Letters to the Editor

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Nuclear Isomers of Ba^{133} and Ba^{135}*

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THE 28.7-hr γ, e^- activity of barium has been identified by Robertson and Pool[1] with Ba^{135}, and has been shown[2] to arise from an isomeric transition of approximately 300 kev. The 39-hr γ, e^- activity of Ba^{133} was first observed by Cork and Smith,[3] and was shown to be associated with an isomeric transition of 276.4 kev. In the present note we give further results concerning these very similar transitions.

Samples of $BaCO_3$ enriched[4] to 51 percent in Ba^{134}, but containing only 0.08 percent of Ba^{132}, were activated in the heavy water pile at the Argonne National Laboratory. Spectrographic analysis using a 180° focusing instrument showed the presence of lines caused by the K- and L-conversion of a 269±2-kev γ-transition. These lines, from which an N_K/N_L ratio of ~2 was estimated, decayed with a half-life of approximately 30 hr. Using a NaI scintillation counter of determined efficiencies for the γ- and x-radiations, a value of 3.5±1.5 was obtained for the K-conversion coefficient of the 269-kev transition.

The Ba^{133m} sources were obtained by chemically separating barium from $CsNO_3$, bombarded by 10-Mev deuterons. Spectrographic analysis showed the presence of K-, L-, and M-conversion lines from a 275.5±1-kev γ-transition, in good agreement with Cork and Smith's value. A scintillation counter experiment gave for this transition a K-conversion coefficient of 3±1, which may be compared with Cork and Smith's value of 1.8.

The lifetimes of both isomers agree extremely well with the theoretical values[5] for magnetic 2^4 transitions, *viz.*, 45 hr for Ba^{135m} and 42.5 hr for Ba^{133m}. Although one would expect the more energetic transition of Ba^{133m} to be shorter lived than the transition in Ba^{135m}, the agreement between calculated and experimental lifetimes is well within the uncertainty factor of $10^{\pm 2}$ arising from the lack of knowledge of matrix elements.

The observed K-conversion coefficients, although not deciding unambiguously between magnetic 2^4 and electric 2^5 transitions, also favor the assignments of magnetic 2^4 transitions. The theoretical values[6] are 3.9 and 3.5, respectively, for magnetic 2^4 transitions in Ba^{135m} and Ba^{133m}, and are 2.1 and 1.87, respectively, for electric 2^5 transitions.

* Assisted by the joint contract of ONR and AEC.
1 B. E. Robertson and M. L. Pool, Phys. Rev. 76, 1409 (1949).
2 Weimer, Pool, and Kurbatov, Phys. Rev. 63, 59(A) (1943); F. Yu and J. D. Kurbatov, Phys. Rev. 74, 34 (1948).
3 J. M. Cork and G. P. Smith, Phys. Rev. 60, 480 (1941).
4 Separated isotope obtained from Y12 Plant, Carbon and Carbide Corporation, Oak Ridge, Tennessee.
5 Weisskopf formula.
6 M. E. Rose, *et al.*, "Tables of K-Shell Internal Conversion Coefficients" (unpublished).

Transition Effect in Pb of the Star-Producing Radiation in the Stratosphere. I*†

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THE behavior in Pb of the star-producing radiation in the stratosphere has been investigated at geomagnetic latitude 56°N by measuring star frequency *versus* depth. Previous studies had shown a weak transition effect in Pb for small stars at mountain altitudes,[1] and a stronger effect in the stratosphere.[2] The latter investigations were limited to depths of 4 cm at most.

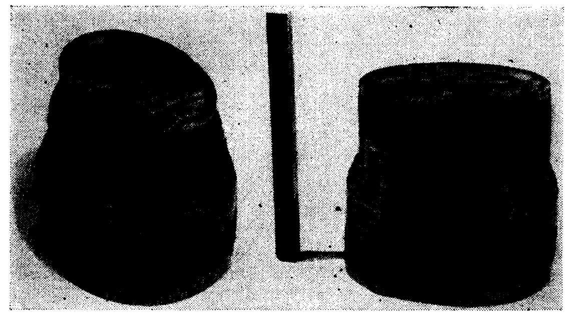

FIG. 1. Two views of Pb absorber. Elliptical in cross section near the top, with axes 10 and 15 cm, it widens toward the base. Total depth, 15.5 cm. At left, complete assembly, upper slab in place. At right, view before insertion of emulsions, showing vertical aperture. Stars were collected only from the central portion of the slot, near the axis.

It is not clear why transition maxima appear at depths of the order of 2 cm, whereas the absorption mean free path in Pb of the incident star-producing radiation[3] is about 28 cm. It seemed worth while, therefore, to explore this phenomenon with better depth resolution, under greater thicknesses of absorber, and using the ultrasensitive emulsions which had become available. Since 1949, we have exposed Pb-covered photoplates in several "Skyhook" balloon flights, and examined some 5000 stars. We report tentative results from two of these flights in Minnesota in which the balloons floated for 6.5 and 5 hr, respectively, at average pressure altitudes of 1.6 and 1.0 cm Hg.

