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Introduction to Scanning Tunneling Microscopy [book review]

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BOOK REVIEWS

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Introduction to Scanning Tunneling Microscopy. C. Julian Chen. 412 pp. Oxford U.P., New York, 1993. Price: $65.00 ISBN 0-19-507150-6. (Reviewed by Walter F. Smith.)

Everyone is excited by scanning tunneling microscopy (STM). To the undergraduate, or even the high-school student, the ability to view individual atoms is incredibly captivating. To the professional surface scientist, this capability has become an indispensable tool. It often allows a researcher to sidestep the laborious interpretation required for Fourier-space methods, and has unique capabilities, especially for nonperiodic structures. The basic theory is remarkably simple, and perhaps in retrospect it is amazing that the STM was not invented earlier.

Unfortunately, this apparent simplicity is often misleading. Too often, experimental STM papers are not presented with careful thought about the effects of the tip electronic structure. Shocking omissions are frequently made in these papers. For example, often the tunneling conditions (sample bias voltage and tunneling current) used to obtain a particular image are not cited, the calibration for the gray scale for an image is not given, or the fact that images have been filtered or otherwise enhanced is not mentioned. To put it bluntly, there are many rather sloppy papers in the field of STM.

Part of the explanation for this is that STM is such a powerful technique that even sloppy science can yield important results. Also, the tip plays a critical role in determining what the images will look like, and yet it is quite difficult to determine the identity and arrangement of the tip atoms. The muddled state of STM theory, however has also contributed. To get beyond the most basic understanding requires considerable sophistication, and the theorists are far from agreeing among themselves. The field has been waiting for a text which covers the theory in detail, yet at a level accessible to the experimental graduate student.

There are, so far, a small number of textbooks on STM. In chronological order, the major ones are: *Scanning Tunneling Microscopy and Related Methods*, edited by R. J. Behm, N. Garcia, and H. Rohrer (Kluwer, Boston, 1990, $149); *Scanning Tunneling Microscopy I, II, and III*, edited by H.-J. Güntherodt and R. Wiesendanger (Springer-Verlag, Berlin, 1992–1993, $59, $69, $79 for each of the respective volumes); *Scanning Tunneling Microscopy*, edited by J. A. Stroscio and W. J. Kaiser (Academic Press, Boston, 1993, $89); and the present book by Julian Chen. The first book was reviewed in this Journal by Terje Vold [Am. J. Phys. **59**, 765 (1991).] In this review, I will compare Chen's book with the other two (Güntherodt/Wiesendanger and Stroscio/Kaiser). (Unfortunately, Vol. III of Güntherodt/Wiesendanger, which contains most of the detailed theory, was published too recently to be included in this review.)

C. Julian Chen is a leading STM theorist. He has endeared himself to experimentalists perhaps most notably by his calculation of the deflection of a quartered piezo tube [Appl. Phys. Lett. **60**, 132 (1992)].

Chen's book is the only one by a single author, i.e., not a collection of chapters by several authors. This allows a more cohesive and linear presentation, and also allows a departure from the usual organizational scheme. Most reviews of STM, including Güntherodt/Wiesendanger and Stroscio/Kaiser, focus on applications—e.g., imaging of semiconductors, metals, superconductors, charge density waves—and include lengthy sections on the cousins of STM (atomic force microscopy, scanning near-field optical microscopy, etc.). Chen telescopes these considerations down to less than one tenth of the book, leaving the rest open for a very detailed discussion of general theory, including derivations, and for practical calculations and hints about construction and operation.

Chen's overview chapter, and most of his lengthy instrumentation section, are accessible to talented advanced undergraduates. However, the rest of the book, which deals with the theory of STM imaging, is aimed at advanced graduate students; many of the derivations will be quite difficult for experimental students. In contrast, the theory in Stroscio/Kaiser does not give real derivations, but essentially consists of presenting and explaining the results.

