N72-33809

COSMIC RAY CHARGE AND ENERGY SPECTRA ABOVE 10 GeV

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We have been working on a program to study the composition and energy spectra of cosmic rays above 1.6 nJ (10 GeV) on balloons and ultimately on the HEAO satellite.

During the last decade, considerable information on the composition and spectra at low energies has been obtained from balloons and satellite measurements. By extending these measurements to higher energy, we can greatly enhance our understanding of cosmic ray sources and their galactic environment. We have obtained some results from a balloon flight in November of 1970 that I would like to show you today.

The instrument is shown schematically in Figure 1. It is designed to identify cosmic ray electrons, protons, and nuclei up through iron and to measure their energies.

Relativistic particles enter the charge module and pass through four detectors, S_1, Cerenkov, cesium iodide, and S_2, all of which measure the charge through a proportionality to the charge squared. In addition, in this section we have four wire-grid spark chambers (s.c.) which measure the trajectory of the particle through the instrument. Particles then enter a large block of high Z material where their energy is absorbed. The first section is layers of tungsten with scintillators (as indicated by the dash marks on the side) where electromagnetic cascades from electrons rapidly develop. The nuclei pass through some of these layers where they interact and, through π^0 decay and the subsequent electromagnetic cascades, deposit their energy in a series of low-energy particles. The number of these particles is then determined; and through a function which we determine by calibration at high-energy accelerators, we can relate this to the energy of the particles.

The energy is a function of the parameter d which indicates the pathlength of the particle through the spectrometer and the constant, which is a slowly varying function of the energy of the particle.

In Figure 2, we show examples of nuclei identified as iron by the four charge detectors. Let's take the dots as an example of one particle. This particle enters the tungsten stack preserving its identity through the first few layers

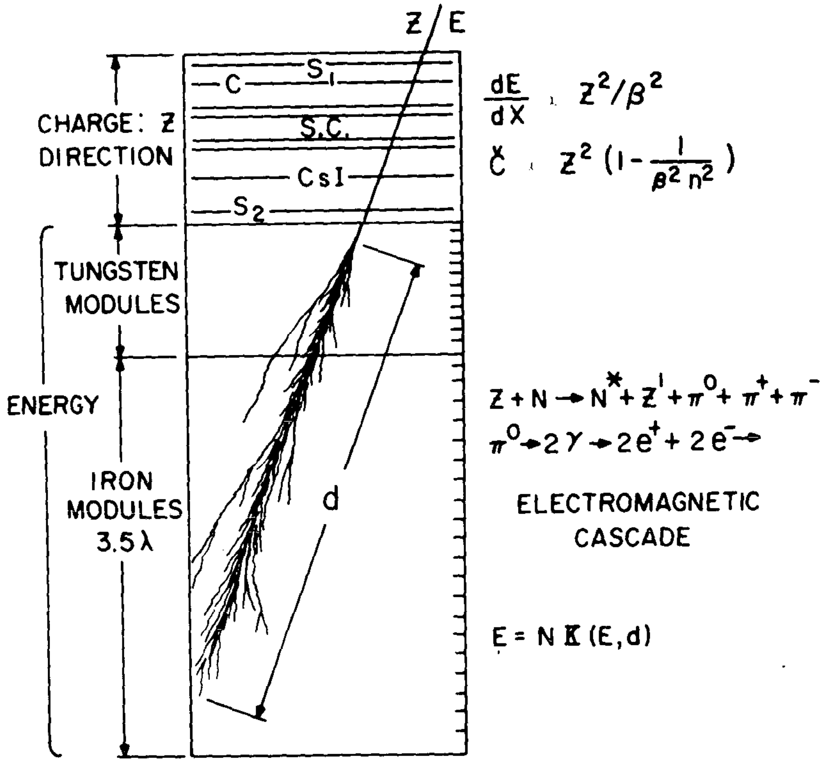

Figure 1–Diagram of instrument designed to identify particles and to measure their energies.

of tungsten, then there is some sort of an interaction, probably a fission-producing interaction. The particle continues to have its identity, then it interacts and produces a cascade shower.

In the case of another iron (represented by the plus marks), the particle comes in, interacts, and has a very large energy deposit. This particle has probably 0.5 μJ (3000 GeV) total energy, and as it passes through one of the layers there is an equivalent number of 1300 singly charged particles going through the detector.

In Figure 3, we show the energy spectra of various groups of nuclei. The nuclei are grouped in the traditional cosmic ray groups in order to obtain statistics that extend to the highest energy. These plots are a function of total energy, which is what our instrument measures.

