

## Channeling, Focusing and Sputtering

### The Observation of Atomic Collisions in Crystalline Solids

By R. S. Nelson

281 pp. Interscience, New York, 1969.  
\$16.50

Reviewed by ALLEN N. GOLAND

Anyone who has examined a model of a simple crystal lattice while turning it around in his hands has observed that there are certain channels that are wide open. If the model is constructed of ping-pong balls, for example, it looks as though one ought to be able to shoot a well aimed ping-pong ball through the lattice along the channels without hitting any of the lattice balls. J. Stark and G. Wendt originally made this suggestion back in 1912 with reference to the passage of charged particles through single crystals. Fifty years later the effect was observed experimentally. It is not too difficult to understand the long time span between the first suggestion and the first observation of "channeling" phenomena. The absence of accelerators, detectors and perfect single crystals over most of this period is reason enough.

However, by the early part of the present decade all three of the aforementioned ingredients were available, as were high-speed digital computers. Thus, almost simultaneously, Mark Robinson and Dean Oen at Oak Ridge "discovered" directional stopping power effects by computer, while John Davies and his collaborators at Chalk River, Hans Lutz and Rudolf Sizmann in Munich, and Stuart Nelson and Mike Thompson at Harwell were demonstrating experimentally that channeling does in fact occur in single crystals. Subsequently, experimental groups throughout the world began to investigate the phenomenon in detail. In addition to the laboratories already mentioned, contributions have come from Aarhus, Argonne, Brookhaven, Bell Telephone Laboratories, Jülich, North American Rockwell Corp and Sandia Laboratories, to mention some of the more active centers in this field.

Early theoretical treatments were provided by Christian Lehmann and Günther Leibfried, and by Nelson and Thompson. Later, general treatments, by Jens Lindhard and Cavid Erginsoy, demonstrated the validity of a classical mechanical description of channeling for heavy particles. For those who still might have been skeptical, further visual evidence of channeling was provided in the beautiful "star patterns" that were recorded photographically. Perhaps the best example of this technique is that produced by Nelson and his colleagues in full color from 1.5 MeV protons passing through a silicon crystal.

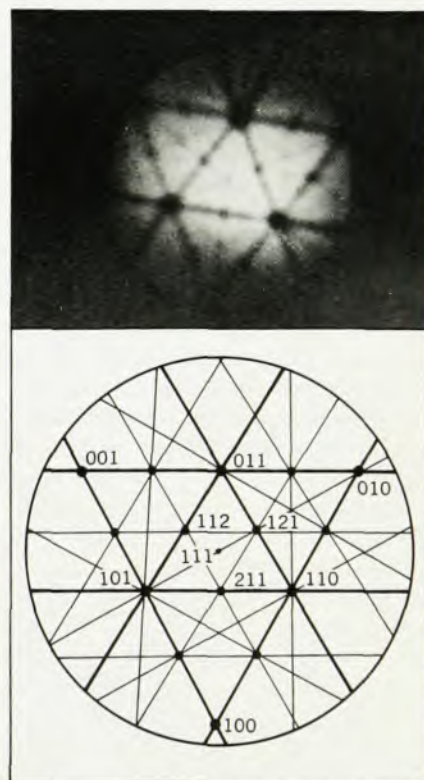
Channeling provides a powerful new tool for the study of energy-loss processes in solids, and there are indications that it will yield information about interatomic potentials as well. For the present, however, channeling (and its counterpart, "blocking") has excited most interest as a means of investigating the position of impurity atoms in solids and surface-layer structure. Thus it has become an important adjunct to the field of ion implantation.

All of these topics are treated in detail in Nelson's book. Having been in the field since its inception, and having made many original contributions to it, he is well qualified to undertake a comprehensive review of the subject. He has succeeded admirably in doing so. Half of his book is devoted to the passage of charged particles through solids. Earlier chapters deal in abbreviated form with the interaction of radiation and matter, and with some of the experimental techniques for observing the consequences of this interaction. Following his extended coverage of primary-particle motion in crystals, Nelson considers the behavior of the lattice atoms that have recoiled following collisions with the incident particles. In particular, chapter 5 contains about as full a description of focusing collisions as one can find anywhere. It includes the analytical treatments of Lehmann and Leibfried, Nelson and Thompson and others, plus the computer-simulation results

of the Brookhaven group. Later chapters cover special topics with particular emphasis upon the directional dependence of sputtering as a tool for observing focusing effects. Here, too, Nelson and his colleagues have made original contributions.

Nelson's book displays a continuity of theme that should be very helpful to those unfamiliar with the field. Thus, readers who are new to the field of atomic collisions in crystalline solids will find it an excellent starting point. Others will be gratified by the author's choice of subject matter, and his generous and frequent references to original publications.

Much of Nelson's own work has been performed in collaboration with Mike Thompson. It is interesting to note that Thompson has just published a book, too. Although the emphasis is different, Thompson's book



**PROTON BLOCKING PATTERN** from the (111) face of a gold single crystal. Proton energy is 20 keV. Below is drawing of simple radial projection of the (111) face of face-centered cubic crystal structure for comparison.

covers much of the same ground. It is a pleasure to record here the fact that both men obviously possess literary talent in addition to their already acknowledged scientific abilities.

