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The Scattering Constant for Doubly Charged Particles in Nuclear Emulsion*

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The measurement of multiple scattering is a widely used technique for the determination of the momentum of a fast charged particle in nuclear emulsion. One obtains the value of $p\beta$ for a particle from the relation

$$p\beta = KZt^{1/2} / \bar{\alpha},$$

where p is the momentum of the particle, β the velocity in units of c, Z the charge of the particle in units of the electron charge and $\bar{\alpha}$ the mean angle of scattering in a cell length t. K is called the 'scattering constant' and is a slowly varying function of β, t and Z. It depends on whether the scattering angle is measured by means of the tangent or the co-ordinate method (see Gottstein et al.[1]. In the present work we use Fowler co-ordinate method[2]). K also depends on the emulsion composition and on the relative humidity with which the emulsion is in equilibrium at the time of exposure.

A knowledge of the scattering is necessary to obtain the value of $p\beta$ of a particle from the measurement of its

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multiple scattering. There have been many theories of multiple scattering[3,4,5] and values of K have been calculated by Gottstein et al.[1] and by Voyvodic and Pickup[6] for singly charged particles. These values have been confirmed by direct measurement on singly charged particles of known $p\beta$[1,6,7,8]. For particles with $Z > 1$ a value of $K = 32$ is customarily used. Fichtel and Friedlander[9] have made calculations of this constant based on Moliere's Theory; in particular they give extensive graphs for K as a function of β and t for particles with charge two for use with Fowler co-ordinate method of measurement. However, there does not seem to exist a verification of any of these values for the scattering constant.

In this experiment we use a nuclear emulsion stack of 25 pellicles of Ilford G-5 emulsions, 20 cm x 10 cm x 600μ, exposed to the 925 Mev He^4 nuclei (external beam) accelerated by the synchro-cyclotron at Berkeley, California**; this stack was the same used by Appa Rao[10]. The tracks of the helium nuclei entering the stack were followed into the stack until they interacted or stopped; these nuclei with energy 925 Mev at the entrance point of the stack had a range of ~ 13.1 cm. Fifty such tracks were subjected to the constant sagitta scattering procedure described in reference 10. The distribution of the mean second difference ($\bar{D}_2$) is shown in Fig. 1. An area scan was also performed for the (He nucleus-in) - (He nucleus-out) type of interactions[11].

** We thank Dr. Burton J. Moyer, Professor Walter Barkas and Dr. T.F. Hoang for kindly exposing the stack.

The outgoing He nuclei are shown to be mostly He^3-nuclei at energies of 6 Bev per nucleon by Appa Rao et al.[11]. However, in our case where the energies of the order of 200 Mev per nucleon, it is likely that there will be a mixture of He^4 and He^3 in the outgoing nuclei. The outgoing He nucleus in each of the above interactions was followed until it stopped or interacted. Sixty such stopping tracks with ranges greater than 3 cms were subjected to the constant-sagitta scattering procedure and the $\overline{D}_2$ distribution is shown in Fig. 2. From the $\overline{D}_2$ distribution of He^4 tracks in Fig. 1 and the $\overline{D}_2$ distribution of He nucleus-out tracks, which are a mixture of He^4 and He^3 tracks it is evident that tracks with $\overline{D}_2$ less than 0.85μ are He^4 nuclei and that tracks with $\overline{D}_2$ greater than 0.85μ are He^3 nuclei. Thus we have a sample of He^4 and He^3 nuclei stopping in G-5 emulsions with known ranges, so that these can be used for obtaining the scattering constant.

We used a cell length of $t = 500\mu$ and the range at which the constant-cell scattering was performed was chosen in each case such that nucleus had a β between 0.46 [redacted] and 0.56 [redacted]; the mean value of β is about 0.51 [redacted].

