On the 'Scattering Constant' in Nuclear Emulsions

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Abstract.

Scattering constant (K) has been determined in G_5 nuclear emulsions by Fowler's coordinate method for cell lengths 3 mm to 4 cm and by coordinate displacement method for cell lengths 4 mm to 8 cm. Whereas the former method gives satisfactory results at all the cell lengths investigated, the latter method has been found to be useful for cell lengths greater than 3 cm. Our results, within statistical errors, agree with the theoretically expected values.

Introduction.

In recent years, many workers (Hossain et al[1] and Yash Pal et al[2]) have performed multiple coulomb scattering measurements with cell lengths ranging from 2 mm to 40 mm using Fowler's coordinate method and have pointed out a possible discrepancy between the experimental and theoretically expected values of scattering constant (K). Aditya[3] has made use of coordinate displacement method (hereafter denoted as Y_{rms} method) for the study of K from 3 cm to 9.5 cm cell lengths and has estimated K to be 27.6 $\pm$ 1.3 instead of 31.3[4] — the value expected from Williams theory taking into account the finite size of the nucleus.

The first aim of the present investigation is to compare Y_{rms} method with Fowler's coordinate method for the determination of K. For this purpose, K has been calculated by both of these methods utilising the same tracks in the π^- stack. Secondly, since the world data of K at cell lengths $\geqslant$ 1 cm does not agree with the theory, K has been redetermined right from 3 mm to 8 cm cell lengths.

2. Experiment.

Microscope:

A Koristka R_4 microscope has been used for multiple coulomb scattering measurements under temperature stability conditions. Observations have been made with 55 x oil objective and 10 x micrometer eyepiece, the least division on micrometer scale estimated being 0.001447μ. The linearity of the stage has been checked with the help of ~~thexxx~~ a straight line etched on the glass plate with grating ruling machine at Upsala.

Stacks:

Two G_5 emulsion stacks, one exposed to 17.2 Gev/c π^- and the second to 19.8 Gev/c protons at CERN have been studied. Both the stacks were processed at CERN by dry hot stage technique. In both of them, the average dip (θ) of the tracks corresponds to cot θ = 170. The average flux of tracks in π^- stack is $5 \times 10^4/cm^2$ and in proton stack it is $5 \times 10^5/cm^2$. Because of high density in proton stack, it has not been possible to follow the beam tracks beyond 3 cms from the leading edge of the proton plates.

3. Scattering Constant (Fowler's coordinate method).

When a charged particle passes through a material medium, it undergoes multiple coulomb scatterings and $p\beta$ of the particle is given by the relation $p\beta = K\, t^{3/2} / 573\, \bar{D}_c$ Mev/c. .... (1)

In this expression, $\bar{D}_c$ is the mean arithmetic value of the second differences due to pure coulomb scatterings and t is the cell length employed in microns. K is the scattering constant with the units $[\,(\text{degrees})\ (\text{Mev})\ (100\mu)^{1/2}\,]$. However, due to the presence of spurious scattering $\bar{D}_s$, irreproducible noise $\bar{D}_\epsilon$ (i.e. temperature, reading and grain noise plus irreproducible stage noise) and producible stage noise $\bar{D}_\gamma$, the measured signal ($\bar{D}_{meas.}$) on the microscope does not represent $\bar{D}_c$. $\bar{D}_{meas.}$ is related to these quantities by the relation

$$\bar{D}^2_{meas.} = \bar{D}^2_c + \bar{D}^2_\epsilon + \bar{D}^2_\gamma + \bar{D}^2_s$$

To eliminate $\bar{D}_s$ and $\bar{D}_\gamma$, $\bar{D}_c$ has been derived from $D_{meas.}$ by relative scattering of two neighbouring tracks. For relative scattering $\bar{D}_r$,

$$\frac{1}{2}\bar{D}^2_r = \bar{D}^2_c + \bar{D}^2_\epsilon \qquad \text{--------- (2)}$$

$\bar{D}_\epsilon$ in the present measurements is (0.08 ± 0.01) μm. By combining equations 1 and 2, K can be calculated for the cell length under investigation. It is obvious that if instead of $\bar{D}_c$, $\bar{D}_{meas.}$ is used in expression (1), then $p\beta = K\, t^{3/2} / 573\, \bar{D}_{meas.}$ ....(3) and K now calculated from equation 3 would be higher than from euqations 1 and 2.

