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ELEMENTAL COMPOSITION OF COSMIC RAYS FROM Be TO Ni AS MEASURED BY THE FRENCH-DANISH INSTRUMENT ON HEAO-3

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ABSTRACT

We report new values for the elemental composition of the galactic cosmic rays between Beryllium and Nickel in the energy range 0.8 to 25 GeV/nuc.

1. Introduction

Galactic cosmic ray abundance values obtained with the French-Danish experiment aboard HEAO-3 have already been published at the last cosmic ray conference in Paris (Engelmann et al. 1981) and we refer to that paper for the description of the data analysis and to Bouffard et al. 1982 for the description of the instrument.

While these values were already rather accurate, we have continued our work to bring the systematic errors down to the very low level of the statistical errors. We understand now better the response of the flash tube hodoscope and are using a different efficiency correction for the instrument. Some non linearities in the counter responses have been better corrected for and a different method is used to correct for the finite energy resolution of the counters, as described in the next section.

2. Derivation of the momentum spectra

The normalized light signal in a Cerenkov counter with threshold momentum P_c traversed by a particle of momentum P can be written :

$$S = 1 - P_c^2/P^2 \pm \sigma \qquad (1)$$

where $\pm\sigma$ denotes a gaussian fluctuation in the signal due for example to the photoelectron statistics.

The normal method of inverting this equation, ignoring the finite resolution of the counter :

$$P^2 = P_c^2/(1 - S) \qquad (2)$$

works well when P is not much larger than P_c, but leads to spectral distortions at high momenta and a number of particles having $S > 1$ (due to fluctuations) cannot be assigned a momentum by (2).

1983ICRC....2...17E

The method we have used to obtain undistorted spectra is to modify the basic Cerenkov formula (2) by truncating the expression :

$$P^2 = P_c^2/(1 - S) = P_c^2(1 + S + S^2 + \dots) \qquad (3)$$

(valid for $S < 1$ only) after N terms, defining :

$$P_N^2 = P_c^2(1 + S + S^2 + \dots + S^{N-1}) = P_c^2(1 - S^N)/(1 - S) \qquad (4)$$

This equation is a good approximation to (2) or (3) as long as S is $\ll 1$ and N large. When S tends to 1, P_N^2 tends to a finite value $P_c^2 N$ and any signal S corresponds to a positive value of P_N^2. By simulation it has been found that if we use equation (1) to derive the signal distribution corresponding to a typical momentum spectrum $F_1(P)$, and then use equation (4) to get a momentum spectrum $F_2(P)$ from this signal distribution, this resulting spectrum $F_2(P)$ agrees well with the input spectrum $F_1(P)$ if N is taken equal to $2/\sigma$ (where σ is the relative fluctuation of the high energy signal in the counter considered). Apart from this truncation, the basic Cerenkov relationship is corrected for a background signal and some non linearities introduced by the δ ray contribution to the signal.

There still remains the serious problem of how one can connect momentum spectra measured by different counters with different resolution. In the experiment, 3 Cerenkov counters are used for the momentum determination : teflon, aerogel block and aerogel sand counters with threshold momenta of 1.07, 2.84 and 6.0 GeV/c respectively(corresponding to a kinetic energy of 0.5, 2.0 and 5.1 GeV/nuc). Fluctuations in the background signal prevent however the use of a counter too close its threshold, so the lower limits of the useful momentum ranges of the counters are somewhat higher than the values mentioned above. Now if the momentum assigned to a particle is the teflon momentum up to 3 GeV/c, the aerogel block momentum between 3 and 7 GeV/c and the aerogel sand momentum above 7 GeV/c, then quite large irregularities appear in the spectra where the ranges meet, since the counter with the lower threshold has a much poorer resolution than the counter with the higher threshold at that point. So we use a different method. The spectra are computed independently for all 3 counters for all particles, i.e. without rejecting those nuclei that trigger the higher threshold counters as well. We can then use the teflon spectra up to 3 GeV/c, block spectra from 3.0 to 7 GeV/c and sand spectra above 7 GeV/c. With this method, no irregularity arises around 3 or 7 GeV/c. Each nucleus is not given a single final momentum, but all three momenta and some nuclei may be counted more than once, having for instance a teflon momentum below 3 GeV/c and a block momentum above that value. Others are never counted as their teflon momentum may be above 3 GeV/c, but their block momentum below that value. When both counters are correctly normalized, equal number of particles is counted twice as is rejected.