Chen's main point is "Remember the tip!" He reminds us that the STM is essentially a symmetrical device, in which the tip and the sample participate equally. When viewing an STM image, it is too easy to think of it as an actual picture of the sample (or, in a more sophisticated view, of the local density of states of the sample at the Fermi surface). Chen presents compelling arguments and calculations which show what a dramatic effect the tip can have. His description of the mechanism for inverted images (when the atoms show up as low points rather than high points) is especially lucid. There is an excellent development of relation between the tunneling conductance and the force between tip and sample. Chen models the STM as a giant molecule, in which there is a controllable bond distance between the apex atom on the tip and the sample atom below it. He argues very convincingly that the s-wave tip model is completely inadequate, and that most atomic-resolution images are taken with tips in which p and d states dominate. This is in marked contrast to the theory treatment by J. Tersoff and N. D. Lang in the Stroscio/Kaiser book, which is essentially s-wave based. Chen's most powerful arguments relate to corrugation amplitude. His arguments are quite convincing, but there is not always adequate comparison with experiment.

Until this year, no STM book or review contained an instrumentation section with a useful level of detail. However, Chen's is excellent. He gives detailed recipes for tip etching and *in situ* sharpening via field emission, for tip density-of-states "flattening" (essential for good spectroscopy), and for repoling piezos. His discussion of the effects of stray capacitance on current amplifiers is excellent, and he presents simple clever circuits to avoid these effects. He gives an outstanding comparison of the different types of piezo materials.

Unfortunately, not everything is as good. Chen's main theoretical focus is on the detailed interaction between tip and sample, and he neglects many gross effects encountered in practice, such as multiple-tip effects, difficulties encountered in imaging highly corrugated surfaces, and possible effects of a meniscus during imaging in air. There is no dis-

of sample preparation or piezo creep. The discussion
ack is good, but there is no explicit treatment of
feedback, which is the most important type for STM.
tments of piezo hysteresis and varying-gap spectros-
e inadequate. The discussion of vibration isolation
is good, but the comparison between one- and two-
pport systems is unclear.
most annoying problem, which occurs not only in the
ntation section but throughout the book, is with the
aptions and the treatment of the figures in the text.
he captions or text mention things such as dottedlines
re not present in the figure. Sometimes symbols are
the figures long before they are encountered in a
or the text. For many images, the tunneling condi-
ray scale calibration, and tip type are not given.
nstrumentation section in Stroscio/Kaiser (by S.-I.
d R. C. Barrett) is also excellent. It is stronger in
reas than Chen's and weaker in others. There is a
discussion of 2-stage vibration isolation, complete
cipe, and numerous useful debugging suggestions
ave certainly never been published elsewhere. There
tire chapter (by Stroscio and R. M. Feenstra) devoted
roscopy methods, including detailed coverage of the
-gap method, in contrast to Chen's scanty treatment.
s another entire chapter (by L. D. Bell *et al.*) on the
nt emerging technique of ballistic electron emission
opy, which is not treated at all in Chen. However,
etails of other subjects are left to be looked up in
ces. There are no detailed tip preparation recipes and
tions for the deflection of a tube scanner.
STM experimentalist, especially one dealing with a
uilt STM in any stage of development, would be a
ad not to read the experimental sections of both books
and Stroscio/Kaiser). There is much to be gleaned
hem, and neither alone is adequate. Güntherodt/
danger has essentially no instrumentation section, a
oversight.
n's book begins with the most beautiful collection of
mages I've ever seen. Another bonus is that the titles
en for all references, and they are all in one place. All
books (Chen, Stroscio/Kaiser, and Güntherodt/
danger) have good indices; Stroscio/Kaiser has the
ntries, followed by Chen. Chen is the only one with a
figures, which could come in very handy when trying
te a dimly remembered item.
ummary, an STM experimentalist should absolutely
at least borrow, both Chen and Stroscio/Kaiser. For
M theorist, it would be Chen and Vol. III of
rodt/Wiesendanger. An undergraduate library should,
possible, buy both Chen and Stroscio/Kaiser. If it can
fford one, it should go with Stroscio/Kaiser, since
f it is accessible to undergraduates.

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nd on mesoscopic devices.

ise and Fall of the Fifth Force: Discovery, Pursuit,
d Justification in Modern Physics. Allan Franklin.
1 pp. American Institute of Physics, New York, 1993.
ice: $29.95 ISBN 1-56396-119-9. (Reviewed by
inton Van Siclen.)

In early 1986, *Physical Review Letters* and *The New York Times* alerted physicists and the public to the discovery of a composition-dependent "fifth force" operative over distances of several hundred meters. What is generally remembered about that initial announcement is that the evidence for existence of the force came from a reexamination of data taken during the famous experimental test of Einstein's equivalence principle by Baron Roland von Eötvös and collaborators in 1922.

