An Anomalous Event Observed in Photographic Emulsion*

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In a stack of 400μ G-5 stripped emulsions flown at high altitude an anomalous interaction of a fast heavy nucleus has been observed (Fig. 1). A fast Be nucleus (a) interacts producing a $6 + 1_{Be}$ star. Two of the prongs are relativistic particles of charge 3 and 2, each making an angle less than 2×10^{-3} radians with the primary. The singly charged particle (b) interacts after 5.09 cm. giving a $0 + 6_{Li}$ star. The doubly charged particle (c) travels for 1.37 cm. at which point it splits into two fast singly charged particles (d and e); there is no observational evidence of nuclear interaction and the event $c \rightarrow d + e$ is coplanar within the accuracy of measurement. Since it is reasonable to assume in interactions of fast heavy nuclei that the fast heavy fragments observed originate from the incident nucleus, the charge of the fragments should not exceed that of the parent. The violation of this aspect of charge conservation provides the anomaly.

The charge of the primary was determined by gap count comparison with slow protons and by comparison of the δ-ray count with that of fast α-particles. The former gave $I_a/I_{min.} = 16.[illegible] \pm 0.2$ and the latter $n_\delta(a)/n_\delta(\alpha) = 4.06 \pm 0.7$; thus $Z_a = 4 \pm 0.1$ establishing particle a as Be. For particle b, $n_\delta(b)/n_\delta(\alpha) = 1.9 \pm 0.2$ giving $Z_b = 2.76 \pm 0.2$. Since b interacts giving 6 minimum ionizing tracks it cannot be a slow α-particle; thus b is established as Li. For c we find $n_\delta(c)/n_\delta(\alpha) \simeq$ [illegible] and $I_c/I_0 \simeq 4$ giving $Z_c = 2$.

Though the track length per emulsion averaged 6.5 mm. the only meaningful measurements were relative scattering measurements. The relative scattering was measurable between b-c for 2 emulsions and between b-d, b-e and d-e for 2 and 1/2 emulsions using 500 and 1000μ cells with noise elimination. The relative scattering angles per 100μ ($\bar{\alpha}_{xy}$) are given in Table I. $\bar{\alpha}_{xy} = k\left((Z_x/A_x P'_x \beta_x)^2 + (Z_y/A_y P'_y \beta_y)^2 \right)^{1/2}$ where $A_x = M_x/M_{nucleon}$ and $P'_x = P_x/A_x$. In table II we give in radians the horizontal (H) and vertical (V) components of the angles between the tracks (θ_{xy}).

Though it is in principle possible from our data to determine the individual $\bar{\alpha}_x$ the values are not too meaningful unless these are of comparable magnitude. The most precisely determined value is $\bar{\alpha}_d$ leading to $P_d c = 2.76 \pm 0.7$ Bev. Since $I_d/I_0 = 0.92 \pm 0.04$ d must be a proton.[1] In addition the similarity of $\bar{\alpha}_{b-d}$ and $\bar{\alpha}_{d-e}$ imply that $(Z/M)_e \leq 1/2$ if P'_b and P'_e are not appreciably less than P_d; this is verified by the similarity of $\bar{\alpha}_{b-c}$ and $\bar{\alpha}_{b-e}$. Since $I_e/I_0 = 0.87 \pm 0.04$ we conclude that e is either a deuteron or triton. With the further assumption of comparable momenta per nucleon for b, c and e we obtain $2.8 \leq P'c(\text{Bev}) \leq 7.5$. These values are consistent both with the angular distribution of the Li star and the angle θ_{be}.

We may characterize the possible reactions for this event as follows:[2]

(1) $Be^9 + "p"("N") \rightarrow Li^{6(7)} + He^{4(3)} + (\pi^-)$; $He^{4(3)} + "N" \rightarrow H^1 + H^{3(2)} + N$

(2) $Be^9 + "p"("N") \rightarrow Li^{6(7)} + \overline{He}^{4(3)} + (\pi^-)$; $\overline{He}^{4(3)} \xrightarrow{\text{decay}} H^1 + H^{3(2)}$

(3) $Be^9 + "p"("N") \rightarrow Li^6 + He^3 + N + (\pi^-)$; $He^3 + "N" \rightarrow H^1 + H^2 + N$

(4) $Be^9 + "p"("N") \rightarrow Li^6 + \overline{He}^3 + N + (\pi^-)$; $\overline{He}^3 \xrightarrow{\text{decay}} H^1 + H^2$

