THE COSMIC RAY ABUNDANCES OF THE PLATINUM-LEAD ELEMENTS
AS MEASURED ON HEAO-3

D.J. Fixsen and C.J. Waddington
School of Physics and Astronomy, University of Minnesota
Minneapolis, Minnesota 55455, U.S.A.

W.R. Binns, M.H. Israel, and J. Klarmann
Washington University, St. Louis, Missouri 63130, U.S.A.

T.L. Garrard, B.J. Newport, and E.C. Stone
California Institute of Technology
Pasadena, California 91125, U.S.A.

ABSTRACT

The relative abundances of elements in the charge ranges of
75 < Z < 79 (platinum) and 80 < Z < 83 (lead) should be a sensitive
indication of the contributions of the r- and s-processes in
nucleosynthesis. Data from the HEAO 3 Heavy Nuclei Experiment
are used to establish abundances, relative to iron, of these
elements in the cosmic radiation, as well as the ratio of
"secondary" elements, in the 62 < Z < 74 range, to the primary
lead-platinum elements. These results appear to suggest that
either the source abundances are deficient in s-process elements
or that they are not organized solely by first ionization poten-
tial. In addition, present propagation models can adequately
represent the relative abundances of primary and secondary
elements.

1. Introduction

The HEAO 3 heavy nuclei experiment was designed to observe nuclei in
the cosmic radiation with atomic numbers, Z, between 16 and 100 (Binns et
al., 1981). In this paper we report our observations on those elements
with Z appreciably above the abundance peak in the 50Sn–56Ba region, with
particular emphasis on the abundances in the platinum-lead region. Our
earlier conclusions on these abundances have been reported elsewhere
(Binns et al., 1982).

A predominant reason to study the abundances of the UH-nuclei is to
compare the abundances present in the source of cosmic rays with those
abundances predicted by various scenarios of nucleosynthesis. Most of
the nuclides in this charge range are synthesized by either the rapid
(r-process) or slow (s-process) addition of neutrons to lighter seed
nuclides. Thus abundances, such as that characteristic of solar system
(SS) material, can be regarded as a mix of predominantly r- and s-process
nuclides. The lead-platinum region provides a sensitive test of the mix
of the cosmic ray source abundances, since "platinum" (actually 76Ga–79Pt)
is almost exclusively produced by the r-process, while "lead" is a product
of both the r- and s-process. An observed ratio of Pb to Pt, here defined
as P80 = N(80 < Z < 83)/N(75 < Z < 79), can be compared with values of P80
calculated assuming a particular source value and a model of propagation.
Alternatively P80 can be propagated back to a source and then compared with various possible source values. The results of typical calculations are given in the table, using the propagation codes of Brewster et al. (1983), with and without allowance for the effects of first ionization potentials (FIP). It can be seen that for an exponential escape length of 5.5 g/cm² of interstellar hydrogen, the differences in P80 between r- and SS-like material are significant and generally measurable. In these calculations we have used the solar system abundances of Anders and Ebihara (1982) and two versions of r-process abundances, that calculated by us (Israel et al., 1981) from a s-process deconvolution of the solar system abundances of Cameron (1982a), "r2", and one deduced by Cameron (1982b), "r1". These differ principally, and sharply, in the derived abundances of lead.

| TABLE |
|--------------------|----------------|----------------|----------------|----------------|----------------|----------------|
| Source Type       | Source Near Earth | Detector | Source Near Earth | Detector | Source Near Earth | Detector |
| SS                | 1.34             | 1.08      | 1.05             | 0.088 | 0.22             | 0.24       | 0.22             | 0.47       | 0.51       |
| SS(FIP)           | 1.93             | 1.48      | 1.42             | 0.13  | 0.26             | 0.28       | 0.31             | 0.67       | 0.72       |
| r1                | 0.047            | 0.064     | 0.062            | 0.10  | 0.27             | 0.29       | 0.40             | 0.74       | 0.80       |
| r1(FIP)           | 0.052            | 0.049     | 0.048            | 0.18  | 0.36             | 0.38       | 0.86             | 1.35       | 1.43       |
| r2                | 0.47             | 0.42      | 0.41             | 0.11  | 0.26             | 0.29       | 0.31             | 0.61       | 0.66       |
| r2(FIP)           | 0.72             | 0.63      | 0.62             | 0.16  | 0.31             | 0.33       | 0.57             | 0.93       | 1.00       |

Observed No. 22/46 27/68 70/68
Ratios* 0.48±0.18 0.46±0.09 1.03±0.22

*Assumes charge resolution dominated by photo-electron statistics.

