III-1-7. The Energy Spectrum of Nuclei with Charge Z≥13 in the Primary Cosmic Radiation*

K. A. NEELAKANTAN and P. G. SHUKLA

Tata Institute of Fundamental Sesearch, Bombay, 5, India

1. Introduction

It is now known that the Primary Cosmic Radiation consists of about 80% protons, 19% α-particles and 1% of nuclei with charge Z ≥3. It is customary to divide the nuclei with charge Z≥3 into three groups namely: L-nuclei (3≤Z≤5), M-nuclei (6≤Z≤9) and H-nuclei ($Z\geq 10$). A knowledge of the form of the energy spectra of these three groups is very important for the construction of any theory for the origin and propagation of cosmic radiation. Until, recently, the energy spectra of M and H-nuclei have been determined from the flux values obtained at various geomagnetic latitudes. The geomagnetic cut-off energy at a particular latitude is assumed to be given by the theory which treats the earth's magnetic field as due to a simple dipole; this procedure is now known to be unsatisfactory. Further it is known that the flux values are subject to time variations.

In order to avoid the above difficulties the energy spectra of M and H-nuclei have been measured in nuclear emulsions by Biswas *et al*[1] using the knock-on electron technique. It has been shown by Biswas *et al* that this method of direct energy determination can be applied reliably over a wide range of energy. By this technique, the energy spectra of M and H groups of nuclei were determined in the energy interval 0.23 to 9.0 Bev/nucleon and it was shown that, within experimental errors, M and H-nuclei have the same form for their energy spectra. But the number of H-nuclei, on which measurements were made, was not sufficient to determine whether there was any finite difference between the spectra of M and H-nuclei.

In this paper we describe the measurements made on the energy spectra of *H*-nuclei only. Since any change in the spectra should be more marked in the case of nuclei with higher charges, only nuclei with charge Z≥13, have been used for energy measurements. The energy spectrum of these nuclei has been determined in the energy range 1.5 Bev/nucleon to 15 Bev/nucleon.

2. Experimental Procedure

The experiment was carried out in an emulsion stack consisting of 60 Ilford G5 stripped emulsions each of dimension 15cm×20cm×.06 cm. This stack was flown from Texas (λ= 41°N) on February 9, 1959 and it floated at an altitude of 118,000 ft. (5.3 g/cm² of residual air) for 6 hours 50 minutes. The stack was sent up with the emulsion surfaces horizontal, but was made vertical as soon as the balloon reached ceiling altitude.

The two outside emulsions were scanned for heavy primary tracks which satisfied the following conditions:

(a) Ionisation greater than that of a relativistic Be nucleus;
(b) Projected track length ≥1.0 mm/plate;
(c) Zenith angle ≤90°.

Tracks satisfying these conditions were followed through successive emulsion to see whether the particles producing them came to rest, interacted or passed out of the stack. Charge determination was done on those tracks with :

(a) Ionisation greater than or equal to a relativistic Flourine nucleus;
(b) Projected length ≥1.1. mm/plate;
(c) Zenith angle ≤45°.

Out of these tracks, those satisfying the following further criteria were selected for energy determination:

(a) Ionisation greater than or equal to that of a nucleus with charge Z≥13 ;
(b) Track length before interaction, if the particle interacts in flight ≥1 cm ;
(c) Length in the stack ≥1 cm, if the particle left the stack without interacting;

Charge measurements were done on a total

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of 242 tracks, out of which 225 were found to be nuclei with $Z \geq 10$. Energy measurements were done on 150 tracks with $Z \geq 13$.

3. Charge and Energy Determination

The charge of each particle was obtained by counting "long δ-rays" on each track. In this convention, all δ-rays which projected outside two parallel straight lines 2.5 μ on either side of the primary track were counted. The charge calibration curve was obtained by using relativistic charge indicating interactions of charges 5, 7, 9 and 14. A minimum of 200 δ-rays was counted on each track with $Z \geq 10$. The charge of each particle was obtained from the relation $N_\delta = aZ^2 + b$ where N_δ is the number of long δ-rays per 100 μ and a and b are constants.

The energy per nucleon of heavy primary nuclei traversing the whole stack or interacting in the stack after a length of 1 cm was obtained from measurements on "knock-on electrons". The details of scanning for these electrons and the criteria for their acceptance are the same as discussed in detail in the paper by Biswas *et al.* A minimum of two knock-on electrons was measured on each primary track and from each of these the primary energy γ_p was evaluated. If these two values were inconsistent, measurements were made on a third knock-on electron and the value of the primary energy was again calculated. It was found that this value of γ_p was in agreement with that obtained from either the first or the second knock-on electron. The final value of the primary energy was obtained from the weighted mean of the two estimated values which were consistent with each other.

