. In this paper we present preliminary results on almost 30,000 nuclei with charge greater than two and energies above 5 GeV per nucleon, by far the greatest such number measured to date.

II. Instrumentation and Flights. The instrument that has been used to carry out this experiment is a scintillation-Cerenkov counter telescope, and is presented in schematic form in Figure 1. It uses almost all of the features of the instrument described earlier by Juliusson (1974), but has a high pressure gas Cerenkov counter C3 replacing a plastic Cerenkov counter, and has a curved scintillation counter C4. The charge of an incident cosmic ray nucleus is determined by the Pilot Y scintillation counters C1 and C4, both shaped to reduce path length variations. Only nuclei that pass through the hole in the annular guard counter G, are used in the analysis. The geometric factor corresponding to this coincidence requirement, $C1 \cdot \bar{G} \cdot C4$, is 910 cm^2 sr. The energy determination is accomplished by the three gas Cerenkov counters C2A, C2B, and C3. The two gas Cerenkov counters C2A and C2B operate at a pressure of one atmosphere. C2A is a light collection box, filled with isobutane gas, and has a Cerenkov threshold of 17 GeV per nucleon. C2B, on the other hand, is a focussing gas Cerenkov counter which contained CO_2 during the first flight and Freon-12 for the second. The thresholds of these two gases are 30 and 19 GeV per nucleon respectively.

The high pressure gas counter C3 contains 18.6 atmospheres of ethylene gas, which was selected because of its low scintillation and good thermodynamic properties. C3 is also a light collection box, with interior walls coated with Eastman High Reflectance White Paint. It contains a light baffle to reduce the width of the path length distribution in the counter. This Cerenkov counter is viewed through plexiglas windows by ten 5" RCA 4525 photomultiplier tubes. The instrument was flown from Palestine, Texas, in September-October 1974. The first flight remained at a ceiling altitude of 4 g/cm^2 of residual atmosphere for 13 hours. The second flight lasted over 42 hours, although during the second night the balloon descended from 4 to about 11 g/cm^2. We plan to use this portion of the flight to produce accurate growth curves which will be used for an experimental determination of the atmospheric corrections. The exposure factor amounted to 5.0 m^2 sr hr.

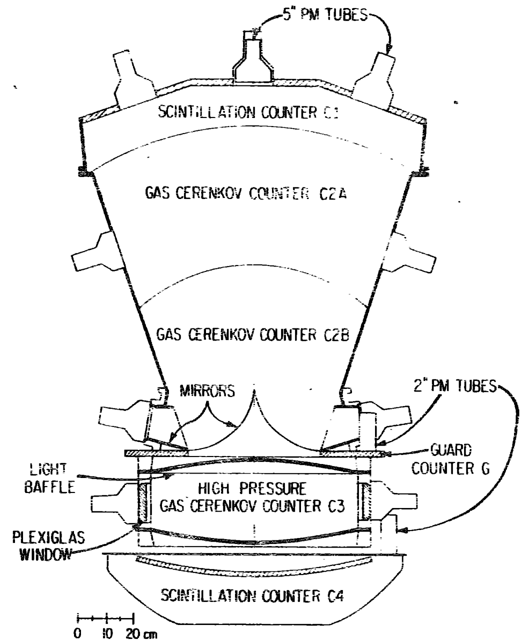

Figure 1. Schematic cross-section of the instrument.

III. Data Analysis. The preliminary data presented here were obtained by closely following the analysis scheme developed by Juliusson (1974). A histogram of a charge function that is the average of the square roots of the scintillator outputs is shown in Figure 2. The selection criteria that we used to produce this figure were as follows: (1) the guard counter output is less than 8% of that which would have occurred had the particle passed directly through the guard scintillator. This criterion avoids rejecting high-Z nuclei accompanied by delta rays. (2) We require the two scintillator pulse heights C1 and C4 to agree within 20%, and, (3) C3 must be at a level corresponding to a kinetic energy above 10 GeV per nucleon. The standard deviation of the charge measurement in the CNO region is less than 0.18 charge units. This implies that less than 1.5%

