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Photometric Measurements of Thin Tracks in Nuclear Emulsion

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Photometric Measurements of Thin Tracks in Nuclear Emulsion

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Abstract
Difficulties observed in the application of track theory to CNO particles are attributed to problems in the application of a light scattering correction in microphotometry.

Work of the Lund group of cosmic-ray–emulsion physicists [1-4] has been instrumental in testing the validity of the theory of particle tracks in emulsion [5] by microphotometry.

In these measurements the microphotometer measured the fraction of light transmitted through a (virtual) slit in the object plane of the microscope objective with convergent light, while the calculated fraction transmitted was based on an assumed beam of parallel light.

To bring the calculated transmittance τ_p into accord with the measured transmittance τ, an empirical polynomial correction was applied, given by the expression [2]

$$1 - \tau = a_1(1 - \tau) + a_2(1 - \tau)^2 . \qquad (1)$$

Fitted values of a_1 were found to be near 1, as expected, and of a^2 were found to be linked to the numerical aperture of the microscope objective used in these measurements. Through use of equation (1), excellent agreement was obtained between measured and calculated transmittance of both track profiles and track segments with different slit arrangements, for the tracks of particles for which $14 \leq Z \leq 26$ and $0.3 \leq \beta \leq 0.8$, in normally developed Ilford G.5 emulsion.

Using parameters fitted to the tracks of heavy particles, difficulties were encountered in the comparison of theory to experiment for light particles.[3, 4] This is illustrated in some results of Behrnetz (private communication) shown in Figure 1. With parameters fitted to the track of a ^{24}Mg ion, in the residual range from 3 to 11 mm in emulsion, the adjusted theoretical calculations departed increasingly from the measurements of lighter particles, down to ^{10}B in this same residual range interval.

Since light scattering from the tracks of particles of low Z is much smaller than for the tracks of heavy particles, where the tracks in G.5 emulsion look like a "hairy rope," we have attempted to explore the question raised by the Lund work, as to whether these difficulties arise from limitations on track theory or from the inappropriate application of the scattering correction to the tracks of light particles, for the empirical nature of the correction gives no clear indication as to its limit of validity.

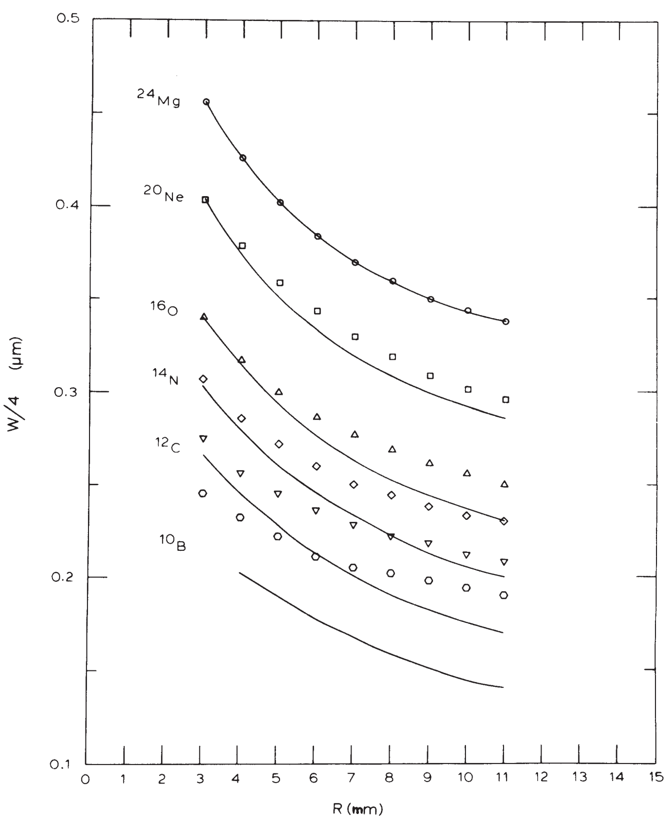

Figure 1. Track width $W/4$ μm vs residual range, of cosmic ray ions in G.5 emulsion. Light scattering parameters are fitted to the track of a ^{24}Mg ion. When the width is calculated for lighter ions (curves) they depart increasingly from the measured width as Z decreases to ^{10}B — (S. Behrnetz, private communication [1976]).

A simple approximation to the "visual width" of particle tracks is given by Katz and Kobetich [5] as

$$W = \frac{3.92\,Z}{\beta\{E_0[-\ln(1-P)]\}^{\frac{1}{2}}} + 0.12\ \mu\text{m}\,. \qquad (2)$$

where Z is the charge number of an ion moving at relative speed β in an emulsion for which E_0 is the characteristic dose (in erg/cm^3) at which 63% of the emulsion grains are developed, and where an observer chooses the track edge to be the profile around a track where P is the probability for grain development. The equation was thought to be valid for flat tracks where $10 < Z < 25$ and $\beta > 0.4$, to within 0.1 μm. In that work, it was suggested that normally developed G.5 emulsion was characterized by E_0 = 12,000 erg/cm^3, and that an observer would assign a track edge to the location where P = 0.4, accommodating for the difference in size between undeveloped and developed grains.

When these values are applied to equation (2), we find

$$\textit{theory:} \qquad W = 0.050\ Z/\beta + 0.12\ \mu\text{m}\,. \qquad (3)$$

The data of Figure 1 are replotted in Figure 2, giving the track width W (as determined by a slit 4 μm wide) as a function of Z/β, with a visually fitted line superimposed on the data points. The equation of that line is

$$\textit{experiment:} \quad W = 0.054\ Z/\beta + 0.048\ \mu\text{m}\,. \qquad (4)$$

We have made no attempt to reassign E_0 and P to conform to experiment.

