LEAD, PLATINUM, AND OTHER HEAVY ELEMENTS IN THE PRIMARY COSMIC RADIATION--HEAO-3 RESULTS

C.J. Waddington,[1] W.R. Binns,[2] N.R. Brewster,[1] D.J. Fixsen,[1]
T.L. Garrard,[3] M.H. Israel,[2] J. Klarmann,[2] B.J. Newport,[3] E.C. Stone [3]

[1]School of Physics and Astronomy, University of Minnesota,
Minneapolis, MN 55455
[2]Department of Physics and the McDonnell Center for the Space
Sciences, Washington University, St. Louis, MO 63130
[3]George W. Downs Laboratory, California Institute of Technology,
Pasadena, CA 91125

1. Introduction. This paper reports an observation of the abundances of cosmic-ray lead and platinum-group nuclei using data from the HEAO-3 Heavy Nuclei Experiment (HNE) which consisted of ion chambers mounted on both sides of a plastic Cherenkov counter (Binns et al., 1981). Previously we have reported on a search for actinide nuclei, $Z > 88$ (Binns, et al. 1982a). Further analysis with more stringent selections, inclusion of additional data, and a calibration at the LBL Bevalac, have allowed us to obtain the abundance ratio of lead and the platinum group of elements for particles that had a cutoff rigidity $R_c > 5$ GV.

2. Analysis. We have analyzed 580 days of exposure and considered selected data for those events where the Cherenkov detector and at least two of the ion chambers were triggered. These selection criteria will be described elsewhere, Binns et al. (1985).

Two sets of events satisfying the selections were formed--one for which $Z > 49.5$; the other, a "normalization" set, with 1/400 of all events with $Z > 19.5$, chosen at random.

The events were separated into two groups, 67% with $R_c > 7$ GV and 33% with $5 < R_c < 7$ GV. The charge scale and resolution for each group were determined independently by examining the iron peak in the corresponding normalization set. In both groups, the nuclear charge of each event was inferred from the Cherenkov signal, assuming that the signal was simply proportional to Z^2, Garrard et al. (1983).

Fig. 1 shows the observed charge spectrum. This data set demonstrates an odd-even abundance effect for $50 \lesssim Z \lesssim 56$ and a sharp falloff in abundances between 56 and 60, similar to that found previously in a data subset having higher charge resolution (Binns et al. 1983). The 322 nuclei with $Z \geq 50$ used in this analysis correspond to $(9.6 \pm 0.5)10^6$ iron nuclei which satisfy the same selection criteria and are observed within

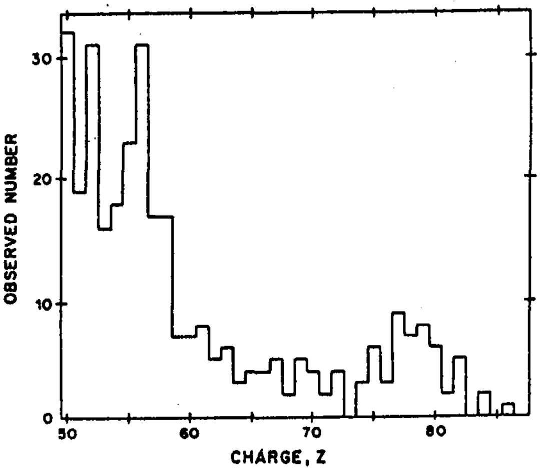

Fig. 1. Observed charge spectrum with charges assigned assuming a Z^2 dependence of the Cherenkov signal.

the instrument, not in free space. The quoted uncertainty is predominately due to the uncertainty in resolving $_{25}$Mn from $_{26}$Fe.