3. Results

The resulting relative abundances at various energies are shown in Table I. They are normalized to Silicon = 1 000 on average, i.e. to the

TABLE 1

HEAO-C2 MAR.23 RELATIVE COSMIC RAY NUCLEAR COMPOSITION

EKIN(GEV) CHARGE	.82	1.03	1.29	1.62	2.03	2.54	3.18	3.99	5.00	6.34	8.23	11.0	15.1	25.0	+/-	SLOPE	+/-
4	655.	626.	679.	672.	704.	679.	663.	673.	662.	581.	480.	407.	497.	404.	15.5	-.238	.012
5	2228.	2240.	2203.	2087.	2017.	1877.	1917.	1760.	1613.	1432.	1285.	1140.	934.	810.	24.0	-.391	.007
6	6935.	6846.	6602.	6576.	6630.	6238.	6630.	6384.	6498.	6322.	6337.	5908.	5486.	4885.	44.3	-.091	.003
7	1952.	2022.	2033.	1834.	1840.	1758.	1788.	1700.	1631.	1507.	1455.	1304.	1147.	1011.	22.7	-.250	.006
8	6398.	6337.	6324.	6330.	6284.	6011.	6235.	6214.	6298.	6221.	6285.	5991.	5830.	5392.	43.6	-.040	.003
9	144.	147.	144.	128.	132.	125.	120.	118.	122.	109.	99.	96.	76.	63.	3.0	-.267	.012
10	1076.	1061.	1032.	1026.	1030.	993.	1006.	1001.	988.	985.	971.	937.	905.	851.	8.8	-.069	.004
11	236.	220.	227.	222.	224.	213.	203.	197.	192.	184.	172.	160.	136.	115.	3.9	-.235	.009
12	1358.	1334.	1303.	1306.	1296.	1268.	1243.	1252.	1278.	1230.	1195.	1179.	1153.	1080.	10.1	-.071	.003
13	235.	225.	242.	225.	225.	224.	220.	218.	213.	203.	199.	194.	171.	178.	4.2	-.115	.008
14	988.	992.	1000.	996.	991.	994.	994.	1018.	1016.	999.	1024.	993.	993.	980.	9.1	0.000	.004
15	50.	46.	48.	42.	41.	46.	44.	37.	39.	35.	35.	30.	26.	27.	1.8	-.238	.021
16	200.	211.	203.	204.	198.	201.	201.	200.	194.	197.	193.	196.	170.	172.	4.1	-.059	.009
17	48.	44.	48.	49.	48.	46.	41.	39.	38.	38.	35.	31.	25.	23.	1.8	-.269	.021
18	93.	92.	91.	84.	83.	82.	80.	70.	70.	67.	61.	56.	51.	49.	2.5	-.260	.015
19	71.	69.	64.	62.	56.	56.	55.	54.	52.	50.	46.	37.	36.	31.	2.2	-.280	.019
20	147.	141.	145.	141.	131.	138.	135.	122.	122.	126.	114.	111.	109.	92.	3.3	-.153	.012
21	30.	36.	34.	30.	27.	26.	24.	25.	20.	21.	17.	21.	18.	16.	1.5	-.302	.027
22	97.	99.	98.	96.	91.	87.	82.	80.	77.	71.	68.	65.	57.	47.	2.7	-.264	.016
23	52.	47.	41.	48.	43.	45.	42.	38.	37.	35.	38.	29.	29.	25.	1.9	-.233	.022
24	97.	102.	99.	95.	90.	92.	82.	84.	75.	80.	71.	71.	66.	57.	2.8	-.203	.015
25	59.	56.	63.	56.	58.	64.	62.	57.	59.	56.	57.	53.	54.	48.	2.4	-.068	.018
26	593.	633.	634.	649.	645.	663.	673.	684.	687.	719.	695.	713.	742.	699.	8.3	.058	.005
27	3.6	3.6	3.6	3.2	4.3	3.8	3.7	3.8	4.2	3.4	4.5	4.1	3,2	4.3	.6	.052	.067
28	25.3	25.3	29.0	29.6	32.5	33.5	38.0	37.4	36.1	34.3	38.1	41.5	41.9	33.9	2.0	.123	.024
SILICON: STAT. ERROR	15.2	12.9	11.4	10.4	9.7	9.0	9.0	8.9	9.1	9.2	9.6	10.7	12.4	11.1			

best power law fit of the Si/(all $Z \geq 9$) ratio (in order to avoid having the statistical fluctuations on each individual energy point of Si affect the abundances of all other nuclei).

