Random, Non-Random and Periodic Faulting in Crystals

M. T. Sebastian and P. Krishna
Gordon and Breach, Langhorne, Pa., 1994. 383 pp. $130.00 hc ISBN 2-88124-925-6

Physicists looking for challenging problems with practical implications should try materials science, which starts where conventional solid-state physics stops. Many important physical properties of real materials are dictated by grain boundaries, stacking faults and dislocations, topics barely touched upon in most introductory courses. How and why these defects occur and what their influence is on mechanical and electrical properties are in the domain of materials science. *Random, Non-Random and Periodic Faulting in Crystals*, by M. T. Sebastian and Padmanabhan Krishna, is a thorough and fascinating survey of one small part of this vast and intimidating enterprise.

The remarkable complexity and difficulty that attend most materials science problems is reflected in a distinctive style of research. In most areas of physics, large groups of scientists can often be found in mad pursuit of a hot topic, one with some intellectual appeal and on which rapid progress appears possible; experimenters can often be persuaded to make samples that fit the criteria of some simplified physical model, if one inconveniently does not exist in nature. Materials science is different. One usually takes materials as they appear in nature or some industrial process, without the luxury of huge single crystals or especially prepared samples. The problems are difficult, and progress is often slow. Experimenters greatly outnumber full-time theorists, in part because real theoretical progress is particularly difficult. Theoretical advances are nevertheless rewarding, because they are highly leveraged by the large body of experiments. The brilliant theoretical work of Charles Frank and John Cahn on crystal growth, defects, liquid crystals, nucleation theory and wetting layers illustrates this point.

The book by Sebastian and Krishna lies firmly in this materials-science tradition. Its focus is on how and why one particular type of defect, the stacking fault, appears in a variety of interesting crystalline solids. The complex issues raised by this seemingly innocuous planar defect are illustrated by the problem of the close-packing hard spheres, in which one close-packed triangular array of spheres leads to two energetically equivalent sets of positions in which to place a second layer. Stacking faults introduce one-dimensional disorder into the familiar face-centered cubic and hexagonal close-packed arrangements. Unless one invokes second (or further) neighbor interactions, there is a large set of energetically equivalent, randomly faulted packings. As emphasized by Sebastian and Krishna, the entropy of random faulting is quite small and provides little guidance in distinguishing between various nearly degenerate layered arrangements.

The effects of stacking faults on well-studied compounds such as zinc sulphide, silicon carbide, cadmium iodide and calcium selenide are described in detail. Depending on the compound's growth history, various simple packings may be interrupted by stacking faults. Careful examination of the quenched diffuse x-ray scattering caused by these defects leads to information about their spatial distribution. Stacking faults also mediate phase changes from one stacking sequence to another. Diffraction patterns taken after first allowing a transformation to begin at high temperatures and then arresting its development by a quench yield information on phase transition kinetics.

The most interesting chapter for many physicists is probably the one on periodic faulting and long-period polytypes. The discussion includes early ideas by Charles Frank about growth mediated by screw dislocations with noninteger Burgers vectors. In some cases, the growth spirals he proposed have been directly observed. Not all long-period polytypes can be explained in this way, however. Among other approaches, the authors describe an intriguing application of the axial, next-nearest-neighbor Ising model to the problem of polytypism. As shown by Julia Yeomans and others, the esoteric phases exhibited by ANNNI spin models may be identified with long-period, stacking-fault sequences in real metallurgical alloys.

This book is an important specialized reference, but at a cost of 33 cents per page it will probably find its way into more physics and applied-science libraries than onto personal bookshelves. Physicists interested in a broader but less exhaustive introduction to materials science might try reading *Physical Metallurgy* by Peter Haasen (Cambridge University, 1978). For a comprehensive treatment of diffraction due to all kinds of defects there is the classic text by M. A. Krivoglanz, *Theory of X-Ray and Thermal Neutron Scattering by Real Crystals* (Plenum, 1969).