3. Comparison with Other Data. Results that cover this charge range have been reported from the Ariel-6 UH-nuclei detector which was exposed in a 55° inclination orbit (Fowler et al. 1984), and hence extends to appreciably lower energies than our data. In order to analyze the Ariel data, Fowler et al. had to deconvolve their data using an extrapolation of the resolution function found for Fe and lighter nuclei. We have not attempted a deconvolution of our charge spectrum, since the results of such a process are quite sensitive to the form of the assumed resolution function, particularly when individual element peaks are not apparent in the data. Due to our limited charge resolution we have considered only the following physically significant groups of charges:

Name	Abbreviation	Range	Number observed
"Lead"	Pb	$81 \le Z \le 86$	10
"Platinum"	Pt	$74 \le Z \le 80$	42

The ratio of the abundance of lead to platinum will be compared with other data and with model predictions. The secondary ratios will be discussed elsewhere, see Klarmann et al. (1985; OG 4.4-6).

The value of 0.24±0.08 for the Pb/Pt ratio derived from our observations differs from that outside the detector because of nuclear interactions during entry and penetration of the detector and the instrumental resolution, which smears the charge distribution. For each of eight plausible models we calculated abundances expected near earth, as described below. Entry into the detector was then simulated by propagation through various slabs of hydrogen approximating the amount of aluminum in the various paths into and through the detector. The resulting element distribution inside the detector was then convolved with the instrument resolution to derive the distribution we would expect to observe. Although the eight models gave very different values for the ratio at the outside of the instrument, the factor by which the ratio changed after propagation into the instrument and convolution with the resolution was nearly the same for all the models. Therefore, we have used a single correction factor of 1.06±0.02 for the ratio.

Our resulting ratio of 0.25±0.09, outside the detector, can be compared with the corresponding result reported by the Ariel experiment of 0.40±0.10. If this result is combined with those on the secondary ratios, there does seem to be a systematic difference between the two sets of results, although of marginal statistical significance on any individual ratio.

4. Comparison with Models. Our observed charge spectrum, Fig. 1, can be compared with those predicted by various models. A series of predictions were made using the solar system abundances of Anders and Ebihara (1982) and the derived s- and r-process contributions to these abundances. These abundances, taken as calculated, or adjusted for the effects of an exponential dependence on first ionization potential (FIP) fractionation, were used as source abundances. An alternative dependence on FIP, with a step at 9 eV or above, Cook et al. (1979); Meyer (1981), would lead to abundances essentially independent of FIP. These various source abundances were then propagated through the

interstellar medium, assuming a leaky-box model, and using the revised code of Brewster et al. (1983 , 1985) with a rigidity dependent escape length (Ormes and Protheroe 1983) that is 6.21 g/cm^2 of hydrogen at 7 GV. We have used the cross-sections calculated from the formalism of Silberberg and Tsao (1983). The predictions of this program are in good agreement with the latest predictions obtained by Margolis and Blake (1983), at least for the solar system source abundances.

In Fig. 2, we have shown the calculated values of this ratio for solar system abundances and for r-process abundances; s-process abundances are not given because they show little relation to the observed values with Pb/Pt ratios of ∿ 1.0.

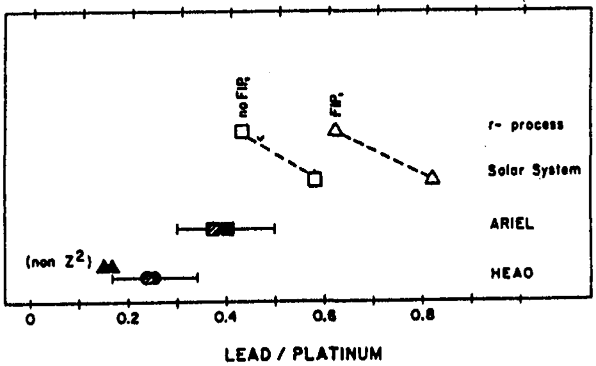

Fig. 2. The "lead to platinum" ratio as observed and predicted. Observed values are shown shaded, while in space values are shown solid and with error bars. The shaded and solid triangles indicate the ratios when a non Z^2 correction to our charge assignments is included.

