Gargamelle heavy-liquid bubble-chamber group at CERN and of the E1A spark-chamber and calorimeter collaboration at the National Accelerator Laboratory, which is now called Fermilab. The experiments these groups performed to test the existence of neutral currents in the early 1970s helped to generate present-day interest in gauge physics.

Galison's detailed case studies provide much insight into the multifaceted processes that transform scientific data into evidence. These include the styles of argumentation developed by the various research teams, heuristic demonstrations, computer simulations and model-making, and the threefold interaction of experimental practices, theory and instrumentation. Science is a creative activity, and in some respects the laboratory is not that different from the artist's studio. Michelangelo is supposed to have remarked ironically that nothing could have been simpler than carving his *David*; all he had to do was to remove everything that was not his masterpiece. In physics, too, removing the effect from its background is a complex process. Quite sensibly, Galison has remained within the bounds of the modern physics about which he knows most. His analysis can be read with profit by physicists, historians and philosophers of science, and should be extended to other branches of science.

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Gauge Fields and Strings

A. M. Polyakov
Harwood Academic (Gordon and Breach), New York, 1987. 301 pp. $48.00 hc ISBN 3-7186-0393-4; $18.00 pb ISBN 3-7186-0392-6

Twenty years ago, quantum field theory was considered by many a mathematical concoction of dubious consistency, good for the calculation of amplitudes in electrodynamics but clearly inapplicable to strong interactions. Today, we generally consider quantum field theory to be the most important theoretical tool not only in elementary-particle physics but also in statistical physics and other areas—that deal with the interactions of many degrees of freedom. A major part of the development of this theory has come through its intertwining with the study of phase transitions; this relationship has brought the ideas of spontaneous symmetry breaking and the renormalization group to their present central position in the subject. Alexander Polyakov has been one of the major figures in this development, from his early use of conformal invariance in the study of phase transitions, to his introduction of topologically nontrivial field configurations and explication of their physical implications, and to his most productive reformulation of the theory of strings. In this volume he attempts to set out the main currents of his thought on this broad subject, emphasizing especially the problems that remain unsolved.

Polyakov's book is intended for students, but he does presume a certain level of sophistication. Each argument that he gives is self-contained, though sometimes new mathematical tools appear out of the blue just when needed. The treatment of quantum field theory anomalies, both the axial-vector anomaly and the conformal anomaly, which plays a central role in string theory, are exceptionally nicely done. But other topics, such as the strong-coupling expansion and the loop equations for QCD, go by very quickly. References to the literature are either useless or nonexistent. More advanced students should be able to follow all of the developments; beginners in field theory will find this book something of a wild ride.

And the ride is wild indeed. Polyakov's imagination is wide ranging, and one of his goals is to tie together bits of intuition from disparate physical situations, using gauge invariance as a unifying principle. He begins with the statement "The garbage of the past often becomes the treasure of the present (and vice versa)." The flow of his ideas at times becomes a jumble, but it does contain an ample supply of gems. The first half of the book is devoted to the applications of gauge invariance and topology in field theory. As one example of Polyakov's approach, he characterizes a superfluid by its superconducting properties (that is, the response of the medium to an externally applied gauge field), and this discussion turns out to be a warm-up for the characterization of the quark-confining state of gauge theories in terms of its response to an antisymmetric tensor gauge field. Instantons are introduced in the setting of the two-dimensional Heisenberg ferromagnet, where Polyakov can derive not only the general solution for these topologically twisted field configurations but also the dipole–dipole character of their interactions. This last piece of information leads to some fascinating (albeit inconclusive) sta-

tistical speculation.

The second half of the book is devoted to string theory. Strings, abstract one-dimensional extended objects that provide a generalization of point particles, have recently attracted the attention of the theoretical community as a possible basis for the unification of all fundamental forces. This interpretation has been brought forward most forcefully by the work of Michael Green and John Schwarz. Polyakov, however, has long held a different point of view, that a theory of "free strings" should be as general a mathematical tool as the harmonic oscillator or the Klein–Gordon equation, and that this theory will finally give a proper description of such problems as the large-distance behavior of QCD. Such a simple and general theory does not yet exist. In pursuit of this idea, Polyakov concentrates in *Gauge Fields and Strings* on the foundations of the quantum theory of strings, and gives a careful and very complete account of the relation between the geometry of strings and their quantization. Some aspects of the currently popular superstring theories are discussed, but the treatment is rather telegraphic. Polyakov also sets out some broader applications of string ideas, including a beautiful derivation of a string equation describing the three-dimensional Ising model.

Throughout the book, Polyakov never hesitates to go beyond what is actually proved, to speculate and to point to unsolved problems. It is this open-ended quality that makes his book especially fascinating. Theoretical physicists of all varieties will be impressed by the breadth of view and the depth of the arguments that Polyakov offers, but above all by the questions, questions, questions to stew over long after they have put this text down.

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Physics of Massive Neutrinos

Felix Boehm and Petr Vogel
Cambridge U. P., New York, 1987. 211 pp. $34.50 hc
ISBN 0-521-30567-5

There may be a place already reserved on the shelf for *Physics of Massive Neutrinos* right next to *Descriptive Anatomy of the Unicorn*, but it is hard to believe that such interesting particles could fail to exist. One can only marvel at a particle so craftily designed that after more than 50 years of research we do not even know if it has a distinct antiparticle, let alone mass.

All this ignorance belies the feverish theoretical and experimental activity in neutrino physics, and this book by Felix Boehm and Petr Vogel is both timely and unique. Boehm, who is Valentine Professor of Physics at Caltech and a major figure in the field, is best known for his careful search for neutrino oscillations with reactor antineutrinos. Vogel, a research professor of theoretical physics at Caltech, has contributed fundamental insights to the theory of double beta decay. Together, they have put into sharp relief both the laborious and beautiful efforts of experimenters and the ingenuity of theorists.

The idea that neutrinos could have mass is as old as Enrico Fermi's theory of beta decay itself, but it fell out of fashion when parity was overthrown. The argument was that in beta decay only left-handed neutrinos were seen, and therefore neutrinos had to be massless and always travel at light speed. Otherwise one could overtake a neutrino and see it spinning in the wrong sense. Later, with the development of the "standard model" of particle physics and the discovery of parity violation in neutral currents without neutrinos, it became clear that parity violation is intrinsic to the weak force itself. There was no longer any reason to saddle neutrinos with the job of violating parity, and massive neutrinos ought to be physically acceptable. Still, in the standard model, neutrinos are not provided with right-handed fields and therefore are massless by fiat. Today this seems artificial, and is a likely weak spot in the gleaming armor of the standard model.

What with theory offering little guidance as to how heavy neutrinos might be, experimenters are searching everywhere their techniques permit. There are two strategies: Observe some kinematic variables at the time a neutrino is created, and deduce its mass, or observe the subtle interplay of lepton-number violation and mass in processes like neutrino oscillation and double beta decay. The former method is free of assumptions, but within the framework of specific assumptions, the latter is much more sensitive.

In 1980 a group at the Institute of Theoretical and Experimental Physics in Moscow reported that their kinematic experiment on the beta decay of tritium had yielded evidence for an electron neutrino mass of 35 eV. This caused a great stir, not only because it menaced the standard mod-