We first calculated the third differences D_3 in each case, replaced all D_3 values greater than $4\overline{D}_3$ by $4\overline{D}_3$ (the bar at the top denotes average) and obtained the new $\overline{D}_3$. This was reduced to the mean second difference $\overline{D}_2$ by the factor $\left(\frac{2}{3}\right)^{1/2}$. Reading and microscope noises are negligible since $\overline{D}_2$ was of the order of 0.75. The mean $p\beta$ corresponding to the position of measurement is obtained from the curves given by Willis and Stableford[12], and Atkinson and Willis[13]. The scattering constant is calculated in each case and the final value of K is obtained by taking a weighted mean of the individual values. The above procedure is adopted both for tracks of He^4 and He^3 nuclei. A total of 2000 cells was obtained in the case of He^4 and 410 cells for He^3. The values of K are given below:

K_{He^4} = 26.9 ± 0.6 for $t = 500\mu$ and $\beta \sim$ 0.51 [redacted]

K_{He^3} = 27.3 ± 1.4 for $t = 500\mu$ and $\beta \sim$ 0.51 [redacted]

There are no theoretically calculated values for the scattering constant for He^3, but we can compare the value of He^4 obtained above with that predicted by Fichtel and Friedlander[9]. For the values $t = 500\mu$ and $\beta \sim$ 0.51 [redacted], from Fig. 2 of reference 9, K = 29.1. This is higher than the experimentally observed value by about 7%. We have not measured the humidity with which the emulsion stack was in equilibrium at the time of exposure, but since the stack was exposed to an external beam, assuming normal humidity, the uncertainty, if any, due to humidity is seen from Fig. 4 reference 9 to be less than 2%.

Thus, there seems to be a discrepancy between the experimentally observed scattering constant and that calculated using Moliere's theory. It might be relevant here to note a discrepancy in the observed and calculated $\overline{D}_2$ for He^3

(Appa Rao[10]) using constant sagitta method. The expected mean for the $\overline{D}_2$ distribution of He^3 is 0.88μ where as the observed mean is 0.92μ with an error of .018μ. This might mean that the scattering constant for He^3 is different from that for He^4. We are investigating both the above discrepancies using the improvement of Moliere's approximation by Nigam, Sundaresan and Wu[14].

References:

1. K. Gottstein, M.G.K. Menon, J.H. Mulvey, C. O'Cellaigh and O. Rochat: Phil. Mag. 42, 708 (1951)

2. P.H. Fowler: Phil. Mag. 41, 169 (1950)

3. E.J. Williams: Phys. Rev. 47, 568, (1935); Proc. Roy. Soc. A, 169, 531 (1939); Phys. Rev. 58, 292 (1960)

4. G. Moliere, Z. Naturforsch: 2a, 133 (1947) and 3a, 78 (1948)

5. H. Snyder and W.T. Scott: Phys. Rev. 76, 220 (1949)

6. L. Voyvodic and E. Pickup: Phys. Rev. 85, 91 (1952)

7. F.A. Brisbout, C. Dahanayake, A. Engler, P.H. Fowler, P.B. Jones: Nuovo Cimento 3, 1400 (1956)

N.D. Prasad and S. Mitra: Acad. of Sci., 66, 167 (1957)

8. S. Biswas, [redacted]: Proc. [redacted], [redacted] ([redacted])

9. C. Fichtel and M.W. Friedlander: Nuovo Cimento No. 6, 1032 (1958)

10. M.V.K. Appa Rao: Phys. Rev. 123, 295 (1961)

11. M.V.K. Appa Rao, R.R. Daniel and K.A. Neelakantan: Proc. Ind. Acad. 38A, 418 (1953)

12. B.H. Willis and C.V. Stableford: University of California Radiation Laboratory Report, (Unpublished) UCRL 2426, Vol. I

13. J.H. Atkinson and B.H. Willis: University of California Radiation Laboratory Report, (Unpublished) UCRL 2426, Vol. II

14. B.P. Nigam, M.K. Sundaresan and Ta-You Wu: Phys. Rev. 115, 491 (1959)

Captions

Fig. 1. The $\overline{D}_2$ distribution obtained by the application of constant sagitta scattering method to stopping He^4 tracks. The gaussian is drawn with its center at 0.76μ with the standard error corresponding to 110 cells and with the area underneath normalized to the total number of tracks.

Fig. 2. The $\overline{D}_2$ distribution obtained by the application of the constant sagitta scattering procedure to stopping He nucleus-out tracks from a (He nucleus-in)-(He nucleus-out) interactions. The gaussians are drawn centered at 0.76μ and 0.92μ with the standard error corresponding to 110 cells and with the area underneath the left and right curves corresponding to the number of tracks to the left and right of 0.85μ respectively.