Tracks were picked up at 1 cm from the leading edge of the plates, keeping in view their direction and magnitude of inclination in projection as well as depth in the emulsion. Tracks once picked up were scattered up to their point of interaction or maximum for 8 cm in π^- stack and 2 cm in proton stack. π^- tracks were scattered with a cell length of 4 mm while a cell length of 1 mm was used for proton tracks. None of the tracks which were studied left the air or glass surface of the emulsions due to large angle deviations. In all, 7 meters of π^- tracks and 3.8 meters of proton tracks were scattered. The average separation of π^- tracks in pairs at the point of start is 50μ in projection and 50μ along depth of unprocessed emulsion. The relative scattering results — K_r , K_r with $4\bar{D}$ replacement and K_r with $4\bar{D}$ cut off are given in table 1. Similar results for 19.8 Gev/c protons from 3 mm to 10 mm cell lengths are given in table 2. Because of high track density in this case, an average separation of 20μ along projection and 10μ along depth between the tracks in pairs could be achieved, thus facilitating the evaluation of K under better conditions of elimination of $\bar{D}_s$.

The mean value of K from 4 mm to 40 mm cell lengths in π^- stack is 31.1 ± 2.3 and that in proton stack from 3 mm to 10 mm is 30.2 ± 1.7.

4. Scattering constant (Y_{rms} method).

The root mean square deviation along projection (Y_{rms}) of a charged particle going in x-direction after a traversal of distance t microns is related to its $p\beta$ by the relation

$$p\beta = \frac{K\,t^{3/2}}{573}\,\frac{\sqrt{\pi}}{2\,Y_{rms}}\ \frac{Mev}{c} \qquad \text{-----} \ (4)$$

In case of a beam of mono-energetic particles available from accelrators, there is always some initial divergence in the tracks which has to be taken into account in order to estimate the Y_{rms} deviations due to scattering. We have estimated the average initial inclination of each 17.2 π^- track by taking five readings with an interval of 250μ over 1 mm distance, from 9 mm to 10 mm from the leading edge of the plates and hence onwards coordinate readings of the tracks in projection after every 4 mm interval have been utilized. K (Y_{rms}) from 4 mm to 8 cm derived from equation 4 is given in table 3. For comparison, K ($\bar{D}_{meas.}$) calculated from equation 3 is included in this table.

From table 3, it is seen that K (Y_{rms}) is in general quite high up to cell lengths $\sim$ 32 mm. There seem to be two major causes for this effect.

i) The actual inclination of track may be different from the experimentally estimated inclination. This is mainly due to the presence of distortions in the 1 mm region over which the inclination of the track has been adjudged. Error in the inclination would depend upon the magnitude of distortion and also on the noises associated with the measurements. This average total error for the 1 mm region which has been used for finding the inclinations of the beam tracks in the present experiment is $\simeq$ 0.15μ. The effect of this error would increase linearly with t whereas Y_{rms} magnitude increases by $t^{3/2}$. Thus it is only after a certain distance t that Y_{rms} magnitude would predominate the inclination error and that some reliable results can be derived. In the present experiment, Y_{rms} value at cell size 32 mm is (15.3 ± 1.5) μ as compared to the inclination error 4.8μ at this cell length. This gives signal to noise ratio of about 3:1 and thus the value of K found by Y_{rms} method is reliable at cell length ⩾ 32 mm. From table 3 and 1, we find that K (Y_{rms}) is higher than K_2 (Fowler's method) up to cell lengths ~ 32 mm but after this K by both the methods agree with each other fairly well.

ii) The distortions in the emulsion at any place along the track change the Y_{rms} displacement of the track. By plotting the tracks on graph paper, the maximum displacements in the contours of the tracks due to distortions in the region where measurements have been made are ~ 5μ, whereas the Y_{rms} value at 32 mm is (15.3 ± 1.5) μ and at 80 mm it is (58.6 ± 6.5)μ. Thus this type of disturbance due to distortions at these cell sizes is also negligible.

The average value of K from Y_{rms} method for 4 cm to 8 cm cell lengths is 32.3 ± 3.3. One significant advantage of this method over Fowler's coordinate method is that with its help we can find K over the whole length of the track followed, thus allowing the evaluation of K at very high cell lengths. ~~Moreover, at higher cell lengths, statistics begin to fall considerably in case of Fowler's method which is not the case with the Y_{rms} method where statistics remain almost the same at all the cell lengths.~~

Conclusions.