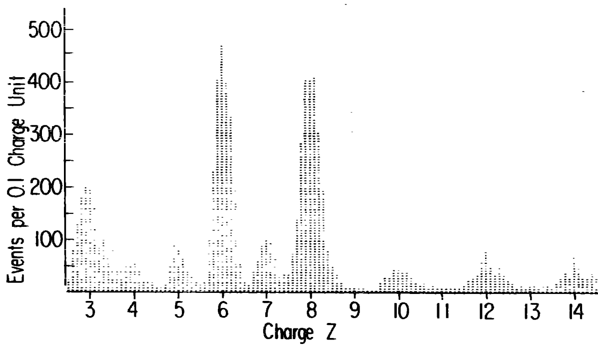

Figure 2. Charge resolution above 10 GeV per nucleon. Charge function is $Z = 0.5 \cdot (\sqrt{C1} + \sqrt{C4})$

of the nuclei of charge Z are misidentified as having either charge Z-1 or Z + 1. Since the fraction of nuclei that overlap into, and also from, neighboring charge intervals can be easily calculated, one can correct for the effect of these overlaps. Thus, except in cases where the relative abundance of adjacent charges are greatly different, the statistical uncertainty in determining a chemical abundance ratio will dominate the error in charge measurements.

At high energies, above 20 GeV per nucleon, the charge resolution and background rejection are improved for then we can use the C3 high pressure gas counter as a charge measuring device, since at those energies its velocity dependence has saturated. Figure 3 demonstrates that if we plot the charge as measured in C3 versus the charge as determined by the scintillators, the instrument is capable of essentially complete separation of charge peaks. If we also employ the selection criteria, $65\% < C3/Z^2 < 130\%$ (shown as straight lines in the figure), which are reasonable on physical grounds, the background in the vicinity of the lithium and beryllium is reduced. A new charge function that includes C3 is seen in Figure 4, showing the charge resolution above 20 GeV per nucleon.

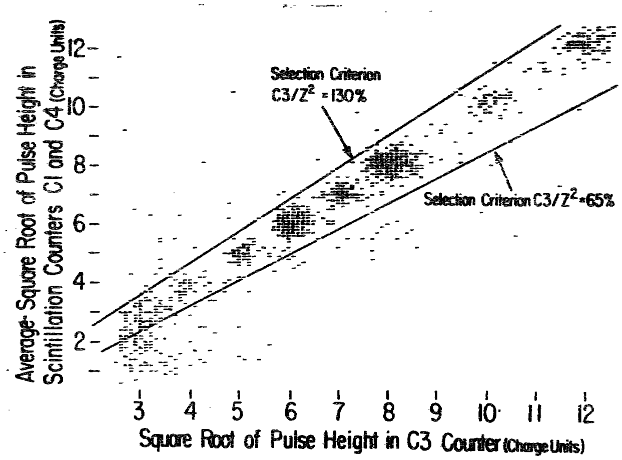

Figure 3. Matrix of charge as measured by the scintillators, C1 and C4, versus the charge as measured in C3 Cerenkov counter. Only events that are high in C2A are included.

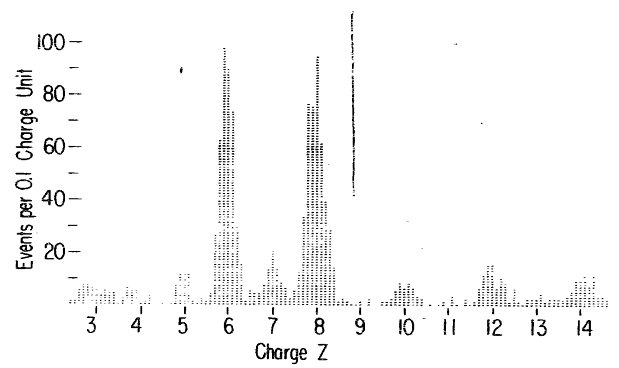

Figure 4. Charge resolution above 20 GeV per nucleon. Charge function is $Z = 0.4 \cdot \sqrt{C1} + 0.2 \cdot \sqrt{C3} + 0.4 \cdot \sqrt{C4}$

To extract differential energy spectra from the observed Cerenkov signals we have used the statistical deconvolution technique described in the appendix of Juliusson (1974). Very briefly, this involves folding the instrumental resolution function into the formula for the production of Cerenkov radiation as a function of velocity (energy per nucleon). This yields the desired relation between energy and Cerenkov signal. The pulse height distribution produced by oxygen nuclei in the high pressure gas counter C3 is presented in Figure 5. Marked on this spectrum are the energies to which several of the pulse heights correspond.