Our observed ratio for Pb/Pt (Fig. 2) is distinctly lower than that predicted from solar system source abundances in any of the four models considered. In particular, even considering the models without exponential FIP fractionation, we find an observed ratio that is distinctly lower than that predicted for either a solar-system or an r-process source. This result might suggest that, unlike the cosmic rays with Z < 60 (Binns et al. 1982b, 1983), the cosmic rays with Z around 80 come from a source with a distinctly different nucleosynthesis history than do the solar system elements. However, two alternatives to this conclusion must also be considered. First, the Pb abundance in the cosmic ray source may be suppressed by some form of source fractionation which depends upon a different parameter than FIP. Second, it could be that the Pb abundances assumed in our model calculations are not really representative of the solar system or of the r- or s- process contributions to the solar system.

We have noted (Israel et al. 1983) that the cosmic ray abundance of Ge relative to Fe is down by a factor of about two compared to the solar system. Ge, like Pb, is one of the few volatile elements with moderate to low FIP. The factor-of-two underabundance of Ge lends support to the suggestion (Cesarsky and Bibring 1980; Epstein 1980) that it is volatile elements, rather than elements with high FIP, which are underabundant in the cosmic rays. Such a source fractionation dependent on volatility could produce our observed low Pb abundance even with a cosmic ray source whose composition is essentially the same as that of the solar system.

Alternatively, there are reasons for believing that the source abundances of Pb used in our models may not be representative of the solar system values. Our observed Pb/Pt ratio could be consistent with that expected from a "Pb-poor r-process", either with or without FIP fractionation.

It is possible that the assumed solar system Pb abundance itself is too high. If the Anders and Ebihara Pb abundance were twice that of typical solar system matter, then a solar system source abundance, either with or without FIP fractionation, would agree with our data.

Finally, we note that Ge and Pb, like most elements with higher FIP, have abundances in C2 chondritic meteorites about a factor of two lower than abundances in the Cl chondrites which are the basis for the Anders and Ebihara solar system abundances. If the C2 rather than the Cl chondrites were more nearly representative of the composition of the heavier elements in the solar system, then our low Pb/Pt ratio would again be consistent with a cosmic ray source of composition similar to that of the solar system.

Thus, while our Pb/Pt ratio is distinctly lower than that predicted by any of the standard models for cosmic ray sources, it is possible that the difference is not an indication that the cosmic ray source composition is greatly different from that of the solar system, but rather that there is less Pb in the solar system and in the r-process than is assumed in the standard model.

5. Acknowledgements. The research was supported in part by NASA under grants NAG 8-498, 500, 502, and NGR 05-002-160, 24-005-050, and 26-008-001.

References

Anders, E., and Ebihara, M. (1982), Geochimoca et Cosmochimica Acta, 46, 2363.
Binns, W. R., et al. (1981), Nucl. Inst. Meth., 185, 415.
Binns, W. R., et al. (1982a), Ap.J. (Letters), 261, L117.
_______. (1982b), Ap.J. (Letters), 247, L115.
Binns, W. R., et al. (1983), Ap.J. (Letters), 267, L93.
Binns, W. R., et al. (1984), Adv. Space Res., 4, 25.
Binns, W. R., et al. (1985), to be published in Ap.J., Oct. 1.
Brewster, N. R., Freier, P. S., and Waddington, C. J. (1983), Ap.J., 264, 324.
_______. (1985), to be published in Ap.J., July 1.
Cesarsky, C. J., and Bibring, J. P. (1980), IAU Symposium, 94, 361.
Cook, W. R., et al. (1979), 16th ICRC, Vol. 12, 265.
Epstein, R. I. (1980), MNRAS, 193, 723.
Fowler, P. H., et al. (1984), 9th European Cosmic Ray Symposium.
Garrard, T. L., et al. (1983), 18th ICRC, Vol. 9, 367.
Israel, M. H., et al. (1983), 18th ICRC, Vol. 9, 305.
Klarmann, J., et al. (1985), this conf., OG 4.4-6.
Margolis, S. H., and Blake, J. B. (1983), 18th ICRC, Vol 9, 283.
Meyer, J. P. (1981), 17th ICRC, Vol. 2, 281.
Silberberg, R., and Tsao, C. H. (1983), Ap.J. Supp. 25, 315, 335.