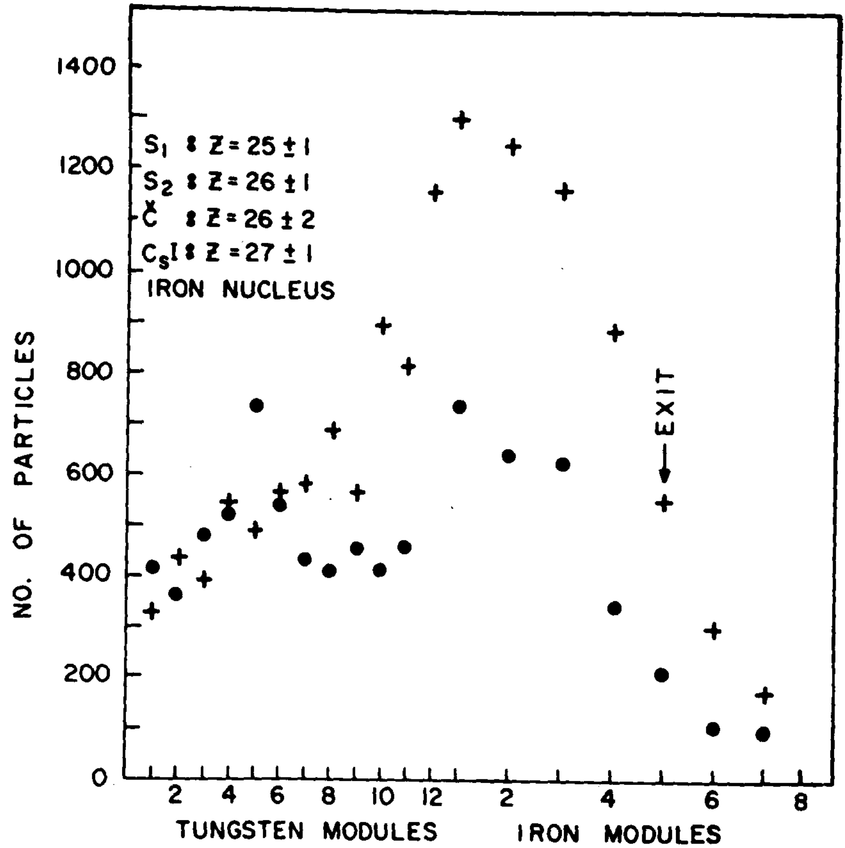

Figure 2–States of two iron nuclei as they pass through the modules. +: 0.5 μJ (3000 GeV) nucleus; •: 69±11 nJ (430±70 GeV) nucleus.

At the low-energy end, we can see evidence of the geomagnetic cutoff, and that is why this spectrum stops at low energy. This would be sharply cutoff except for the fact that our balloon drifted with respect to the cutoff.

All the nuclei have differential spectra with a power of -2.7±0.1. These data are from the iron group, the *L* nuclei, the *M* nuclei, and so on.

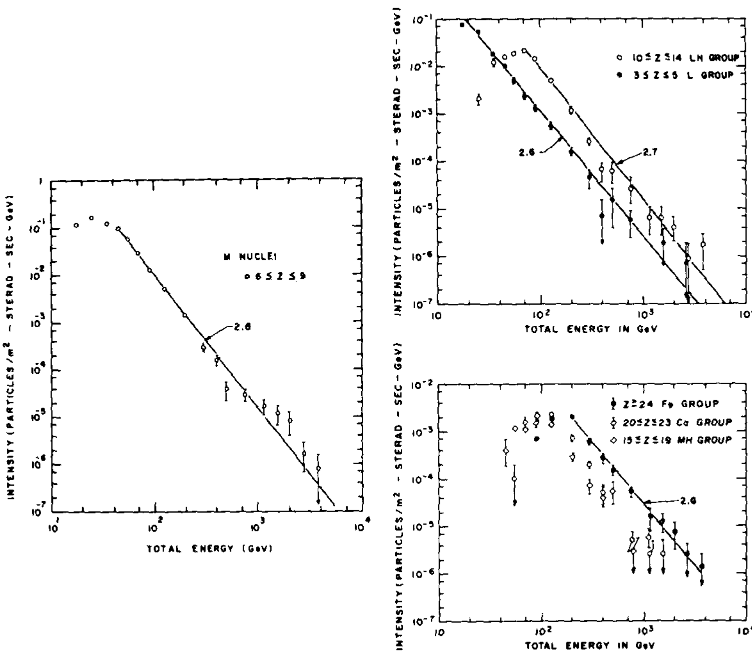

Figure 3—Energy spectra.

There is a suggestion of an interesting structure around 0.2 μJ (1000 GeV), particularly in the *M*-nuclei spectrum. This structure may be instrumental because we see some evidence for it in the spectra of all the nuclei. However, if it proves to be real, it will be very interesting.

In Figure 4, our proton integral spectrum is compared with that of Grigorov et al., (Ref. 1). The Grigorov data are from the Proton series of satellites. The often-discussed bend in their spectrum at about 10^{-7} J (10^{12} eV) is shown.

We find no evidence for any bend in the proton spectrum up to energies that are two or three times as great as where their bend is. Our helium spectrum agrees quite well with other published data, and the intensity of protons is nearly equal to that reported by the Russians (Ref. 2).