IV. Results. The results presented at this time are preliminary. We shall restrict ourselves to examining measurements of the energy dependence of the relative composition of N to C + O to demonstrate the quality of the data as well as their consistency with earlier published results. Figure 6 shows the N/(C+O) ratio from 1 to 120 GeV per nucleon. To the results of Juliusson (1974) and Smith et al. (1973), we have added 6 data points obtained with this new instrument. The lowest of these new points in energy represents those nuclei that were above the geomagnetic cut-off at Palestine, yet did not produce Cerenkov light in the high pressure gas counter C3. There are four data points from the analysis of the C3 gas Cerenkov counter. We have not yet completed the analysis of the energy range covered by the gas counters C2A and C2B and hence cannot yet present differential energy points at the higher energies. We have, however, included an integral flux point for those nuclei that did produce Cerenkov light in the C2A gas counter. At the time of the Munich conference we hope to be able to present much more complete results on the charge composition and energy spectra of cosmic ray nuclei between 5 and 100 GeV per nucleon.

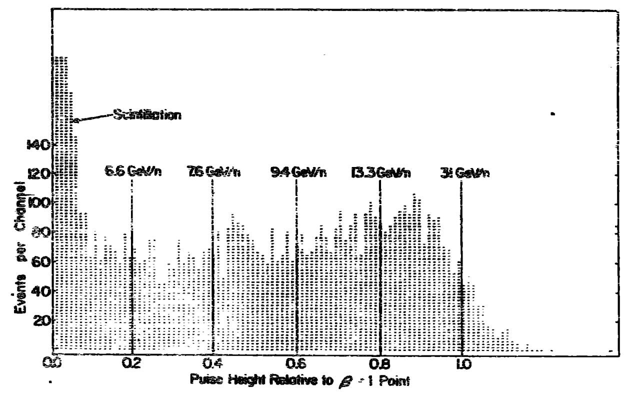

Figure 5. Pulse height distribution of the High Pressure Gas Cerenkov Counter C3 for oxygen nuclei. The corresponding energy scale is indicated by lines.

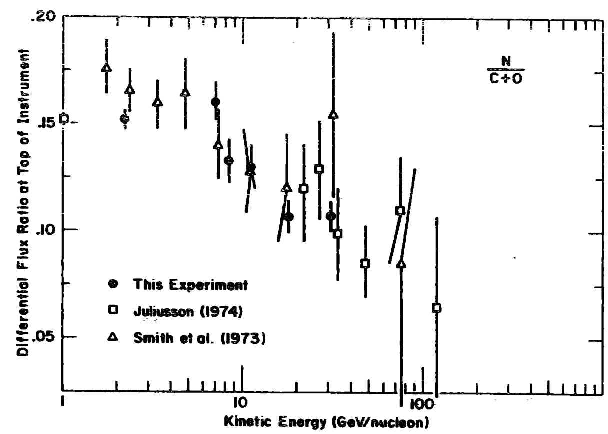

Figure 6. The N/(C + O) ratio in the cosmic rays from 1 to 120 GeV per nucleon.

V. Acknowledgements. We are grateful to Dr. E. Juliusson for his earlier contribution to this project. Of the many individuals in this laboratory who have assisted this work, we would like to especially mention Wayne Johnson, Gary Kelderhouse and William Hollis for their tireless efforts in the preparation of the instrument for the balloon flights. This work has been supported by the National Aeronautics and Space Administration under grant NGL 14-001-005.

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