LETTERS TO THE EDITORS

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Relative Abundances of Different Charge Groups of Heavy Primary Cosmic-Ray Nuclei

SINCE the discovery in 1948[1] that primary cosmic rays entering the Earth's atmosphere contain nuclei of elements ranging in size up to iron, many measurements have been made to establish the charge distribution of the primary radiation. Knowledge of this distribution is of crucial importance for astrophysical investigations into the origin of cosmic rays. There is agreement between different laboratories regarding the flux of nuclei of medium charge, M nuclei, but disagreement on the flux of both light (L) ($3 \leqslant Z \leqslant 5$) and heavy ($H$) ($Z > 10$) charge groups. Figures given for the relative primary abundances of L and M nuclei exhibit a particularly wide spread, for L/M ranges from $< 0{\cdot}1$ to $> 1{\cdot}0$. The spread in published values of the heavy-to-medium ratio is less, 0·2 to 0·5, but enough to make further work necessary.

The main reasons for the conflict between the results are the experimental difficulties of separating the charge groups and, especially for H nuclei, the smallness of the numbers found in any one experiment. Also, in all experiments involving high-altitude balloon flights, there is some atmosphere above the detector (for example, 11 gm./cm.^{2} at 100,000 ft.) and, in addition, packing and other materials are traversed by the incident radiation. Since the interaction mean free path is only about 18 and 26 gm./cm.^{2} for the heavy and medium groups respectively[2], it is necessary to have balloon altitudes well above 100,000 ft. if the corrections for the effects of interactions are to be kept small. This is particularly important because L-group nuclei are frequently produced in the interactions of heavier nuclei.

If the ratio L/M at flight altitudes around 100,000 ft. were of order 0·1, all observed L nuclei would probably be secondary fragmentation products, but a value of order 1·0 would prove that light nuclei exist in the primary radiation.

We have recently completed an experiment to determine whether L nuclei are abundant in the primary radiation or not. Detailed accounts will appear shortly[3]. The results were obtained from a large-area stack of nuclear-emulsion sheets without glass support, flown for around 6 hr. at above 110,000 ft. (8·6 gm./cm.^{2} air + 2 gm./cm.^{2} packing) in Texas (41° N. geomagnetic), in February 1956.

In Table 1 we give our absolute fluxes and relative abundances both for flight altitude and extrapolated to the top of the atmosphere. The extrapolation was carried out using the usual diffusion equations[2], and two different values[2,4] were used for the probability p of a light nucleus being produced in an interaction of a heavier primary one in the atmosphere above the stack. Table 1 contains, for comparison, the cosmic abundances obtained from astrophysical data by Suess and Urey[5]. The results show (*a*) that lithium, beryllium and boron are definitely present in the primary radiation, and (*b*) that the relative abundances of the different charge groups found in cosmic rays are quite different from those given for matter in the universe[5]. The L group is more than 10^3 times as abundant (relative to the M group) in cosmic rays as in the universe, and the heaviest nuclei (the H group) appear to be relatively six times more common in cosmic rays.

Table 1

	$Z=2$	$3 \leqslant Z \leqslant 5$	$6 \leqslant Z \leqslant 10$	$Z>10$
Flight altitude : Numbers found		46^{+10}_{-7}	46 ± 7	20 ± 4
Relative to M group		1·00	1·00	0·43
Top of atmosphere : Flux* with $p=0{\cdot}45$	100 ± 20	3·5	5·5	2·6
$p=0{\cdot}23$		4·2	5·5	2·6
Relative to M group $p=0{\cdot}45$	18	0·64	1·00	0·47
$p=0{\cdot}23$		0·76	1·00	0·47
Cosmic abundances (relative to M group)	100	5×10^{-4}	1·00	0·08

* Fluxes are given in particles m.$^{-2}$ sec.$^{-1}$ sterad.$^{-1}$

The observed cosmic-ray charge distribution depends not only on the relative abundances in the source regions but also on the acceleration mechanism and the fragmentations in collisions with matter encountered during acceleration or in interstellar space. If L nuclei are absent in the source regions, and if they are not produced during acceleration there, the light-element flux must be due to fragmentations with interstellar material so that one can derive from it an upper limit to the time cosmic rays have travelled before reaching the Earth's atmosphere. Assuming that most interstellar matter is hydrogen with a density of 1 atom/cm.^{3}, our data give a travel time of the order of a few million years. If light nuclei occur in the source or are produced during acceleration there this time is reduced.

The large proportion of nuclei with $Z > 10$ is of great importance, for it implies either that very heavy nuclei are more abundant in cosmic-ray source regions than in the rest of the universe or that the acceleration mechanism strongly favours heavy nuclei, or both. Recent work on supernovæ[6] and on possible mechanisms of accelerating particles to cosmic-ray energies in them[7] suggests that supernovæ might be a source of cosmic rays giving a charge distribution with a high proportion of heavy elements. This hypothesis could be tested if the effects of fragmentations were better understood, and if the charge spectrum of heavy nuclei were known in greater detail.

J. H. NOON
A. J. HERZ
B. J. O'BRIEN

The F.B.S. Falkiner Nuclear Research and
Adolph Basser Computing Laboratories,
School of Physics,
University of Sydney. Dec. 10.

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