High Energy Nuclear Interactions in Lead and Light Elements

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In order to extend previous measurements[1] on nuclear interactions in the energy region 10^{12} - 10^{14} ev an emulsion cloud chamber consisting of a "Block" of emulsion 6" x 4" x 2" placed on top of an emulsion cloud chamber of 25 alternate 3mm lead plates and 250 micron G-5 emulsion was flown for six hours at White Sands. The "Block" of emulsion consisted of 92, 6" x 4" x 400 micron G-5 stripped emulsions, which were separated after flight and processed by the NRL technique[2] (emulsions attached to glass backing prior to development).

Fig. 1 shows the results for interactions observed starting in the lead. The multiplicty observed on the plate directly below the lead absorber in which the interaction occured is plotted against the distance back to the point of interaction. The line of the graph which appears to represent the data is calculated assuming an initial production of 20 charged particles and ten neutral π mesons decaying into two photons with a laboratory lifetime less than 3×10^{-12} sec.[3] (For 3×10^{-12} sec., the mean decay distance of 0.9 mm. is short compared to the radiation conversion length in lead). The calculated line seems to fit the data well and accordingly in the majority of showers the initial multiplicity of charged particles would appear to be about 20. The median energy of this group of interactions was about 2×10^{12} ev. as estimated from the median angle of the shower particles.

Seven primary interactions were found in emulsion. Table I gives

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the value of N_s, the number of minimum ionizing particles and N_h the number of gray plus black prongs occuring in the interaction. The median energy for this group was $\sim 10^{13}$ ev. The multiplicity appears to be independent of N_h with an average value of about 16. If the interaction cross section for primaries of these energies is geometric, approximately half the collisions in emulsion would occur in Ag or Br and the rest in C,N,O and H. Though the division of interactions on the basis of the number of star prongs is not certain, it seems likely that the cases with $N_h = 0$ occur in light elements and the case with $N_h = 15$ must have arisen from an interaction in an Ag or Br. nucleus. If the dividing line between the light and heavy elements is taken to be $N_h \approx 4$ or 5 then our data is consistent with half the interactions occuring in light elements and half in heavy elements. It is seen that the mean number of shower particles for interactions with $N_h < 4$ and $N_h > 4$ is 16 for both cases.

If we now utilise previous results[1] and correct for the differences in median energies on the assumption that the multiplicity varies as $E^{1/4}$, we can compare multiplicities of shower particles in various elements for primary energies of $\sim 5 \times 10^{12}$ ev. For lead the multiplicity is ~ 24, Brass ~ 18, Ag and Br ~ 14 and light elements ~ 14. It would appear that the multiplicity in this energy region is almost independent of the target nucleus. There have been cases found in which the multiplicity of shower particles is much higher than those considered above.[4]

Our observations can be explained by a theory in which the particles are produced multiply in the initial interaction.[5] The multiplicity apparently does not seem to increase by a large factor through subsequent interactions inside the target nucleus; this is probably because the shower particles do not interact individually inside the nucleus because of their extreme collimation.[1,6,7] The fluctuations from the average behavior as noted above could be the result of large fluctuations in the angular distribution of the shower particles. A few shower particles of the first or possibly the second generation projected at angles considerably greater than the average could be effective in starting independent cascades inside the nucleus which could increase the observed multipliocity by a considerable factor.

We have also noted the occurence of both high and low energy pairs of charged particles produced by neutral radiation, in observing the passage of the high energy showers through the stripped emulsions block. The most reasonable assumption is that these pairs are electron-positron pairs produced by photons; though our statistics are too low to draw any definite conclusion, the contribution of bremsstrahlung according to Schiff's theory[8] seems to be too low to account for the low energy pairs.

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Table I

High Energy Stars in Emulsion

Number of Evaporation Prongs	Number of Shower Particles
N_h	N_s
0	10
0	16
2	19
4	12
6	15
15	16
1	15[9]
7	18 [10]
Secondary Interaction	
1	15

Footnotes

1. M.F. Kaplon and D.M. Ritson, Phys. Rev. 88, 386 (1952)

2. Stiller, Shapiro and O'Dell, Phys. Rev. 85, 712 (1952)

3. A lifetime of $3x10^{-12}$ sec. in the laboratory system corresponds approximately to a mean life of $\sim 10^{-15}$ sec. in the rest system of the π^{0} meson.

4. Daniel, Davies, Mulvey, Perkins, Phil. Mag. 43, 753 (1952) Recently in this laboratory a proton induced star of about sixty shower particles has also been observed.

5. E. Fermi, Phys. Rev. 81, 683 (1951)

6. U. Haber-Schaim, Phys. Rev. 84, 1199 (1951)

7. F.C. Roesler and C.B.A. McCusker, Nuovo Cimento 10, 127(1953)

8. L. Schiff, Phys. Rev. 76, 89 (1949)

9. This case was obtained by Lord, Fainberg and Schein, Phys. Rev. 80, 972 (1950)

10. A. Gerosa and P. Levisetti, Nuovo Cimento, 8, 601, (1951)

Apparent Multiplicity of Showers versus Distance Back in Lead.