Ilford G.5 emulsions, 15×7.5 cm, and 400μ thick, were inserted into a narrow vertical aperture in a Pb block (Fig. 1); the slot was then covered with a ½-cm Pb slab. Other plates at the surface provided a zero-depth reading. With this absorber, the range of depths was considerably extended.[2,4] Moreover, the vertical orientation of the photoplates enabled us to measure star frequency as a continuous function of depth, where this seemed desirable. In scanning horizontal strips of emulsion, we stayed close to the vertical axis of the absorber; the average distance of a star from

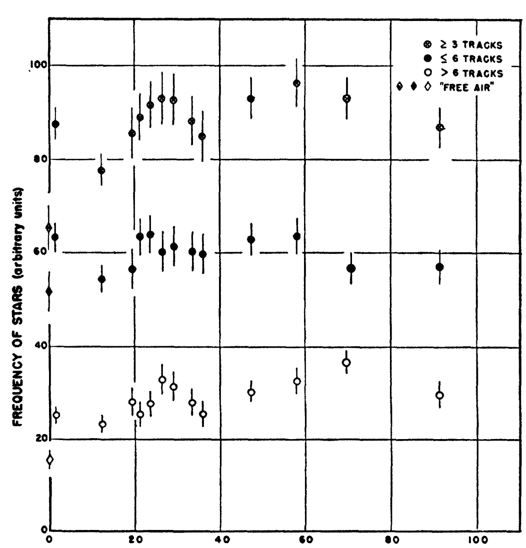

FIG. 2. Star frequency versus depth for all 3565 stars, for small stars, and for large ones. The diamond-shaped points refer to "free air" emulsions. Probable errors, based on counting statistics alone, are shown throughout.

the axis was 1.2 cm. The number of "black" and "gray" tracks (grain density >1.4 times minimum) was used as an index of star size, in order that our results could be more readily compared with those of others.[5]

Figure 2, based on 3565 stars, shows their frequency *versus* depth. Frequencies were corrected for stars accumulated prior to the balloon flight, and during ascent and descent of the equipment. The upper points show the frequency of all stars with ≥ 3 prongs. The black circles refer to small stars, and the open circles to larger ones. The first circle in each set is plotted just beyond zero, to take account of a bit of overlying aluminum. The three diamond-shaped points give frequencies in "free air" emulsions, suspended far from any dense materials. These three values were obtained from the second flight and normalized to the first; the rest of the data are derived from a single flight. Stars initiated by π^--mesons coming to rest were not included in the data.

The results may be summarized as follows:

(1) The frequency of the larger stars, as well as that of the small ones, increases noticeably between "free air" and the upper surface of the Pb.[6] This suggests that some energetic secondaries (>200 Mev) with an appreciable upward component may be generated in the Pb.

(2) In the first centimeter there is a drop in frequency, associated with the smaller stars. This initial decrease has not been reported before. We have confirmed its existence in other experiments with geometries similar to this one. A possible explanation for this effect is given in the following letter.

(3) A maximum occurs at $\simeq 27$ g/cm², as in other experiments. However, it differs from previous results (except Blau's[7]) in that stars with >6 prongs contribute significantly to this effect.

(4) A broader peak at $\simeq 60$–70 g/cm², not observed heretofore, probably represents the major contribution of locally generated secondaries to the star population. This becomes more apparent as follows: Let us adopt as a measure of the transition effect at depth x, the ratio $T(x)$ of the observed star frequency $f(x)$ to that which would appear if the incident nucleonic radiation were absorbed exponentially without generating star-producing secondaries; i.e., let

$$T(x) = f(x)/f(\text{free air})e^{-x/\lambda}.$$

For λ, we take[3] the value 310 g/cm². Figure 3 gives $T(x)$ *versus* x for all stars ≥ 3 prongs.[8] The appearance of $T(x)$ suggests that the second maximum in Fig. 2 is due to a saturation of the star frequency at $\simeq 70$ g/cm².

In view of the near isotropy of intensity over a wide range of θ at high altitudes, our data could be plotted as a function of mean path of absorber traversed by the incoming radiation (at various θ), instead of the vertical depth. This procedure would be especially justified if the energy spectrum as a function of θ (not well known at these altitudes) could be taken into account. We are attempting to do this.

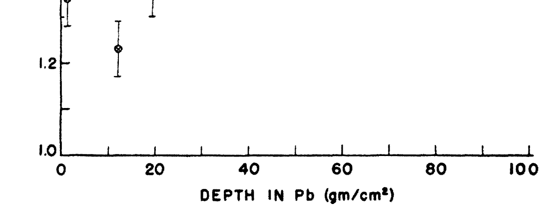

FIG. 3. Ratio $T(x)$ of observed star frequency to that expected if the incident nucleonic radiation were absorbed exponentially.