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Introduction to the Theory of the Integer Quantum Hall Effect

M. Janssen, O. Viehweger, U. Fastenrath and J. Hajdu
VCH, New York, 1994. 296 pp. $45.00 pb ISBN 3-527-29209-8

The various quantum Hall effects are a remarkably rich set of phenomena with deep and truly fundamental theoretical implications. The fractional effect has yielded the ideas of fractional charge, spin and statistics, as well as unprecedented order parameters, and there are beautiful connections between the quantum Hall effects and a variety of topological and conformal field theories studied as formal models in particle theory, each made manifest by the twist of an experimental knob. Where else but in condensed-matter physics can an experimenter change the number of flavors of relativistic chiral fermions, or set the Chern–Simons θ angle by hand?

In *Introduction to the Theory of the Integer Quantum Hall Effect*, Martin Janssen, Olaf Viehweger, Ulrich Fastenrath and Janos Hajdu, all members of the Institut für Theoretische Physik in Cologne, Germany, return to the fascinating question of the integer quantum Hall effect's localization transition. The book begins on a seemingly pessimistic note with the statement that there is no theory of the integer quantum Hall effect. While true in a certain limited sense, this statement belies the tremendous progress that has been made, beginning with and building on Robert Laughlin's initial argument for the universality of the quantization. The basic phenomenology of the integer quantum Hall effect is completely understood. There is no question from either experiment or numerical simulation that a quantizing magnetic field applied to a disordered two-dimensional system produces a set of delocalized critical points at which the localization length diverges with critical exponent v approximately equal to $7/3$.

It is true, however, that, despite valiant attempts, the quantum field theory describing the universal longwavelength aspects of this transition, though perfectly well defined, has so far resisted exact solution. Nor has anyone yet been able to derive analytically the value of the critical exponents such as υ. In this strict technical sense there is no (solved) theory of the effect.

This book is a good introduction to the open questions in this subject. It covers the basic phenomenology of the bulk transition (and related edge states) for noninteracting electrons, recent progress in numerical methods such as transfer matrix techniques, network models, and multifractal analysis of broadly distributed quantities. The authors also provide an overview of some of the analytical field-theoretic approaches, without going into the details (which can be pretty horrible). The approach to some of the transport theory is a bit formal for my taste, but nevertheless this is a good book for students interested in learning about what is known and unknown in this field. It also has helpful references and practical hints for people interested in actually working on this problem.

Conformal field-theory methods, for example, have been used with great success in two-dimensional statistical mechanics. However, they have so far been singularly unsuccessful in solving problems with quenched disorder. Here is a classic and fundamental problem waiting to be solved. This book will help you get started.

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Solar Magnetic Fields: Polarized Radiation Diagnostics

Jan Olof Stenflo
Kluwer, Norwell, Mass., 1994. 385 pp. $108.00 hc ISBN 0-7923-2793-4

Pieter Zeeman's investigation "On the Influence of Magnetism on the Nature of the Light Emitted by a Substance" first appeared in *Philosophical Magazine* in March 1897. Significantly, it was reprinted only two months later in the *Astrophysical Journal*; astronomers immediately recognized the possibility that the Zeeman effect could be used to detect magnetic fields in remote objects. This potential was realized in 1908, when George Ellery Hale observed the splitting and circular polarization of spectral lines in sunspots.

Today the Zeeman effect remains our most powerful tool for measuring magnetic fields in the atmospheres of the Sun and other stars, but atomic physics and solar physics have otherwise changed wonderfully. The interaction of an atom in a magnetic field with a quantized radiation field is now a standard (although hardly simple) problem. We know how to calculate the transfer of polarized radiation through a magnetized medium, even if we can't often carry out the calculations without severe simplifications. More important, we know that the magnetic field of the Sun—pervasive yet intermittent in time and space, occupying every distance scale from the solar radius to below our finest Earth-bound measurements and intimately yet mysteriously linked to the existence of solar activity and its effects on the Earth's environment—is itself worth studying.

Jan Stenflo, a leader in the theory and practice of solar magnetometry, aimed to write "a textbook that tries to expound the basic theory in some