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## Einstein's Vision

By John A. Wheeler

(In German) 108 pp. Springer-Verlag, New York, 1968. \$4.95

According to Albert Einstein's general theory of relativity, the observable geometry of spacetime is not rigidly given but is a physical field, subject to changes governed by field equations; gravity is but one aspect of this variable geometry.

One is faced, then, with at least two alternatives: One may either consider the geometry as a classical, macroscopic field or as a field subject to quantization; independently, one may imagine the geometry as one among several fields, or venture the bold hypothesis that "geometry is everything." It is well known that Einstein himself emphatically preferred a classical geometry that represents "everything;" he always considered an inhomogeneous field equation, with an energy tensor as a source, as provisional.

In his book *Einstein's Vision*, John A. Wheeler follows Einstein in adopting the hypothesis that "physics is geometry," that matter is but a manifestation of geometric structures. However, he takes "quantum geometrodynamics" as basic, and views classical geometrodynamics only as an approximation. The subject of the book is an

exposition of the main ideas and problems of this (vision of a) theory.

After a brief review of the possibilities for representing massive objects ("geons"), their motion, and electric charges ("wormholes") by classical, source-free Einstein-Maxwell fields, Wheeler turns to his central theme: superspace. This basic entity of quantum geometrodynamics is a "space" whose elements are all three dimensional (probably) oriented, compact Riemannian spin manifolds, that is with positive and definite metric manifolds. This superspace  $S$  is asserted, at least if space multiplicity is disregarded, to carry the structures of a Banachable manifold and an indefinite, semi-Riemannian metric. A physical state is represented by a complex-valued functional on  $S$ , satisfying an Einstein-Schrödinger functional equation of which, so far, only its WKB approximation (the Einstein-Hamilton-Jacobi equation) is known.

One such functional determines the probabilities with which various 3-geometries occur in a dynamically possible history. A localized wave packet (in  $S$ ) determines a family of most probable 3-geometries that fit into a single Riemann-Einstein spacetime. The finite extension of any wave packet means, however, that "really" the geometry resonates between many topologically, metrically, and spin-wise different configurations.

This picture is vividly elaborated, with many illuminating analogies and ten "Wheelerian" figures. Wheeler speculates about possibilities for understanding the existence of electric charge, elementary particles and spin. He discusses the possibly fundamental importance of the Planck length,  $L = 1.6 \times 10^{-33}$  cm, in connection with quantum-field fluctuations, and the breakdown of the classical spacetime concept during the final stages of gravitational collapse.

The discussion is mainly qualitative, except for order-of-magnitude estimates and some considerations about the relativistic Hamilton-Jacobi equation and the initial-value problem. Superficially the book might appear to be semipopular, but in fact only a reader with a good background in classical and quantum physics, general relativity, and some familiarity with modern geometry will appreciate the depth, difficulties, and subtleties of these considerations.

Some technical details would per-

haps have been welcomed by many readers, as well as a comparison with other approaches to the problem of quantizing general relativity. A more serious drawback is the lack of hints as to how this theory could make contact with specific observable phenomena, or even how such a quantum-geometrical formalism could be interpreted physically in the sense of a theory of measurement. Nevertheless, a reader who lets himself be carried away by Wheeler's fascinating, enthusiastic journey into the unknown will have some thought-provoking hours, and he is offered one coherent way of thinking about the role of spacetime geometry in physics.

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## Handbook of Techniques In High-Pressure Research And Engineering

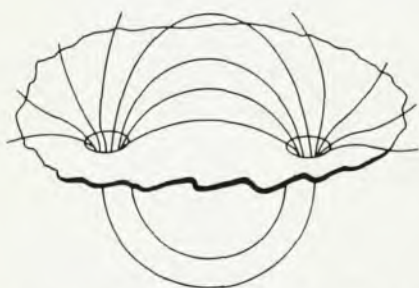
By Daniil S. Tsiklis

(Trans. from Russian), 504 pp. Plenum, New York, 1968. \$35.00

Anyone involved even peripherally with high-pressure research is certain to be aware of the extensive Russian work extending over many decades. It is especially gratifying, therefore, to have available an English translation of the third edition of a handbook written by a recognized Russian authority.

D. S. Tsiklis has long been active in many aspects of high-pressure research and has made numerous contributions to apparatus design. The translation by Albert Peabody appears of excellent quality, and the final product has also benefited significantly from the attention of the editor, Alfred Bobrowsky, who, from his own extensive knowledge of the field, has added numerous footnotes and comments in the text.

The book is, precisely as the title claims, a handbook of techniques. There are certain limitations. In order that no one be misled, it is advised that "Russian" be mentally prefixed to the title as an adjective. Most of the apparatus described is Russian. The bibliography of Russian literature is extensive, if not complete, through early 1965, but selections from the remainder of the world literature are highly incomplete and appear to have been made only from ne-



WORMHOLES are to the topological explanation of electric charge what geons are to the geometrodynamics model of mass. (From *Einstein's Vision*.)