This Week's Citation Classic


A theoretical discussion is given of ranges of heavy ions passing through matter with moderate velocities, based on a simple scaling theory of ion-atom collisions. Probability distributions in total range and various averages are studied, as well as ranges projected on initial direction of motion. [The SC! indicates that this paper has been cited in over 2,240 publications since 1963.]

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"The main background of this paper is Niels Bohr's celebrated survey of atomic collisions, conceived before World War II, but published in 1946. From Bohr's discussion we learned to look for the simple essence of physical phenomena; to value experiments and their results, but to view them critically; and, not least, to understand when to apply classical mechanics, instead of quantum theory. Soon after, in connection with measurements by N.O. Lassen, it was realized that, for heavy ions carrying electrons, the ion charge theory of electronic stopping was somewhat uncertain.

"In the mid-1950s, an energy loss measurement by R.E. Leachman and H. Atterling was found not to be in agreement with Bohr's simplified version of ion-atom scattering. Morten Scharff and I began to remedy this, but we gradually conceived the ambitious plan of forming a comprehensive theory of collisions of all ions with all atoms, at moderate and low ion velocities. In fact, we were already experienced in Thomas-Fermi scaling properties in perturbation cases, as well as in dynamic properties of electron gases. At low velocities, ion scattering by atoms is important, but seems to be complicated. We were slow in discovering that a universal formula holds approximately for differential cross sections in ion scattering. A slightly different scaling was obtained in the average energy loss to electrons.

"The foundations of the work were laid, and a group of four papers conceived, with the common subtitle: 'Notes on atomic collisions.' They embraced the theory and its consequences. We were able to finish a brief summary before Scharff died, in 1961, at the age of 34. A group of young scientists, Vibeke Nielsen, Hans Schiøtt, and P.V. Thomsen, joined the work, and by a sustained effort, three papers2,3 were published in the years 1963-1968.

"The present paper does not give a derivation of the collision theory, being merely an application of the theory. Its topic was a study of ranges of heavy ions passing through matter, and probability distributions of ranges. This required a detailed investigation of integro-differential equations belonging to evolution of probabilities. The comprehensive solutions were meant to represent an average behaviour, disregarding individual deviations due to quantal shell resonances in ions or atoms.

"Our paper allowed quite direct comparisons between experiments and theory. It so happened that many stopping measurements were performed in the 1960s with accelerators originally used in nuclear physics, and also new, interesting phenomena were revealed within the physics of atomic collisions in solids. Moreover, direct applications of ion implantation were found, for instance in electronic devices. To this end, several books have been published containing tables of the simple range formulae. Because of such coincidences, seemingly, the paper has been quoted a number of times, and more frequently than the other two papers."