The statistical errors on Silicon (bottom) and on the 4 GeV/nuc. column (right) are given, from which all the other statistical errors can be quickly estimated - However when calculating relative abundances of widely different charges systematic errors are to be considered, especially due to the corrections for nuclear interactions and hodoscope efficiency. To give an idea of the magnitude of these corrections, when normalized to Si, the correction factor for nuclear interactions varies between 0.83 for B to 1.22 for Fe and the correction factor for efficiency varies from 0.97 for low energy Iron to 1.22 for high energy Boron.

For the Beryllium, the individual spectra given by the three counters agree poorly, so the small statistical error quoted in the table is probably meaningless.

The relative spectral indices in total energy per nucleon are given in the last columns of Table I and plotted in Fig. 1, showing at a glance the steeper spectra of the secondary nuclei and some gradual flattening of the spectra with charge.

Astrophysical implications of these results are discussed in our companion paper.

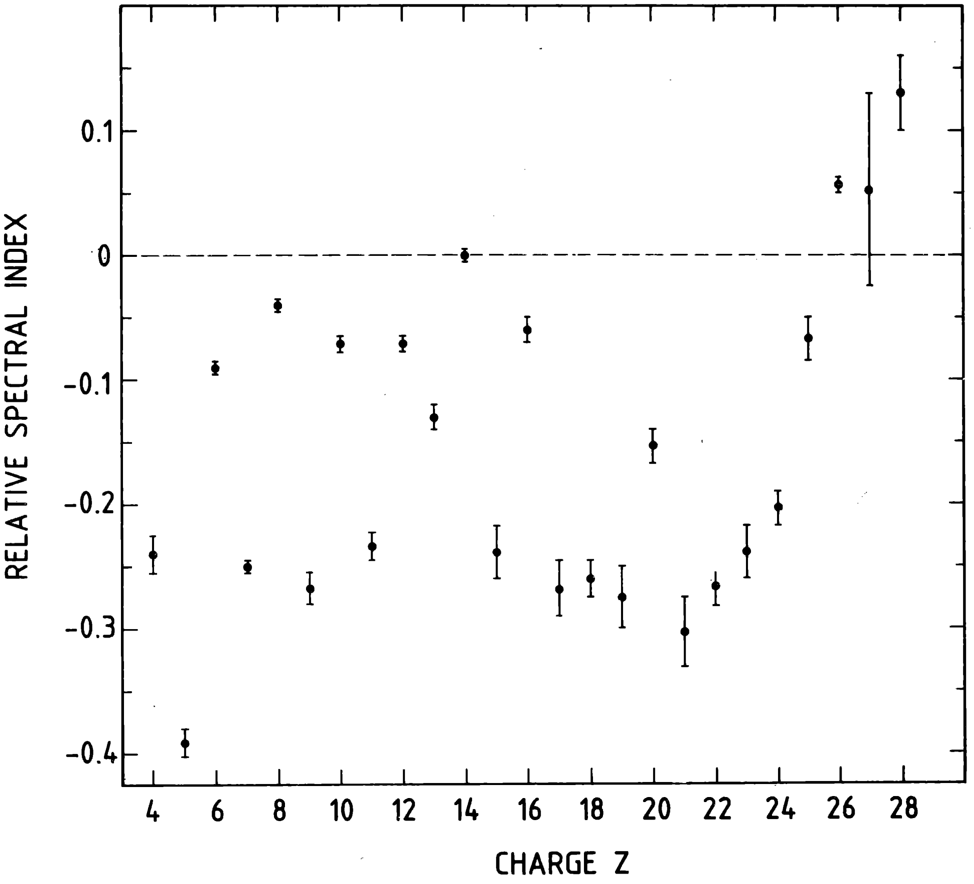

Figure 1. Relative power law indices in total energy per nucleon for cosmic rays from Be to Ni.

References

Bouffard, M., et al. (1982), Astrophys. and Space Sc. 84, 3

Engelmann, J.J., et al., (1981), Proc. of 17th ICRC Paris, 9, 97