During propagation the heavy Pb-Pt nuclei will produce lighter secondary fragments which will significantly contribute to the observed abundances of elements in the range 62 ≤ Z ≤ 74. We have examined these changes by considering two abundance ratios of secondary to primary elements, S70 = N(70 ≤ Z ≤ 74)/N(75 ≤ Z ≤ 83), and S60 = N(62 ≤ Z ≤ 69)/N(75 ≤ Z ≤ 83). Predictions for the values of these ratios are also given in the table and again show differences that should be measurable. The significance of these results is discussed by Klarman et al. in paper OG5.2-13. Also shown in the table are ratios corrected for the effects of the overlapping matter in the detector. This correction is only approximate and has been obtained by assuming that the 1.5 g/cm² of Al overlying the detector can be represented by a slab of 0.15 g/cm² of Hydrogen for nuclei with Z > 60.

2. Analysis

From the data collected over a period of 574 days, we selected all events for which any of the ion chamber signals or the sum of the Cherenkov signals was greater than what would be produced by a Z = 60 particle, assuming Z² scaling from iron. Along with the true Z > 60 events this data set included many lower charge and spurious events which were subsequently rejected. Events with high ionization due to their having low energy were rejected by the relative magnitude of Cherenkov and ion chamber signals. Events in which a spurious coincident particle hit a
photomultiplier or an ion chamber were rejected by requiring consistency of signals among Cherenkov elements or ion chambers. Events in which the particle trajectory was not well enough defined to give reliable charge estimates were also rejected. Of these criteria only the last may be significantly charge dependent, since higher Z nuclei can be expected to produce more knock-on electrons capable of triggering additional hodoscope wires. However, by keeping these criteria quite relaxed, the influence of any charge dependent effects has been minimized.

The result of our selections is a file of events that was then individually examined, enabling us to identify several further small classes of nonacceptable events. The experience gained from this event by event analysis has allowed us to construct algorithms that can be systematically applied to the data to produce a final "good" data set of 166 events with Z > 62.

We have then to determine the best available charge estimates for this data set. This problem has been approached by using the abundant iron nuclei, Z = 26, to normalize both the abundances and charge scales. Some 12,000 Z = 26 events were selected from a representative sample of the original data. As part of the selection process, particles were separated into various groups, depending on whether they had low or high geomagnetic cutoffs, and whether the signals implied the particles had medium or high energies. For each of these groups the iron nuclei provided a well-defined charge peak that has been used to fix the charge scale at Z = 26. If the signals are assumed to scale as Z^2 then this also determines the charge scale in the 60 < Z < 90 region. Our calibration with beams of Mn and Au nuclei (Garrard et al., paper T2-10) was only to energies up to 960 MeV/amu for Au and showed distinct non Z^2 effects in ionization response but much smaller non Z^2 effects in Cherenkov response. In the present paper we deal only with high energy (greater than 1.5 GeV/amu) nuclei for which the charge assignment is based on the Cherenkov signal. While we have no direct calibrations at these energies, the lack of strong deviations from Z^2 Cherenkov responses in our calibration leads us to adopt a simple Z^2 response here.

3. Results

Our charge spectrum is given in Fig. 1, which shows the actual numbers of measured particles. These abundances have been normalized to \((17.4\pm1.0) \times 10^6\) iron nuclei in the detector, assuming no Z dependent selection effects. They can be approximately corrected to near earth space by an 11% correction for losses due to interactions within the detector and by 9%, 4%, and 0% corrections for the "Pb", "Pt" and secondary elements due to propaga-
tion through the front window.

The table shows the observed counts for P80, S70 and S60. By considering the observed resolution of the iron peaks in the data set, we have estimated the possible effects of charge smearing on these ratios and show in the table our deduced values for each ratio together with their estimated uncertainties.

4. Conclusions

The cosmic ray abundances, when compared with the solar system, appear to be depleted in lead by a factor of at least two to three. Similarly, we also find that in the Sn-Ce region the ratio of r-process to s-process contribution to the cosmic ray source abundances (taking account of FIP effects) is $1.5^{+0.8}_{-0.5}$ times the corresponding ratio in the solar system (Stone et al., paper OGI-21).

One interpretation of the Pb depletion would note that Pb is one of the few volatile elements with low FIP (Meyer, 1981). If volatility rather than FIP is the organizing parameter for cosmic ray source depletion, then an underabundance of lead would be expected, while there would be a smaller effect in the Sn-Ce region, since although Sn like Pb is a low FIP volatile s-process element, the s-process in that region is not only determined by Sn. In this interpretation it may not be necessary to require any depletion of the abundances of s-process nuclides.

An alternative interpretation of these two results is that both indicate an s-process depletion which implies that the source composition is measurably different from that of solar system matter.

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References