JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN Vol. 17, SUPPLEMENT A-III, 1962
INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-1-16. The Fragmentation of Heavy Nuclei in Light Elements

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A stack of 154 30 cm by 16 cm 600 μ Ilford G5 emulsions has been exposed for 10 hours at an altitude of $\sim$4 g/cm^2 over Texas. These emulsions were interleaved with 500 μ thick sheets of polythene and teflon. The purpose of the experiment is to study the characteristics of the nuclear interactions produced by the heavy, $Z\geq3$, nuclei of the primary cosmic radiation as they pass through these sheets of plastic material. Those interactions in the teflon should resemble those produced in air, while the differences between the characteristics of the interactions in the two types of plastic should be indicative of the effects of hydrogen target nuclei.

At the present time, while preliminary data are available from this experiment, we do not feel that they are in a form suitable for publication since they might be subject to later revision. Instead we will merely give an estimate of the statistical weight of the data that should be available eventually. It is intended to detect 10^4 nuclei with $Z\geq6$ which enter the stack. Of these we expect 30% to escape without interacting and of the remaining 7000, 4000 to interact in emulsion, 1800 in polythene and 1200 in teflon.

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III-1-17. Fragmentation Parameters Involved in the Collisions of the Heavy Nuclei of the Primary Cosmic Radiation of Charge $Z\geq6$ in Graphite**

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§1. Introduction

The chemical composition of the cosmic radiation observed at balloon altitudes (3-20 g/cm^2 of air) depends primarily on the composition near the source region, the method of acceleration and its subsequent transformation during its passage through the interstellar matter and the overlying atmosphere above the point of detection. Therefore in order to infer the composition at the source region, it is necessary to know the parameters like interaction mean free path λ_i, absorption mean free path Λ_i and the fragmentation parameters P_{ij} for various groups of nuclei in interstellar medium (consisting essentially of hydrogen) and air (consisting mostly of nitrogen and oxygen). The data

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** This paper was read by R. R. Daniel.

available at present on the fragmentation parameters comes from interactions in nuclear emulsions which is a composite medium. The process of separating collisions as due to hydrogen, medium nuclei (C, N, O) and heavy nuclei (Ag, Br, I) of the emulsion involves some specific assumptions which can be questioned. However the study of these parameters in air can best be done by studying the interactions of heavy nuclei of the cosmic radiation in media like graphite, teflon etc. whose mean atomic weight is very close to that of air. The fragmentation parameters for collisions with hydrogen as target can be deduced in two ways: (i) By studying the inverse process in which protons accelerated to high energies in machines are made to interact with nuclei of different targets. The cross section for producing different fragment nuclei can be determined from radiochemical and chemical methods. (ii) By studying the fragmentation parameters associated with collisions of the cosmic ray heavy nuclei with graphite or teflon and a hydrogeneous material like paraffin or some suitable plastic, it is possible to estimate the corresponding values in hydrogen by taking the differences.

We have attempted to determine the P_{ij} values associated with the collisions of heavy nuclei of the cosmic radiation with the nuclei of air and hydrogen by the method (ii) described above. For this purpose we have exposed emulsions sandwiched between sheets of graphite and paraffin in balloon flights made from Hyderabad, India duriug 1960. Work on the graphite-emulsion sandwiches have already started and in this paper we present some preliminary results obtained on the basis of about 100 interactions in graphite.

§ 2. Experimental details

2.1. *Exposure*

The following assemblies were exposed in a balloon flight made from Hyderabad, India ($\lambda=8°$N) on 24 March 1960 for a period of 7 hours under 7 g/cm^2 of atmosphere:

(i) Four units each containing two sheets of graphite, each of size $20\times20\times0.5$ cm sandwiched between emulsions of size $20\times20\times0.06$ cm in the following order G5, C2, graphite, G5, C2, graphite, C2, G5.

(ii) Four units identical with those of (i) but the graphite sheets were replaced by paraffin layers of same size.

The expected total number of interactions produced by cosmic ray nuclei of $Z\geq6$ in graphite and paraffin from these assemblies is about 700.

2.2. *Scanning*

The results reported here were obtained from scanning made in one of the graphite assemblies. In this, the three G5 emulsions were scanned for tracks satisfying the following criteria:

(a) projected leugth ≥1 mm per emulsion

(b) grain density corresponding to an ionisation ≥16 I_0

(c) all zenith angles.

The tracks with ionisation $\lesssim50$ I_0 were scrutinised carefully for their straightness with the aid of a hairline under a total magnification of $\times375$ and those consistent with their being produced by slow singly charged particles were rejected. From the results of an earlier investigation[1] of similar nature from this laboratory it can be said that this selection criterion will still have $\sim2\%$ slow particles among the relativistic carbon nuclei; further measurements will be made later to remove even this small proportion of slow particles.

2.3. *Charge estimation*

Charge measurements were made on all selected tracks using the ordinary δ-ray measurements in the G5 emulsions. Charge calibration was obtained by making δ-ray measurements on tracks of α-particles and two favourable charge indicating collisions of $Z=6$ and 8.

2.4. *Tracing of tracks*

Tracks identified as due to heavy nuclei of $Z\geq6$ entering the emulsions assembly were traced through the stack by a method of matching. In case of events where a track was not found in the following emulsions a box of area $5\text{ mm}\times5\text{ mm}$ at the expected region was scanned carefully for fragment particles.

However, the detection efficiency for singly charged particles is not high due to the low minimum of ionisation (≈15 grains/100 μ) in these plates. Further for the present analysis we have included only tracks which have lengths between 1 and 3 mm per plate. Tracks which are not found in the subse-

Table I. Fragmentation Parameters of nuclei $Z \geq 6$.