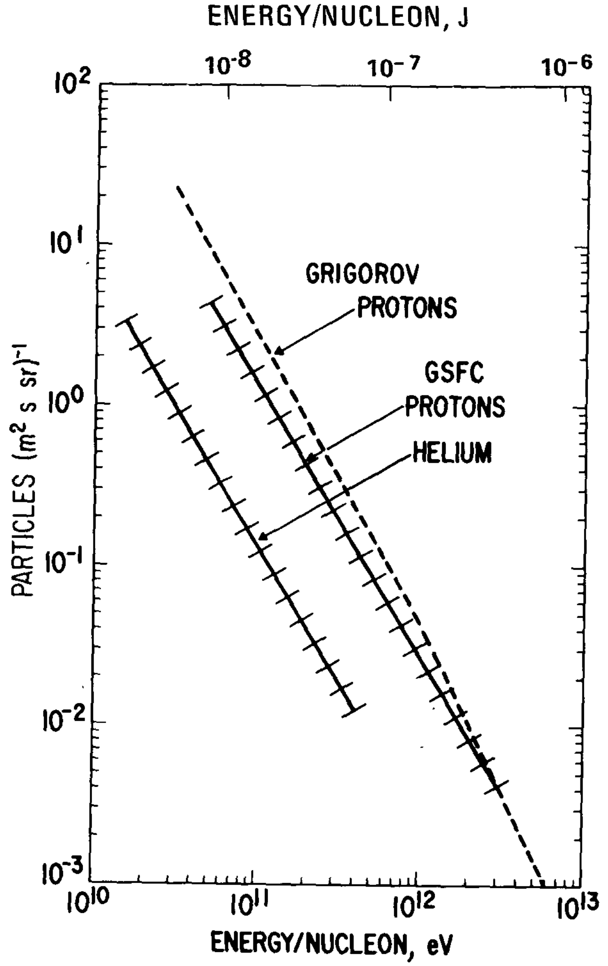

Figure 4–Integral spectra.

Our data give a proton-to-alpha ratio of 26 ± 3 constant from 40 GeV/nuc to 400 GeV/nuc. In addition to the protons, Grigorov measures the total-energy spectrum of all cosmic rays in his calorimeter. At the recent cosmic ray conference at Hobart, he reported evidence for spectral structure at about 0.2 μJ (10^{12} eV) which he attributes to the break that he has in the proton spectrum. However, our results suggest that only a quarter of the particles at a given total energy, which is what he is measuring at the same total energy, are protons. In fact, the energy is roughly equally distributed between protons, helium, the nuclei carbon through silicon, and the heavy nuclei.

So our suggestion is that the all-particle spectrum structure may be related to the structure we see at 0.2 μJ (10^{12} eV) in the medium nuclei spectrum.

In closing, let me just emphasize two points. First, the composition is apparently independent of energy and all the nuclear components have spectral exponents between -2.6 and -2.8, up to several tenths of a microjoule (several thousand gigaelectron volts) total energy; and, second, we find no evidence for any bend in the proton spectrum at 0.2 μJ (10^{12} eV).

CHAIRMAN:

Are there any questions for Dr. Ormes?

MEMBER OF THE AUDIENCE:

How will you decide if the structure in your medium nuclei spectrum is real or experimental?

DR. ORMES:

These results are based on a preliminary analysis. One of the problems we have is to estimate how much energy leaks out the back of the spectrometer and how strong a dependency that has on energy. The first preliminary analysis did not take into account differences in Z and so on. What one has to do now is just go back and do things more carefully. Looking at individual events above a certain energy, we can try and estimate for each event how much fluctuation there is. This will tell us how much error we have in estimating the energy. Once we have done that, we can have a lot more confidence in this kind of spectrum.

MEMBER OF THE AUDIENCE:

How many radiation lengths are there in the calorimeter?

DR. ORMES:

It is 3.5 nuclear interaction mean-free paths thick. The tungsten section on top is 12 radiation lengths thick. That is where we developed the electron cascades. And for the nuclei, the appropriate length is the nuclear mean-free path. The total thickness in radiation lengths is greater than 40.

MEMBER OF THE AUDIENCE:

Where do you calibrate your instrument?

DR. ORMES:

We have calibrated it already in the proton beam at the AGS at Brookhaven, and we have scheduled a calibration at the National Accelerator Laboratory. We are looking forward to that.

MEMBER OF THE AUDIENCE:

Can you measure interaction cross sections at high energy?

DR. ORMES:

We have not looked into that yet, but the problem is that it would be very difficult. The way we would do it with an instrument like this would be to determine the distribution of the first interaction points. We probably do not have enough data. They are not accurate enough and we do not have enough statistics at very high energies to say much about that.

REFERENCES

1. Grigorov, N. L.; et al.: Acta Phys. Suppl. 1, vol. 29, 1970, p. 510.

2. Akimov, V. V.; et al.: Acta Phys. Suppl. 1, vol. 29, 1970, p. 517.