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 multiplicity by a considerable factor.

We have also noted the occurrence 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 block of stripped emulsions. 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.

We are indebted to the Aero Medical Field Laboratory, Holloman Air Force Base for their cooperation in obtaining successful balloon flights. We wish to thank Miss Barbara Hull and Miss Katherine Merry for their assistance in scanning the plates.

---

* This research has been supported in part by funds from the Department of the Air Force.

[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 3×10^{-12} sec in the laboratory system corresponds approximately to a mean life of $\sim10^{-15}$ sec in the rest system of the π^0 meson.

[4] Daniel, Davies, Mulvey, and 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).

Nonuniform Track Shrinkage in Nuclear Emulsions*

John R. Horan
American Cyanamid Company, Atomic Energy Division, Idaho Falls, Idaho

(Received February 20, 1953)

Several Eastman NTA and NTB nuclear track plates have been exposed to monoenergetic alpha-particles from Po^{210} plated silver foils, and a study has been made of the resulting alpha-tracks as a function of the angle of incidence.

Observation of the tabulated data indicated that the average track length increased as a function of the dip angle θ. Experiments by Rotblat and Tai[1] with lithium-loaded emulsions showed that shrinkage was uniform at all depths of the emulsion. Also the shrinkage factor for alpha-tracks was a function of both the gelatin content and the dip angle. They concluded that the shrinkage factor remained fairly constant with angles of dip up to 25–30°. Roberts,[2] in studying $n-\alpha$ reactions, measured tracks with values of θ up to 40° and found that resolution was considerably improved by limiting θ to $\leq 20°$.

Figure 1 is a plot of the average track range in microns *versus* the angle of dip in the processed emulsions. The empirically determined shrinkage factor 2.7 ± 0.3 was used in these calculations. Both NTA and NTB plates show substantially the same results with the average range of the particles continuing to increase with increasing angles of dip. Extrapolation of the curve to zero yields the range of the alpha particles without shrinkage error. This value, 21.3μ, agrees within experimental error with Steigert's[3] empirical value of 21.2μ as well as his theoretical value of 21.3μ for NTA plates.

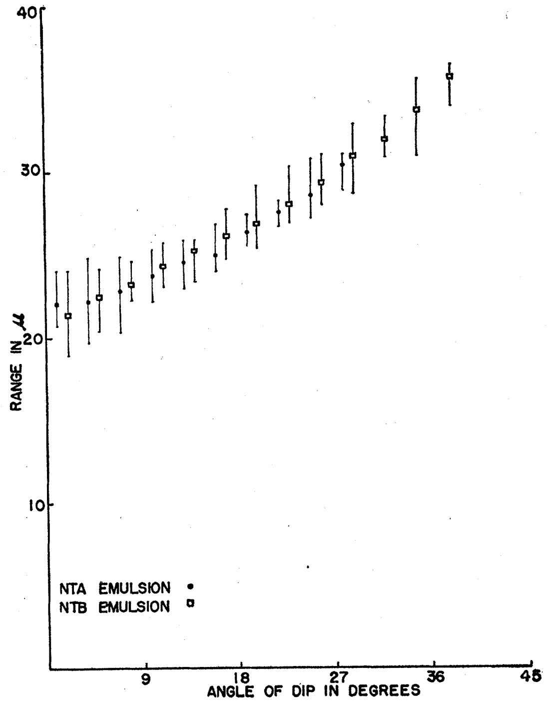

Fig. 1. Average alpha-track range *vs* angle of dip in processed emulsions.

Thus, the usual method of correcting for emulsion shrinkage by multiplying the vertical track projection by the shrinkage factor should be restricted to angles of dip less than 6° for heavily ionizing particles if the error of measurement is to be less than 2 percent.

The final criterion for selection was that each alpha track should lie entirely within the depth of focus of the microscope which was approximately 0.5μ, which is equivalent to a variation of less than 2° in the angle of dip. The maximum error introduced by measuring only the horizontal component, with the above limitation, is 0.1μ. This modified procedure resulted in histograms having a maximum dispersion of 5μ and a half-width at half-maximum of 0.5μ.

---

* Work performed at the Oak Ridge Institute of Nuclear Studies, Oak Ridge, Tennessee.

[1] J. Rotblat and C. T. Tai, Nature **164**, 835 (1949).

[2] J. H. Roberts, U. S. Atomic Energy Commission Report AECU-1381, 1950 (unpublished).

[3] Steigert, Toops, and Sampson, Phys. Rev. **83**, 474 (1951).

Rotational States in Even-Even Nuclei

Aage Bohr and Ben R. Mottelson*
Institute for Theoretical Physics, Copenhagen, Denmark

(Received March 24, 1953)

In a recent note,[1] an interpretation of the short-lived $E2$ isomers has been suggested in terms of rotational states of the deformed nucleus. Empirical evidence is rapidly accumulating on the low energy spectra of even-even nuclei;[2–4] the purpose of the present note is to call attention to the extensive support which exists in these data for the above interpretation, and to suggest its usefulness in the analysis of decay schemes.

In the model describing the nucleus in terms of the coupled particle motion and surface oscillations, low-lying rotational states are associated with the large deformations expected in regions with many particles outside of closed shells. In such regions, the rotational spectrum is expected to be given rather accurately by the simple expression[1]

$$E_I=\frac{\hbar^2}{2\mathcal{J}}I(I+1),\quad I=0,2,4,6,\ \text{even parity} \qquad (1)$$