Absorber	Primary/Secondary	H	M	L
Graphite $E \geq 7.5$ Bev/n	H (43)	0.37 (16)	0.37 (15)	0.05 (2)
〃	M (66)	—	0.12 (8)	0.26 (17)
Emulsion[3] $E \geq 1.5$ Bev/n	H	0.31 ± 0.04	0.33 ± 0.04	0.14 ± 0.03
〃	M	—	0.16 ± 0.02	0.21 ± 0.02

The numbers within brackets refer to the observed number of events.

quent plate, or show definite evidence of interacting by the presence of satellite tracks or have a definite decrease of δ-ray density corresponding to a charge degradation ≥ 2 units are considered as interactions in graphite.

§ 3. Results

A total area of 355 cm^2 was scanned in each of the G5 emulsions satisfying the criterion mentioned above. 520 tracks have been found to enter the two outer faces of the G5 emulsions. 346 M-nuclei and 138 H-nuclei have been identified from δ-ray measurements (≥ 3 grains). The separation between boron and carbon has been done by these measurements alone. A second measurement like gap counting has yet to be done. The ratio of H/M at the observed depth, uncorrected for scanning efficiency for carbon, which is yet to be precisely determined, was found to be 0.40 ± 0.04. This value is in fair agreement with the results of previous workers.

109 interactions of $Z \geq 6$ have been obtained so far in graphite (of total thickness 1.7 g/cm^2). Of these, 66 are due to M-nuclei and 43 are due to H-nuclei. In these events, except in the case of carbon, the primary particle always suffers a charge degradation of at least two charge units or greater.

The values of fragmentation parameters derived from 109 interactions are shown in Table I. H-group is classified as a single group here, partly due to poor statistics (to less number of interactions). Further the charge identification from Z=5 to Z=26 has been made from δ-rays only and the charge resolution at higher charge values may not be good. It may be remarked that the highest charge measured by this method corresponds to a Z value of 26.9, thus ensuring no drastic errors in charge estimation at these charge values.

The parameters shown in Table I are for a cut-off energy ≥ 7.5 Bev/n. If fragmentation parameters are independent of energy, then they can be compared with the ones obtained at a lower energy *e.g.* 1.5 Bev/n. The values observed in emulsion ($N_h \leq 7$) as summarised by Waddington[3] at this energy range is also shown in the Table.

Statistically, the parameters derived from graphite and emulsion seem to agree. It may be remarked that our value of P_{HH}(0.37) is about 20% higher than the value of P_{HH} obtained in emulsion. However, conclusions about this, as well as about P_{HL} and P_{VHL} can be reached only when better statistics is obtained and charge estimation done by a second method. Such attempts are being made.

References

1) R. R. Daniel and N. Durgaprasad under publication in Nuove Cimento.
2) M. F. Kaplon, B. Heters, H. L. Reynolds and D. M. Ritson: Phys. Rev. **85** (1952) 295.
3) C. J. Waddington: The Composition of Primary Cosmic Radiation.-Progress in Nuclear Physics, Vol. 8, (1960).

Discussion

Burbidge, G. R.: If much of the material traversed is in the cosmic ray source then composition there might be very different from that in the interstellar gas.

Therefore these experiment should be made in all kinds of materials.

Peters, B.: I agree completely. It is also necessary to study the production of spallation products not only as group, but also as individual nuclear species and this will, I believe, be possible only in accelerator laboratories. The reason is that the relative abundance of various fragmentation products will change as a result of radioactive cooling. For instance Boron fragments will be enhanced by the decay of Be^{10}, C^{10} and C^{11} fragments and probably diminished only slightly by the decay of B^{12}. Lithium fragments will be increased by the decay of He^{6} and Be^{7} and decreased by that of Li^{8}, etc. Only a very accurate study such reactions will permit us to decide whether the observed composition is compatible with spallation reaction in a gas consisting of mostly hydrogen with some admixture of helium.

Yagoda, H.: The fragmentation coefficients of heavy nuclei in hydrogen can also be measured directly with the aid of hypersensitive nuclear emulsions which maintain a fair degree of sensitivity at liquid hydrogen temperatures. I believe that a preliminary experiment of this nature has been made at the University of Moscow using the NIKFI emulsions. Perhaps Prof. Zhdanov might like to comment on this work.

Zhdanov, G. B.: We have done one experiment of this kind with improved NIKIFI-R/ emulsions surrounded by liquid hydrogen. The sensitivity of emulsions was about 30 grains per 100 μ. So in principle such an experiment would be possible.

Koshiba, M.: How about He in interstellar medium?

Burbidge: Regarding the hydrogen/helium ratio in interstellar matter, measures of emission lines in ionized region around high temperature stars (*e.g.* Orion Nebula) give a ratio not significantly different from the ratio actually obtained from stars (as might be expected since the high-temperature stars must be young and recently condensed). Probably the interstellar gas should be well-mixed throughout the galaxy, so one should be safe in taking the "cosmic abundance" H/He ratio to apply in the interstellar medium.

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III-1-18. Introductory Remarks

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Since the last Conference in Moscow, in 1959 several important questions regarding the composition of the primary radiation have been clarified. Progress was made particularly in three directions.

1) Evidence has finally been produced to the effect that primary electrons and γ-rays are present near the earth. Adequate technical means for their study appear to be available now. If present day notions about gas density and about the uniformity of nucleon flux in interstellar space are correct, one must expect that, even if there were no specific galactic sources of high energy electrons and γ-rays, there should be a continuous production in interstellar space due to the decay of pions produced in collisions of cosmic ray nuclei with the gas in the spiral arms and the halo. Observations reported at this Conference indicate the presence of these components with approximately the expected intensity.

It is perhaps too early to state that the galactic character of γ-rays observed by