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

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ABSTRACT

We report measurements by the French-Danish instrument on HEAO-3 of the relative elemental composition of cosmic rays from Be to Zn in 12 energy windows from 0.7 to 20 GeV/nucleon.

1 . Introduction

Much of our current understanding of the cosmic ray sources and propagation has come from steadily improving measurements of its elemental composition and energy spectra.

This progress should continue with the French-Danish instrument on HEAO-3, which has 5 high resolution Cerenkov counters associated with a flash tube hodoscope to measure the charge and energy of each nucleus and which has collected more than 5 millions non interacting nuclei heavier than Be (ref. 1 to 5)

The abundance values we are presenting in this paper have been obtained after a careful selection of the registered events by using several criteria on the signals from the counters and on the hodoscope response. The selection process and the probability for a particle to interact with the instrument causes some bias in the measured abundances, making it necessary to apply some correction factors to the raw data. Due to the difficulty to measure accurately the differential energy spectra of the cosmic rays with a near-earth orbiting satellite, as discussed in ref. 6, the present paper is only devoted to the presentation of the relative abundances at given energy per nucleon, and to the relative slopes of the spectra.

2. Event selection

The conditions used to select the "good events" are the following :

1) Interacting nuclei are rejected by asking for consistency between the individual charge determinations made by different counters (2 counters below 2.5 GeV/n, 3 counters between 2.5 and 6 GeV/n and 4 counters above 6 GeV/n).

2) We also use certain criteria on the quality and position of the particle track through the instrument as measured by the flash tube hodoscope. This hodoscope consists of 4 trays of two perpendicular layers of flash tubes inserted in the space between the counters (ref. 5). Here we select events

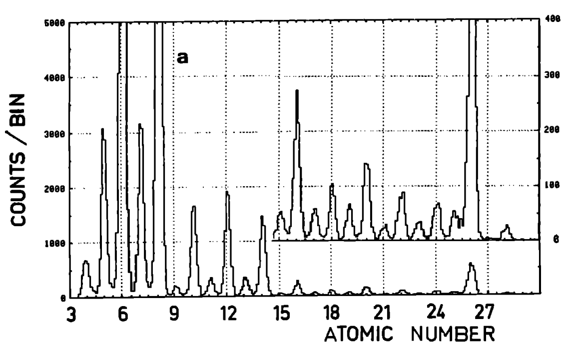
having at least 3 well defined impact points.

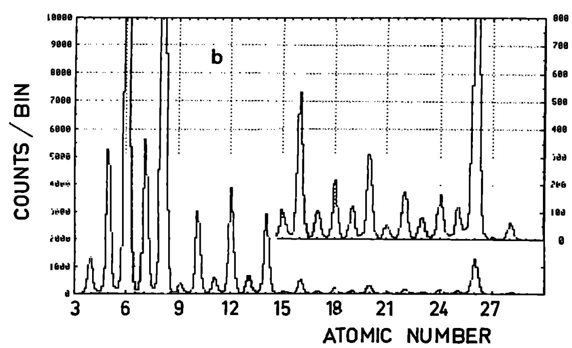
3) For the momentum determination, we need to know the direction of propagation of the particle through the double ended instrument. For charges >8, we use the direction deduced from a time of flight measurement, since it is rarely in error (98% of correct direction assignments). For lower charges, where the time of flight measurement is no more accurate enough, we accept only the particle with a track inside the earth's shadow where the track is unambiguously known to be towards the earth. The two sets of data are normalized to oxygen.

The momentum per nucleon of each particle is derived from the signals from the 3 velocity counters, as described in ref. 3. The momentum resolution is better than 25 % between 1 GeV/c/n and an upper limit depending on the charge of the particle : this upper limit varies from about 12 GeV/c/n for Be to 20 GeV/c/n for Fe nuclei, as shown in Fig 2 of ref 4

4) We reject the particles having a momentum per nucleon close to the momentum/n threshold p_{co} corresponding to the rigidity cut-off calculated for the position and direction of the particle, in order not to affect the abundances by the differebt mean masses of the nuclei.

The charge spectra obtained with the selection conditions are displayed in fig. 1 for the 3 energy ranges corresponding to the 3 velocity counters of the instrument (.8 to 2.5 GeV/n, 2.5 to 6 GeV/n and above 6 GeV/n). As can be seen in these graphs, good separation is obtained for the peaks corresponding to the different charges, except for Mn and Co which are contaminated by the Fe peaK. For these last elements, the charge spectra have been plotted in each energy bin and the Fe contamination evaluated by extrapolation of the Fe peak. The abundance of these elements was then determined with respect to Fe.