In this admirably brief volume, Allan Franklin, a physicist and philosopher of science at the University of Colorado, presents a detailed history of the Fifth Force. He begins by describing the experimental and theoretical searches for gravitational effects at the quantum level and the attempts to modify and test Newtonian gravitational theory occurring at that time, in order to convey the context within which Ephraim Fischbach *et al.* developed their startling hypothesis. In their Letter, they cite as particular motivation "recent geophysical determinations of the Newtonian constant of gravitation G [that] have reported values which are consistently higher than the laboratory value G_0" and "the $K^0-\bar{K}^0$ system at high laboratory energies, where, in fact, anomalous effects have previously been reported [by two of those authors]," but Franklin shows convincingly that, to a considerable extent, this was an idea whose time had come.

By providing detailed descriptions of the subsequent experiments and theoretical work undertaken to accommodate the various, often contradictory, experimental results, Franklin shows how physicists confront a novel and experimentally testable hypothesis. His sources include the major participants in the research as well as the published literature. Particularly interesting is the e-mail correspondence, presented verbatim to preserve the immediacy and intimacy inherent in its informality, between members of the Fischbach collaboration following publication of their hypothesis, as they considered the ensuing criticism.

The story of the Fifth Force is a vehicle for Franklin, in his words, to "examine the roles that evidence plays in the contexts of discovery, of pursuit, and of justification." Regarding the evidence that Fischbach *et al.* presented, Sheldon Glashow reportedly said, "Unconvincing and unconfirmed kaon data, a reanalysis of the Eötvös experiment depending on the state of the Baron's wine cellar [an allusion to the importance of local mass inhomogeneities], and a two-standard-deviation geophysical anomaly! Fischbach and his friends offer a silk purse made out of three sow's ears, and I'll not buy it." In contrast, following a talk by Fischbach at Stony Brook in the spring of 1986, Tobias Haas wrote to Sam Aronson (a member of the collaboration), "It was a very impressive lecture—I think physics at its best (even if it should turn out there is no fifth force)." Referring specifically to later criticism by Philip Anderson expressed in a "Reference Frame" column in *Physics Today*, but certainly applicable to Glashow's statement above and to other public criticism as well, Franklin makes the key observation that Anderson "fails to distinguish between the evidence necessary for believing in a hypothesis and that needed for investigating it further. At the time of the original publication the question was not one of belief, but whether or not one should pursue the possibility of such a force." Indeed, Franklin emphasizes that there were no "true believers" among the experimentalists; rather, "all of the researchers remarked that the idea of testing a fundamental law of physics with a table-

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top experiment, or with a comparatively inexpensive and conceptually simple apparatus, was an important part of their motivation."

One very curious aspect of this whole episode, that Franklin recognizes but doesn't seem to know quite what to make of, is the tremendous influence exerted by the 1922 Eötvös data: "It seems clear that the fact that the original paper [by Fischbach *et al.*] contained the reanalyzed Eötvös data made the hypothesis of the Fifth Force more plausible and led to the subsequent work. Recall that similar theoretical work ... had been going on since the early 1970s without stimulating the large amount of work that followed publication of the Fifth Force hypothesis." This fascination with historical data brings to mind the speculation a few years ago that Robert Millikan had observed fractional electric charge on his oil drops; perhaps that assertion legitimized the search, seventy years after the experiment, for free quarks.

This thought-provoking book will reward scientists and would-be scientists alike.

Clinton Van Siclen is a theoretical physicist at the Idaho National Engineering Laboratory, currently working in condensed matter/materials research. He wrote an early (1986) paper influential in the subsequent "cold fusion" controversy.

Bad Science: The Short Life and Weird Times of Cold Fusion.

Gary Taubes. 503 pp. Random House, New York, 1993. Price: $25.00 ISBN 0-394-58456-2 (Reviewed by A. F. Burr.)

Cold fusion burst into the news in March of 1989. It did not take an advanced degree to see that, if the claims were true, the impact of the discovery on society would be great. The room temperature fusion of nuclei promised much. Unfortunately, the number of physical principles that were apparently violated required much in the way of suspended judgement. The possible economic consequences, however, guaranteed great popular interest, and the technical questions that were raised engaged the attention of many scientists.

