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"HAVE WE SEEN A HEAVY ANTI-NUCLEUS?"*

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ABSTRACT

The event of Price et al.[1] might be explained as a heavy anti-nucleus. The crucial experimental question is the nuclear emulsion track. Simple comparison of nuclear emulsion tracks should reveal a great difference between heavy nuclei and their charge conjugates. These electrodynamic differences could allow greatly increased anti-matter searches. Any disagreement of the present analysis of the event of Price et al. with null results in previous anti-matter searches is speculative.

The cosmic ray event of Price et al.[1] has received much critical comment. M. W. Friedlander,[2] P. H. Fowler,[3] L. W. Alvarez,[4] R. L. Fleischer and R. M. Walker[5] have all proposed alternative hypotheses to the interpretation presented in Ref. 1. These alternative hypotheses have not been accepted by the authors of Ref. 1:[6] The success of each of these alternative explanations hinges upon disregarding the original interpretation of the nuclear emulsion data. This disregard was justified because the technique for measuring the lateral track structure, i.e., the extension of darkening away from the

track center, was an unpublished experimental technique. The authors of Ref. 1 claim greatly depleted lateral track structure whereas the critics must doubt this claim to succeed with their alternative explanations. I propose an alternative explanation of this remarkable event which may account for <u>all</u> the experimental claims. Specific steps will be proposed to allow definitive tests of my explanation and to allow at least partial settlement of the doubts raised in Refs. 2-5.

Let us consider a simplified and qualitative description of the experimental claims of Price et al.[1] for their event, including their revised measurements from the Lexan.[6]

(1) <u>It is the most penetrating ionizing particle seen to date</u>: As nuclei slow, their ionization rises steeply. This event had so high an ionization ($|Z/\beta| \approx 114$) that, were it any nucleus previously seen in cosmic rays ($-1 \leq Z \leq 96$), it should have slowed considerably in passage through the Lexan stack. Nevertheless, the ionization did not rise.[6]

(2) <u>It has greatly diminished track structure away from the dense central core of the nuclear emulsion track</u>: Since the value of $|Z/\beta|$ was accurately measured in the Lexan, we need only consider various nuclei by specifying β, since $|Z|$ is then also determined. Nuclear emulsion tracks of known Z/β reflect β very weakly until β is very small, less than $\beta = 0.45$ in one controversial model.[3] Thus, if the emulsion track of a normal nucleus is significantly depleted relative to those expected from fast normal nuclei with $Z/\beta \approx 114$, the particle must be very slow and should come promptly to rest in the Lexan stack beneath. The penetrating behavior in the Lexan stack prohibits such slow speeds.

(3) It has a diminished image on the fast-film Čerenkov detector: The Čerenkov image was reported to exhibit a central darkening due to ionization electrons and a lack of darkening in the region where darkening would be attributed to Čerenkov photons. The size of these regions was not reported, nor was any quantitative appraisal of the statistical dependability of the measurement offered.

The expected behavior of heavy anti-nuclei is qualitatively compatible with the three preceding observations:

($\bar{1}$) It has long been known that negative particles are more penetrating than their charge conjugates, the difference being attributable to higher order electrodynamics.[7] The stopping powers for heavy nuclei and their charge conjugates differ by 10% to 30% in the applicable realm.[8]

In addition, it has been pointed out, for instance in Refs. 2-5, that reactions which slightly diminish $|Z_{projectile}|$ allow a projectile to appear more penetrating. The probability of any chain of fragmentations occurring is rather small. Certainly the cross-sections for noncataclysmic charge loss will be different for anti-nuclei. It is likely that such cross sections are considerably larger for anti-nuclei than for normal nuclei. Such a possibility may be subjected to partial experimental test.[9]

Since anti-nuclei as a class are more penetrating, they will match the Lexan data better than their charge conjugates. Therefore, let us consider as possible candidates the charge conjugates of the normal nuclei proposed in Refs. 2-5, i.e. $-96 \leq Z \leq -75$.

($\bar{2}$) Distant energy deposition in nuclear emulsions reflects, in convoluted form, the production of knock-on electrons with energies in the range $25\ \text{KeV} \leq E \leq 1000\ \text{KeV}$. The appropriate electron-nucleus cross section for knock-on electron production from cosmic nuclei is the "Mott exact 'phase shift' formula".[10] Table 1 exhibits relevant ratios of these cross sections for appropriate anti-nuclei to their charge conjugates. The distant energy deposition in emulsions will be greatly reduced for anti-nuclei.