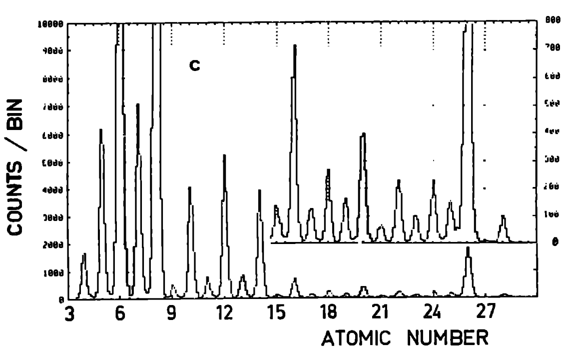


Fig. 1 Charge histograms in 3 energy ranges :
a) from .8 to 2.5 GeV/n
b) from 2.5 to 6 GeV/n
c) above 6 GeV/n
In the inset, the vertical scale has been multiplied by a factor of 10

3. Coefficients of correction

1) The relative flux values are first corrected for loss due to nuclear interactions in the counter material. This correction is calculated by using the charge changing cross sections drawn from Westfall et al. (ref.7) The correction varies between 1.46 (within 2%) for Be and 2.21 (within 3%) for Fe

2) The efficiency of the flash tube hodoscope is not 100%, as discussed in ref.4. This efficiency is charge-dependent and slightly energy-dependent. To determine the correction needed to compensate for this effect, we first select the "good" events by requiring signal consistency between the counters, and then we measure for each charge and energy window the proportion of those events giving a track with at least 3 points per view seen by the flash tube hodoscope. The systematic error on this correction is always small compared to the statistical error.

3) Overlap corrections.

With the consistency criteria used for the signals from the counters, the overlap between charges is insignificant and no overlap correction is needed, except, as mentioned previously for Mn, Co and Cu. This has been verified by varying the selection criteria : this did not cause any significant variation in the measured relative abundances of the other elements.

4. Results

The resulting abundances normalized to Si are presented in Table I for 12 energy windows. For a given element, the statistical error is nearly the same for all energy windows and is given in the last but one column of the Table.

For the very rare elements Co, Cu and Zn, the 12 energy bins have been grouped in 3 energy windows. To improve the statistics, their abundance was mesured with an extended gometry : particles were accepted even if they did not cross one of the two lead glass counters. The correction factor for efficiency variation with charge in these conditions was derived from a comparison of the Cr , Fe and Ni abundances measured in normal and extended geometry

TABLE 1

EKIN(GEV/N) CHARGE	.9	1.1	1.4	1.8	2.2	2.8	3.5	4.5	5.6	7.2	9.6	15.0	STATIST. ERROR,%	POWER LAW FIT,SLOPE
4				793.	820.	745.	750.	654.	642.	617.	513.	400.	2.7	-.27
5	2232.	2193.	2213.	2154.	2163.	1936.	1786.	1637.	1460.	1360.	1150.	810.	1.7	-.42
6	6944.	6868.	6853.	6952.	7256.	6653.	6507.	6290.	5885.	6200.	5960.	5180.	.7	-.12
7	1936.	1901.	1898.	1867.	1911.	1708.	1637.	1598.	1441.	1430.	1330.	1110.	1.4	-.24
8	6234.	6394.	6238.	6200.	6406.	6006.	5963.	5988.	5862.	6120.	6020.	5590.	.7	-.04
9	134.	140.	126.	123.	137.	125.	118.	121.	120.	106.	103.	80.	2.5	-.17
10	1028.	1056.	972.	784.	1004.	976.	957.	967.	916.	930.	900.	860.	1.1	-.09
11	229.	227.	232.	216.	218.	205.	185.	189.	185.	175.	165.	139.	2.0	-.20
12	1324.	1316.	1291.	1254.	1305.	1243.	1219.	1226.	1226.	1200.	1181.	1132.	1.0	-.06
13	228.	229.	230.	224.	237.	225.	212.	212.	202.	197.	186.	175.	2.0	-.14
14	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1000.	1.0	0.00
15	50.	55.	53.	47.	47.	49.	42.	37.	37.	36.	33.	27.	4.0	-.31
16	205.	213.	199.	203.	206.	204.	198.	188.	195.	195.	186.	185.	2.1	-.07
17	50.	47.	49.	47.	48.	44.	40.	39.	36.	34.	34.	28.	4.0	-.26
18	93.	93.	89.	82.	85.	81.	69.	68.	66.	62.	58.	56.	3.5	-.29
19	74.	74.	67.	61.	60.	61.	51.	52.	52.	46.	41.	37.	4.0	-.31
20	145.	148.	137.	142.	141.	144.	128.	125.	118.	114.	110.	108.	2.7	-.20
21	32.	39.	35.	28.	26.	25.	23.	23.	19.	19.	18.	16.	6.0	-.42
22	107.	107.	96.	97.	91.	91.	77.	74.	71.	64.	60.	55.	3.5	-.36
23	58.	52.	47.	45.	47.	44.	36.	39.	34.	34.	32.	25.	4.0	-.30
24	107.	105.	100.	94.	90.	98.	80.	85.	77.	70.	67.	65.	3.5	-.27
25	63.	65.	64.	63.	60.	62.	56.	57.	56.	52.	48.	51.	4.0	-.17
26	635.	654.	636.	627.	659.	685.	655.	663.	661.	650.	641.	687.	1.5	.02
27			3.9				4.1				4.0		6.0	
28	28.1	26.9	30.6	28.5	29.0	33.6	35.0	35.3	33.4	32.0	36.0	37.0	5.0	.16
29			.38				.46				.47		15.0	
30			.35				.42				.43		15.0	