The near quantitative agreement between equations (3) and (4) suggests that the difficulties encountered in extending the scattering parameters a_1 and a_2 from thick tracks to thin tracks arise from limitations in the form of the scattering correction itself, rather than from problems with track theory in this region of track width.

This conclusion is reinforced by an examination of the earlier results of Jacobsson and Rosander,[6] who applied track theory in a different way to photometric measurements of track width in the charge interval $6 \le Z \le 26$, in the residual range interval $100 \le R \le 1{,}000$ µm. They defined a theoretical width λ after processing to be

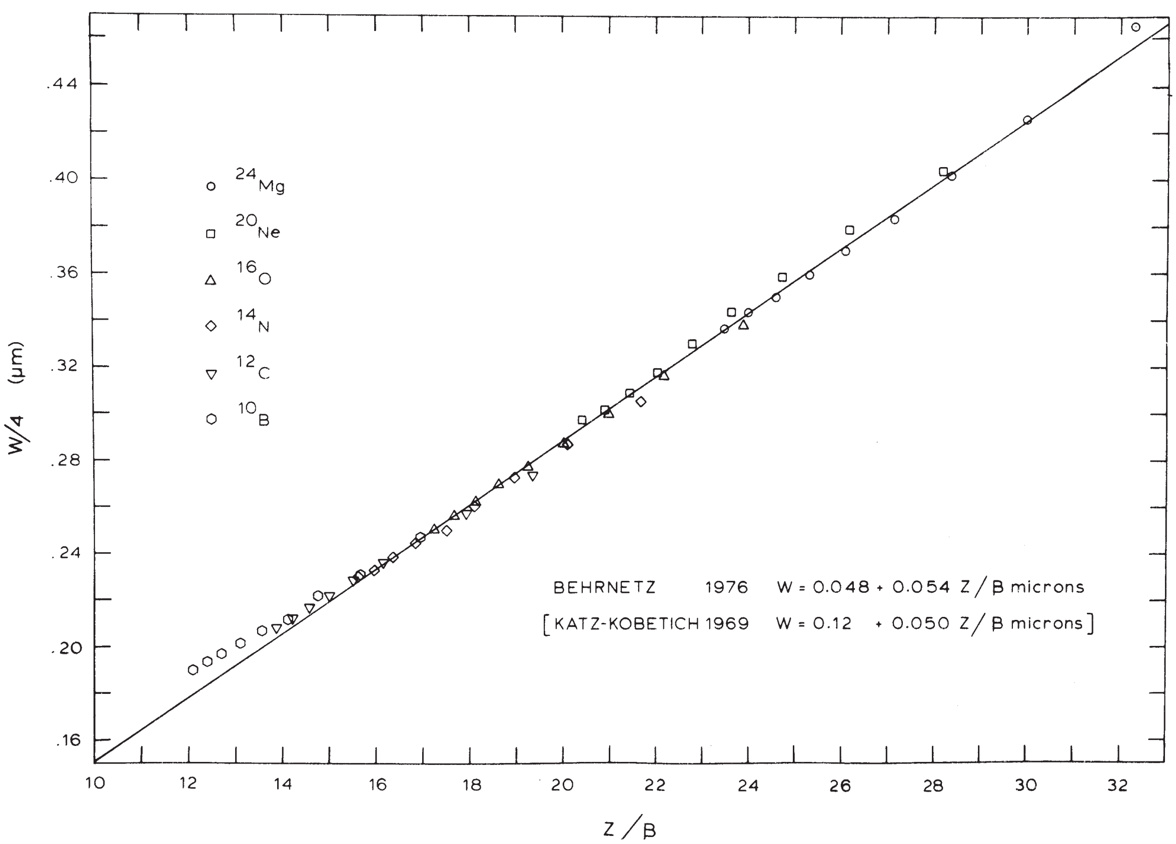

Figure 2. The data of Figure 1 are replotted as $W/4$ μm vs Z/β. A straight line is fitted to these data visually. The equation of that line is compared to an expression for the "visual width" of a heavy ion track, from theory, using values of E_0 and P suggested for G.5 emulsion in 1969.

$$\lambda = 2x + \lambda_0 \quad (5)$$

where it was assumed that the track is defined by a cylinder of radius x, inside which the dose $\overline{E}(t)$ exceeds a critical limit E_c and the effect of development can be accounted for by an additive term, λ_0. It was their finding that the theory agreed with experiment with thin tracks with $\lambda < 3\ \mu$m, but that theory departed from experiment for thicker tracks. Thus tracks in Ilford K.2 emulsions in this interval agreed with theory, but only the tracks for $Z \le 12$ in G.5 emulsion agreed with theory, when no light scattering correction was used.

In the application of track theory to experiment, we must expect that a light scattering correction must be applied to the measurement of the photometric track width in an optical microscope, for thick tracks. Some refinement is needed in the form of the scattering correction so that it is applicable to all track width measurements.

A further limitation on the application of the theory to thin tracks arises from the approximation that the emulsion is homogeneous, especially in the thin-down region near the stopping end. Here there is yet another difficulty from grain growth.

Occasional delta rays may penetrate radially to substantially greater distances from the particle's path in a real emulsion than in the ideal, homogeneous, approximation.

In the thin-down region virtually every grain is made developable, so that grain growth on development causes a swelling of the developed track, increasing its width substantially beyond the original width of the latent image. In extreme cases this can lead to the collapse of the silver column. Unless corrections for both inhomogeneity and grain growth are applied to the measurement of particle tracks in this region, it is inappropriate to compare theory to experiment.[7,8]

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