1. In stacks exposed to ~ 20 Bev particles, and where distortions are not large, coordinate displacement method is quite useful to find K at a cell lengths ≥ 3 cm.

2. The present experiment on K does not show any deviations from theory.

Note on scattering measurements (By P. M. Sood and V. S. Bhatia)

It is usual to make fine observations in emulsions with oil objectives. However one can suspect that oil can produce some disturbance in the track contours and thus can be one of the sources for s.s. In order to check this point, one G_5 plate exposed to 27 Gev/c protons was covered with polythlene (refractive index 1.5) and then eleven tracks were scattered in projection and depth with 100 x oil objective and cell length 4 mm. Again, polythlene was removed and sandal wood oil was poured on the emulsion plate directly. The same very eleven tracks were scattered once again. The results are as follow:

	Without oil	With oil
Signal in xy plane	1.62 ± 0.11 μ	1.49 ± 0.10 μ
Signal in xz plane	6.73 ± 0.45 μ	7.00 ± 0.47 μ

Our results do not show any effect of using oil objectives for multiple scattering measurements.

References.

1. A. Hossain, M.F. Votruba, A. Wataghin and D. Evans: Nuovo Cimento, 22, 861 (1961).
2. Yash Pal and A. K. Ray: Nuovo Cimento, 27, 960 (1963).
3. P. K. Aditya: Nuovo Cimento, 31, 473 (1964).
4. L. Voyvodic and E. Pickup: Physical Review, 85, 91 (1952).

TABLE I (π^- - stack)

Cell length (m.m.)	K_T	K_T(4 $\bar{D}$ replacement)	K_T(4 $\bar{D}$ cut off)
4	34.4 ± 0.9	33.6 ± .8	32.3 ± .8
8	32.7 ± 1.2	31.9 ± 1.1	30.7 ± 1.0
12	31.2 ± 1.6	31.0 ± 1.5	30.6 ± 1.4
16	30.5 ± 1.6	30.4 ± 1.5	29.3 ± 1.4
20	30.8 ± 1.9	30.8 ± 1.9	30.8 ± 1.9
24	29.2 ± 2.9	29.2 ± 2.9	29.2 ± 2.9
28	32.0 ± 3.5	32.0 ± 3.5	32.0 ± 3.5
32	32.4 ± 3.5	32.4 ± 3.5	32.4 ± 3.5
36	32.3 ± 3.5	32.3 ± 3.5	32.3 ± 3.5
40	31.3 ± 3.5	31.3 ± 3.5	31.3 ± 3.5

TABLE II (Proton stack)

3	32.2 ± 1.1	31.2 ± 1.0	30.9 ± 1.0
4	32.2 ± 1.2	31.5 ± 1.2	30.4 ± 1.1
5	31.2 ± 1.4	30.0 ± 1.3	29.0 ± 1.2
6	29.8 ± 1.6	29.3 ± 1.5	28.7 ± 1.5
7	29.8 ± 2.2	29.8 ± 2.2	29.8 ± 2.2
8	29.2 ± 2.2	29.2 ± 2.2	29.2 ± 2.2
9	31.2 ± 2.3	31.2 ± 2.3	31.2 ± 2.3
10	32.3 ± 2.4	32.3 ± 2.4	32.3 ± 2.4

TABLE III

Cell length (m.m.)	$K(\bar{D}_{meas.})$ Fowler Method	K Y_{rms} Method
4	43.4 ± 1.8	53.0 ± 5.3
8	35.8 ± 1.8	47.3 ± 4.7
12	33.9 ± 1.6	42.6 ± 4.3
16	33.2 ± 1.8	41.3 ± 4.1
20	34.4 ± 2.3	37.6 ± 3.8
24	34.2 ± 2.6	35.8 ± 3.6
28	34.9 ± 3.9	35.0 ± 3.5
32	35.5 ± 3.9	34.2 ± 3.4
36	36.2 ± 4.0	33.1 ± 3.3
40	34.4 ± 3.8	33.1 ± 3.3
44	. . . . . .	31.9 ± 3.2
48	. . . . . .	32.4 ± 3.3
52	. . . . . .	32.5 ± 3.3
56	. . . . . .	32.1 ± 3.3
60	. . . . . .	31.9 ± 3.3
64	. . . . . .	32.5 ± 3.3
68	. . . . . .	31.2 ± 3.2
72	. . . . . .	32.7 ± 3.3
76	. . . . . .	32.7 ± 3.3
80	. . . . . .	32.7 ± 3.3