Gary Taubes, the author of *Bad Science: The Short Life and Weird Times of Cold Fusion*, is well qualified to write about this phenomenon. He is a journalist who has studied physics and aeronautical engineering. He wrote a detailed account of part of the cold fusion story for *Science* magazine. Based on this start, he interviewed over 260 people in person and by phone to collect a detailed description of much that took place. He lists his sources and includes copious footnotes, over 300, some of which are not very important. He even includes chronological information when it is of particular interest, as in the case of the interaction between people from the University of Utah and Brigham Young University during the time before the fateful press conference at Salt Lake City on March 23, 1989.

The book is not a scholarly work or even a popular retelling of the physics of the phenomenon. It is a popular book of current history written by somebody who spent a great deal of time trying to get the facts straight and who brings a broad and relevant background to the task. The book is not a conclusionless recitation of details but is the work of somebody who looked at a large part of the action, came to a conclusion, and tried to explain why so much bad science made such a big splash in the national press.

It has as many details (if not more) of the affair as most people will want. It is readable, suspenseful, and insightful. It covers most of the important efforts, most of the important people, and cites most of the important lessons that can be learned.

The book clears up many points which a physics teacher who followed the progress of the investigations in the popular press and on the Internet might have missed. The relationship between the work being done at the University of Utah and at Brigham Young University is discussed in some detail. Most of the reports of work done in the United States that were taken as confirming the initial report are covered in detail also. In particular, the circumstances that led to the retraction or discounting of the early results are set out. The whole story is not just a scientific anomaly that was corrected by the usual scientific process. Personal as well as scientific reputations were tarnished, good students and post docs were misused, large sums of money were spent, and even one scientist was killed in a hydrogen explosion while working on this problem.

The disastrous effect of bypassing the usual peer review channels and failing to perform appropriate control experiments is repeatedly mentioned. The tensions between the University of Utah and Brigham Young University, between administrators and scientists, between physicists and chemists, even between the *Wall Street Journal* and the *New York Times*, are invoked to illuminate the causes of the debacle. But most of all, the author shows how the pressures of our society and the workings of human nature all combined to lead otherwise reasonable people into actions which, in retrospect, were unreasonable, to say the least.

A. F. Burr is Professor of Physics at New Mexico State University. He does work on the physics of x rays and is interested in the applications of computers to undergraduate physics teaching.

Special Relativity: Applications to Particle Physics and the Classical Theory of Fields.

Mohammad Saleem and Muhammad Rafique. 257 pp. Prentice-Hall, Englewood Cliffs, New Jersey, 1992. Price: $75.00 ISBN 0-13-827106-2. (Reviewed by G. Lyle Hoffman.)

Saleem and Rafique offer a fairly thorough compendium of special relativity as it was commonly taught about 30 years ago. The book might be of use to students who need a reference in the areas of relativistic mechanics, relativistic electromagnetism, and relativistic scattering theory and who have resolved never to study general relativity; however, those students may find it confusing to shift from this book to any modern text on electrodynamics (such as Jackson's *Classical Electrodynamics*, 2nd ed.) or on particle physics. It is not clear for whom the book is intended: the chapters on electromagnetism and scattering theory suggest an audience of graduate or very advanced undergraduate students, but the problems that accompany the first four chapters would insult the intelligence of such students. The text assumes familiarity with tensor calculus and group theory, which few students in the US encounter before they are introduced to special relativity. There are appendices in the text giving essential details of those areas of mathematics, and those appendices would be required reading for most US students attempting to learn special relativity from this book.

The main difficulty with the book is that the authors do not recognize special relativity as the vacuum limit of general relativity. Throughout the text, they rely on the archaic concepts of "relativistic mass" and imaginary fourth components of 4-vectors ("*ict*")—concepts which are not compatible with the extension of special relativity to curved spacetime (as explained eloquently by Misner, Thorne, and Wheeler in *Gravitation* and by Taylor and Wheeler in *Spacetime Physics*). Neither the "relativistic mass" nor "*ict*" is essential to the development of special relativity; neither advances the pedagogy of special relativity; and both must be abandoned when one goes on to study general relativity. They are at best mnemonic devices to make relativistic physics look as much like Newtonian physics as possible, thus obscuring essential differences. Why introduce them at all?