We are grateful to Mr. E. O. Davis for help with photoplate processing and microscopy; and to Miss K. DeAngelis, Mrs. D. Applyby, Mrs. N. Redfearn, and Mrs. F. Brewster for their assistance in scanning the emulsions. The flights were arranged through the ONR and the General Mills Aeronautical Research Laboratory.

* Reported at the Washington meeting of the American Physical Society, Bull. Am. Phys. Soc., **26**, No. 3, 7 (1951).

† See accompanying letter by M. M. Shapiro, Phys. Rev. **83**, 456 (1951).

[1] Bernardini, Cortini, and Manfredini, Phys. Rev. **74**, 845 (1948); Malaspina, Merlin, Pierucci, and Rostagni, Nuovo cimento **7**, 145 (1950); Schopper, Höcker, and Kuhn, Phys. Rev. **82**, 444 (1951). Earlier, an effect for singly charged particles had been found by Heitler, Powell, and Heitler, Nature **146**, 65 (1940).

[2] J. J. Lord and Marcel Schein, Phys. Rev. **75**, 1956 (1949); Blau, Nafe, and Bramson, Phys. Rev. **78**, 320 (1950). In both experiments, C.2 emulsion were placed horizontally at 4 depths, up to a total of 4 and 3 cm, respectively. Blau *et al.* also investigated the effect in Cu.

[3] George and Jason, Proc. Phys. Soc. (London) **A62**, 243 (1949). This value, $\lambda = 310 \pm 20$ g/cm², is observed at altitude 3.5 km. It may be different in the stratosphere, but is unlikely to differ by as much as a factor 2.

[4] Thus far our data do not extend beyond 100 g/cm², since due allowance for rays at oblique incidence would require an absorber wider at the base. This was precluded by restrictions in flight pay-loads. Despite this limitation, the extra depth should prove useful in evaluating (a) λ for relativistic, star-generating protons incident at small (<25°) zenith angles; (b) attenuation of heavy primary nuclei in the Pb.

[5] We are now re-examining all the stars to arrive at a distribution based more directly on the energy release, including thin tracks.

[6] This effect is known for very small stars; see reference 2. It has not heretofore been reported for larger ones.

[7] Dr. M. Blau kindly informs us that she has observed a similar peak for stars with ≥ 6 prongs at $\simeq 23$ g/cm² Pb.

[8] The errors are probable errors in the relative values of $T(x)$. The absolute values of $T(x)$ are more uncertain, because they also involve an error in the free-air frequency.

Transition Effect in Pb of the Star-Producing Radiation in the Stratosphere. II

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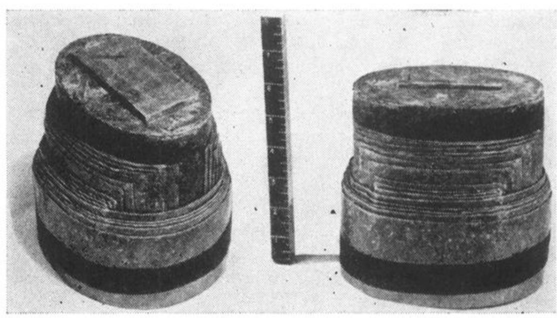
SOME of the results on frequency of cosmic-ray stars *versus* depth in Pb reported in the preceding letter[1] may be provisionally interpreted as follows:

(1) *Transition effects for larger stars.*—At mountain altitudes, transition effects have been found only for 3- and 4-prong stars. In the stratosphere, on the other hand, they occur for larger stars as well. This is not surprising, since the N-radiation at pressure altitudes of 1 or 2 cm Hg contains a considerable proportion of particles with energies in the Bev region. Some of their secondaries have energies of hundreds of Mev, enough to produce stars with >6 prongs.

Another feature of the star-producing "primaries" in the stratosphere is that they arrive over a wider range of zenith angle than those at mountain altitudes. This may help explain some of the effects found at relatively shallow depths in an absorber. For example, the increase in star frequency between "free air" and the top of an absorber implies the production of rather energetic secondaries with an upward component of velocity. These can be generated by obliquely incident primaries even though the secondaries be emitted predominantly into the forward hemisphere.

(2) *Initial drop in frequency of small stars.*—This appears to be explicable in terms of the energy loss by ionization of relatively "slow" protons arriving obliquely—protons which can initially produce small stars, but are no longer able to do so after losing a large fraction of their energy in the lead. This diminution is closely connected with the type of geometry we employed.[2] The mean path $\bar{p}$ in our absorber for particles at zenith angles θ exceeding, say, 40° and arriving near the axis of the block at a depth of $\simeq 1$ cm is 3.6 cm (see Fig. 1). The energy spectrum of the protons incident at $\theta > 40°$ contains relatively more slow ($\simeq 100$–



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