From the measured energy of the particle inside the stack, its energy at the entrance point was obtained using the rang-energy relation for various nuclei in emulsion. Then, using the range-energy relation in air, the energy of each particle at the top of the atmosphere was estimated from the amount of air (and packing material) traversed by it before entering the stack.

4. Energy Spectrum

The integral energy spectrum can be represented by the relation:

$$N(\geq E) = \frac{C}{(1+E)^m}$$

where N=number of particles above energy E, E=the kinetic energy expressed in Bev/nucleon and C=a constant.

From energy measurements on 150 particles with $Z \geq 13$, it is found that the value of m is 1.70 ± 0.30; this value has been obtained by employing the maximum likelihood method for the integral energy spectrum in Fig. 1. From a similar procedure the value of m for nuclei with $Z \geq 17$ is found to be 1.55 ± 0.25

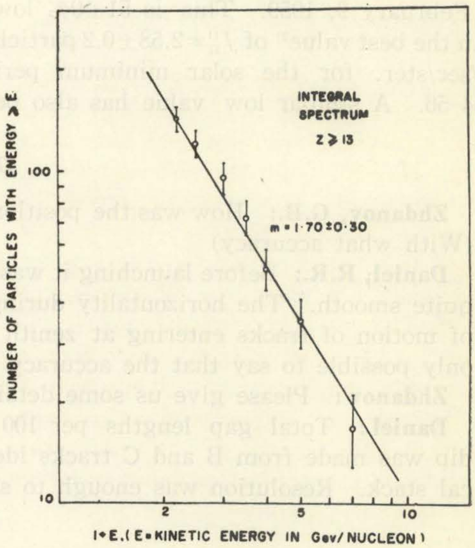

Fig. 1.

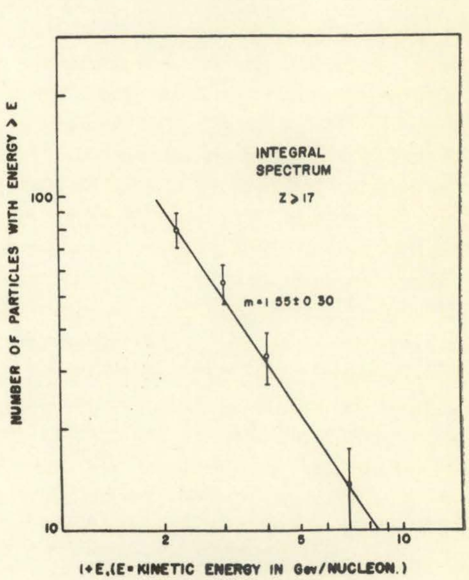

Fig. 2.

(Fig. 2). These values may be compared with the results of Biswas *et al* for M-nuclei where they got a value of $m=1.65\pm0.27$. It can therefore be concluded that within the experiment errors the value of m is the same for all nuclei.

5. Flux Values

From the observations made on nuclei with $Z\geq10$, their flux at the top of the atmosphere has been calculated as

$$J_{\mathrm{H}}^{0}=1.26\pm0.09 \text{ particles/m}^2\text{/sec/sterad.}$$

on February 9, 1959. This is 51±9% lower than the best value[2] of $J_{\mathrm{H}}^{0}=2.58\pm0.2$ particles/m²/sec/ster. for the solar minimum period 1954-56. A similar low value has also been obtained by Van Heerden and Judek[3] from a balloon flight made on March 9, 1958; they set a value of $J_{\mathrm{H}}^{0}=1.11\pm0.11$ particles/m²/sec/ster.

We have also obtained the flux of very heavy nuclei with $Z\geq20$ the value is found to be $J_{\mathrm{VH}}^{0}=0.39\pm0.06$ particles/m²/sec/ster. This again is 44±27% lower than the best value[2] for the solar minimum period of 0.69 ±0.16.

References

1) S. Biswas, P. J. Lavakare, K. A. Neelakantan and P. G. Shukia, Il Nuovo Cimento, **16** (1960) 644.
2) C. J. Waddington, Prog. in Nuclear Physics, Vol. **8** (1960)
3) I. J. Van Heerden and B. Judek, Canad. J. Phys., **38** (1960) 964.

Discussion

Zhdanov, G.B.: How was the position of the stack in the horizontal plane checked? (With what accuracy)

Daniel, R.R.: Before launching it was checked accurate to about 0.5°. The launch was quite smooth. The horizontality during ceiling flight was checked from the direction of motion of tracks entering at zenith angles >80°. With the available data it was only possible to say that the accuracy was better than 5°.

Zhdanov: Please give us some details about the gap measurements.

Daniel: Total gap lengths per 100 μ of gaps $\geq$.60 μ were used. Correction for dip was made from B and C tracks identified by grain counts (in C2 plates) in vertical stack. Resolution was enough to separate B and C.