For the most part, derivations are correct and thoroughly detailed. There are some unfortunate exceptions: the derivation of hyperbolic motion (p. 80), for example, takes both the 3-force f and the 3-acceleration a to be constant, ignoring the factor $(1-v^2/c^2)^{-3/2}$, which is not constant since v is the speed of the accelerating particle. Fortuitously, Saleem and Rafique get the right result. The derivation of kinetic energy on pages 82 and 83 starts off by assuming that the Newtonian work-energy theorem will carry over unscathed to special relativity. It is not obvious *a priori* that this should be true. It would be much more sound pedagogically to seek out the functional form for kinetic energy by requiring energy to be conserved in particle interactions, as is done in most texts on the subject. For the most part, derivations and calculations are carried out in frame-dependent language; even though 4-vectors are introduced in Chap. 2, they are hardly ever used before Chap. 6 (scattering theory). Much more extensive use of invariants and 4-vector techniques would make many calculations much more straightforward and elegant. Spacetime diagrams, which are very useful tools for developing insight into many relativistic phenomena, are used remarkably sparsely.

On pages 86 and 87, the authors make an extraordinary equivalence between inertial reference frames and rigid bodies, concluding that "a reference frame will always interact with the material system under observation." Surely a frame of reference is an abstraction and can be chosen (that is, imagined) not to interact with anything. There is no difficulty in choosing a *sequence* of inertial frames such that the velocity of one frame of the sequence coincides with the velocity of the object at each instant—and then the concerns of pages 86 and 87 vanish completely.

In sum, for students who have no interest in ever studying physical processes in curved spacetime, this book could serve as a reference in the areas of relativistic electromagnetism and two-particle collisions. But I cannot recommend the book as an introduction to special relativity, especially because attempting to make the transition from special relativity, as it is presented in this book, to general relativity would be unnecessarily confusing.

G. Lyle Hoffman is Associate Professor of Physics at Lafayette College. His primary area of research is extragalactic radio astronomy.

BOOKS RECEIVED

Connecting Time and Space. (An AAPT reprint volume.) Edited by Harry E. Bates. 136 pp. AAPT, College Park, Maryland, 1992. Price: $18.00 (paper) ISBN 0-917853-47-4.

From Alchemy to Quarks: The Study of Physics as a Liberal Art. Sheldon L. Glashow. 692 pp. Brooks/Cole, Pacific Grove, California, 1994. Price: $45.00 ISBN 0-534-16656-3.

Laser Spectroscopy. (An AAPT reprint volume.) Edited by R. Gupta. 149 pp. AAPT, College Park, Maryland, 1993. Price: $18.00 (paper) ISBN 0-917853-49-0.

The Making of a Soviet Scientist: My Adventures in Nuclear Fusion and Space—From Stalin to Star Wars. Roald V. Sagdeev. 376 pp. Wiley, New York, 1994. Price: $24.95 ISBN 0-471-02031-1.

McGraw-Hill Dictionary of Scientific and Technical Terms, 5th ed. (Includes floppy disk.) Edited by Sybil P. Parker. 2194 pp. McGraw-Hill New York, 1994. Price: $110.50 ISBN 0-07-042333-4.

Polarization de la lumière. Serge Huard. 339 pp. Masson, Paris, 1994. Price not given. ISBN 2-225-84300-7.

Quantum Field Theory, revised ed. F. Mandl and G. Shaw. 358 pp. Wiley, New York, 1984. Price: $64.95 (paper) ISBN 0-471-94186-7.

Quantum Methods with Mathematica. (Includes floppy disk.). James M. Feagin. 482 pp. Springer-Verlag, New York, 1994. Price: $54.95 ISBN 0-387-97973-5.

Science Frontiers: Some Anomalies and Curiosities of Nature. Compiled by William R. Corliss. 356 pp. Sourcebook Project, Glen Arm, Maryland, 1994. Price: $18.95 (paper) ISBN 0-915554-28-3.

Symmetries, Gauge Fields, Strings, and Fundamental Interactions, Vol. 1: Mathematical Techniques in Gauge and String Theories. Tulsi Dass. 506 pp. Wiley Eastern, New Delhi, 1993. Price not given. ISBN 81-224-047-7.

The Undivided Universe. David Bohm and Basil J. Hiley. 397 pp. Routledge, New York, 1993 Price: $29.95 ISBN 0-415-06588-7.

Used Math: For the First Two Years of College Science, 2nd ed. Clifford E. Swartz. 264 pp. AAPT, College Park, Maryland, 1993. Price: $20.00 (paper) ISBN 0-917853-50-4.

Particles and Policy. Wolfgang K. H. Panofsky. 232 pp. AIP, Woodbury, New York, 1994. Price: $29.95 ISBN 1-56396-060-5.