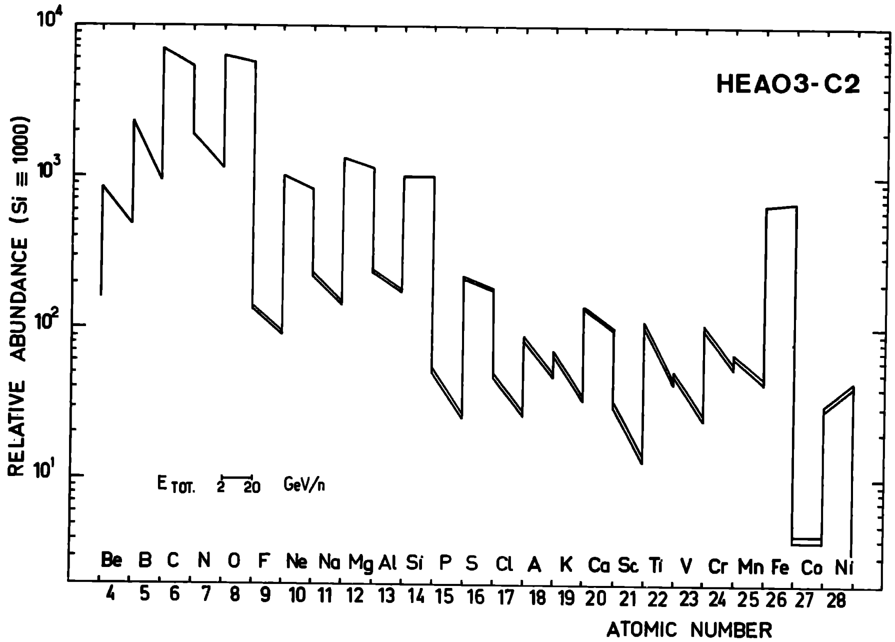


Fig. 2 - Elemental abundances between 2 and 20 GeV/n (total energy) normalized to Si.

These results are also plotted in fig. 2 where both the abundance and its energy dependence are shown from 2 to 20 GeV/n. Here a power law in total energy was assumed and the slope relative to Si was calculated as giving the best fit to abundances measured in the different energy windows. The differences in power law index to that of Si (absolute indices are not available) are included in the last column of Table I. The results show clearly the difference in spectral slopes for the primary and secondary elements. Also the spectra get systematically harder as the charge increases

Detailed presentation of relative spectra and their interpretation in terms of propagation in the galaxy and abundances at cosmic ray sources can be found in ref. 8 and 9.

The results are in general agreement with previously measured values but are much more accurate, particularly above Silicon, due to the good charge resolution of the instrument and the high statistical accuracy, with about 150 000 Fe nuclei analysed. One must however include additional non-statistical errors when comparing widely different charges since the corrections for hodoscope efficiency and nuclear interactions introduce systematic errors, which may reach 5% for elements as far apart as Be and Fe. The instrument complexity and the amount of data are such that the present results should not be considered as final.

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