The differences between the emulsion tracks of nuclei and anti-nuclei responsible for this event would be unmistakable. Various anti-nuclei which might fit the Lexan data would leave emulsion tracks similar to those from normal nuclei with $75 \leq Z/\beta \leq 85$. Such a track would differ greatly from that of a normal nucleus which might fit the Lexan data ($110 \leq Z/\beta \leq 120$). The total number of knock-on electrons with energies $25\ \text{KeV} \leq E \leq 1000\ \text{KeV}$ would be less than 2400 for anti-nuclei but greater than 3000 for normal nuclei. The summed kinetic energy of these electrons would be < 240 Mev and > 380 Mev, respectively. The statistical significance of these differences is great. Simple comparisons of photomicrographs of the track in question with tracks of identified nuclei would be sufficient to deny the anti-nucleus hypothesis completely or else to offer considerable encouragement. The most valid basis for comparison would be to compare tracks of nearly equal pitch angles to allow for systematics of observation and to equalize the effects of edge loss of knock-on electrons, which effects have been emphasized by M. W. Friedlander[2] and P. H. Fowler.[3]

If the emulsion track is small, and if it is similar to the

tracks of the normal nuclei with $75 \lesssim Z/\beta \lesssim 85$, we must disregard the alternative explanations as normal nuclei in favor of the anti-nucleus hypothesis or more radical explanations.

(3) The Čerenkov detector of Ref. 1 is an essentially unproved experimental tool. In separating regions of the recording film as reflecting exclusively ionization electrons or exclusively Čerenkov photons, we must make a theoretical determination of the relative magnitudes of the two processes. Analysis of this problem[11] indicates that for distances less than, say 100μ, energy deposition by knock-on electrons dominates that by the Čerenkov photons. Without thorough knowledge of the relative efficiencies for darkening by photons and electrons, diminution of images smaller than this size cannot necessarily be attributed uniquely to lack of Čerenkov energy or knock-on energy. The nuclear emulsion clearly shows us that the knock-on energy is depleted, so we certainly should expect the fast film image to be diminished.

The claims for this Čerenkov detector need clarification. A great deal of clarification would be obtained by publication of the actual images of events from this experiment. The anti-nucleus hypothesis would be less attractive if a firm claim for $\beta < 0.68$ can be substantiated in the Čerenkov detector, because the Lexan value of $|Z/\beta| \approx 114$ would then imply $Z \approx -75$, which anti-nucleus would certainly need to fragment in order to fit the Lexan data.

We must consider whether this anti-nucleus interpretation can be reconciled with other experimental observations,[12] in particular, the previous searches for cosmic anti-nuclei.[13] The previous searches had such small collecting power that no nuclei with charges approaching

the appropriate magnitude ($|Z| > 75$) could possibly have been expected. In addition, almost all of the searching was conducted at high rigidities whereas the event of Price et al., if an anti-nucleus, was of low rigidity. There is little reason to expect that either the charge spectrum or the rigidity spectrum of anti-nuclei must be the same as for normal nuclei. Of course, one can not confidently predict a flux rate on the basis of a single observed event. Nonetheless, we can guess that if the event of Price et al. truly was an anti-nucleus, the spectrum of anti-nuclei is biased toward higher charges and lower rigidities perhaps a factor of 50 or more above that of normal nuclei. Various schemes may be imagined which might produce such an enhancement.[14] Further efforts in this vein would be fruitless, as the discrepancy, if any, with previous experiments is speculative.

It is always necessary to confirm any single event observation: Expanded searches should be conducted among the highly charged, lower rigidity cosmic nuclei. The differences in electron knock-on cross sections between positive and negative nuclei might be exploited to expand the previous anti-matter searches.[15]

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Table 1

Knock-on energy spectra. The ratio of $d\sigma/dE$ for various anti-nuclei to $d\sigma/dE$ for $Z = +92$, $\beta = 0.81$. The ratios vanish when $E > E_{cutoff}$. The ratios on this table are computed from cross sections obtained via interpolation from Doggett and Spencer.[16] The stated ratios are uncertain by $\pm$ 0.02.

		$\left(\frac{d\sigma}{dE}\right)_{Z,\beta} \Big/ \left(\frac{d\sigma}{dE}\right)_{Z=+92,\beta=0.81}$ Energies (KeV)					
Z	β	E=30	E=100	E=300	E=700	E=1000	E_{cutoff}(KeV)
-92	0.81	0.88	0.78	0.53	0.32	0.27	1909
-82	0.72	0.87	0.76	0.52	0.31	0.26	1096
-78	0.68	0.88	0.78	0.53	0.32	0.00	900
-75	0.66	0.87	0.76	0.53	0.32	0.00	780

FOOTNOTES AND REFERENCES

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