Here "P"("N") means a proton or neutron of the target nucleus and $\overline{He}$ an excited state. Reactions (1) and (2) are pick-ups while (3) and (4) are charge exchange. Though it is impossible to rule out completely a nuclear interaction as the cause of the He breakup, the observed coplanarity tends to favor the occurrence of a decay in flight with a time τ in the rest system satisfying $0.6 \times 10^{-11} \leq \tau \text{ (sec.)} \leq 1.6 \times 10^{-11}$. Assuming that a two body decay in flight has occurred we find $15 \leq Q(\overline{He}^3) \leq 250$ and $3 \leq Q(\overline{He}^4) \leq 65$ Mev. where the limits take into account estimated errors in momenta and angles consistent with the ionization and scattering measurements.

If we consider the decay in flight of an excited state of He we can rule out ordinary nuclear excitation on a lifetime basis, since one should expect lifetimes less than 10^{-16} sec. On the other hand the observed time of flight and Q value for $\overline{He}^3$ suggest the excited state to be of the type involving a bound hyperon; either (i) $\overline{He}^3 = \Lambda^+ + P + N$ or (ii) $\overline{He}^3 = 2P + \Lambda^0$. Type (i) should have Q value of ~ 240 Mev while (ii) should have ~ 170 Mev. We believe the latter formed in reaction (3) with the production of a π^- the most likely interpretation. Another, though less likely a possibility, would be the mesonic decay mode of either $\overline{He}^3$ or $\overline{He}^4$ (of either type (i) or (ii)) in which a π^0 meson is emitted. However, the formation of $\overline{He}^3$ seems more likely than $\overline{He}^4$ since the latter involves a pick-up reaction.[3] This case provides some evidence for the formation of an excited nucleus by addition of positive charge to a breakup fragment.

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FOOTNOTES

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[1]This is corroborated by the Li star; if d was a π of $P_c = 2.76$ Bev, the momentum of b should increase by $M_{nucleon}/M_{\pi}$ and the Li star should show a narrow cone of at least 3 tracks; this is not the case. (We imply here equal velocities for all particles).

[2]The minimum ionising track emitted from the first star could be the π^- indicated below.

[3]Prof. J.B. French has estimated the pick-up process and finds it is improbable at our energy due to the large momentum transfer involved. The charge exchange process without meson production is almost certainly equally improbable.

Table I

	b–c	b–d	b–e	d–e
100 $\bar{\alpha}$	0.326 ± 0.09	1.052 ± 0.28	0.43 ± 0.12	0.98 ± 0.26

Caption for Table I – Relative scattering angles in degrees per 100μ between the tracks a, b, c, d and e.

Table II

	θ_{ab}	θ_{cd}	θ_{ce}	$\times 10^3$
H	2.4 ± 0.2	5.5 ± 0.2	1.5 ± 0.2	
V	0.6 ± 0.6	5.6 ± 0.8	1.8 ± 0.8	

Caption for Table II – Horizontal and vertical components in radians for the angles between the tracks ab, cd and ce.

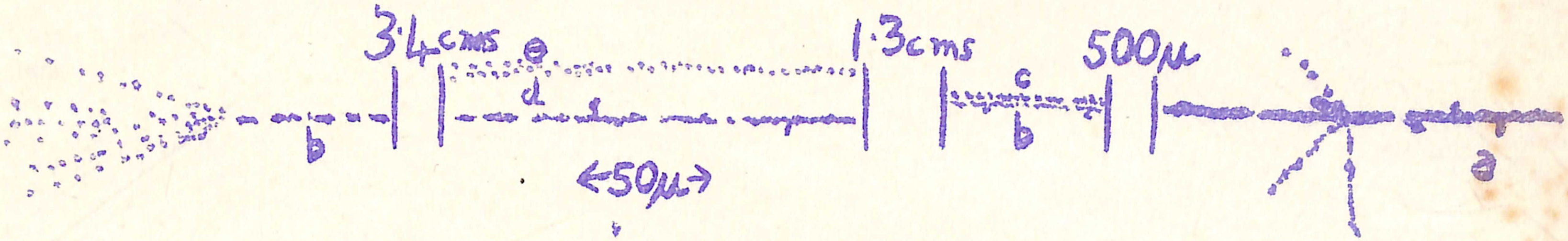

Fig. 1

A fast Be (a) nucleus interacts in emulsion making a star. Two of the prongs are relativistic triply (b) and doubly (c) charged particles emitted in the forward direction. The triply charged particle makes a star of 6 minimum tracks and the doubly charged particle appears to decay into 2 minimum tracks d and e.