Captions

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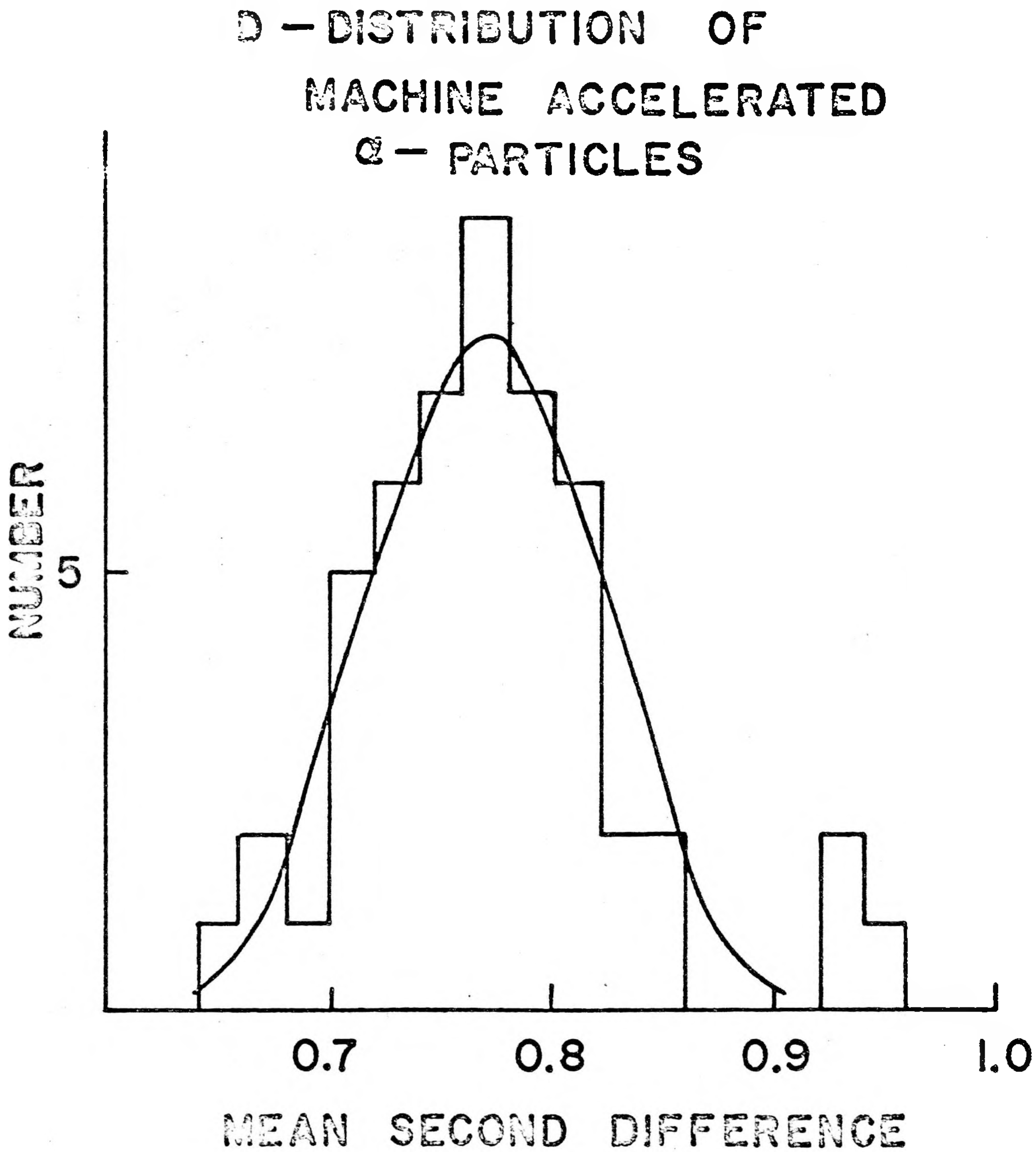

D — DISTRIBUTION OF
MACHINE ACCELERATED
α — PARTICLES
NUMBER
5
0.7
0.8
0.9
1.0
MEAN SECOND DIFFERENCE

$\overline{D}_2$ - DISTRIBUTION OF α - OUT FROM α-IN-α-OUT INTERACTIONS