

Robert Hofstadter, using electron scattering, determined the charge distribution in the proton. Frederick Reines and Clyde Cowan Jr showed that antineutrinos are absorbed by protons. (The 1950s were a great time for elementary particle experiments.) Later papers examine the properties of K mesons and excited states of the nucleon, including the Ω^- . The quark structure of nucleons and mesons was established. Heavy quarks, and the corresponding mesons, were studied.

"Particle Theory" contains a lot of general theory papers, notably the quantum electrodynamics of Richard Feynman and Freeman Dyson's unification of this theory with that of Schwinger. (Schwinger appears separately in the book, in the "Atomic Physics" chapter.) Parity nonconservation is represented by the original papers by T. D. Lee and C. N. Yang. Many of the papers on particle theory are concerned with symmetries and the breaking of symmetries and feature authors such as Murray Gell-Mann, Peter Higgs and Steven Weinberg. There is the proof of asymptotic freedom of many non-Abelian gauge theories by David Gross and Frank Wilczek. The volume concludes with a chapter on science and technology, followed by one on quantum mechanics.

One thing is striking when looking at the timing of papers reproduced in this book: They are concentrated in the 1950s and 1960s. That would be my view of physics, as an old man. But did papers in the 1970s and 1980s turn out to be much less important?

Once more, this is a monumental book. It will be most useful as a way to find important papers and, from the references in them, to be guided to others that have marked the development of physics.

The Quantum Theory of Fields, Vol. 1: Foundations

Steven Weinberg
Cambridge U. P., New York, 1995.
609 pp. \$49.95 hc
ISBN 0-521-55001-7

Paul Dirac, Werner Heisenberg and Wolfgang Pauli introduced quantum field theory in the late 1920s. They proposed it as a generalization of quantum theory that allows the description of systems with many (even infinitely many) degrees of freedom and of systems in which particles are created and destroyed. Quantum field theory originally focused on the

interactions of electrons with the electromagnetic field (quantum electrodynamics). It later found applications to the many-body problem in nuclear and condensed matter physics as well as to the two legs of the standard model of elementary particle physics: the theory of the strong interaction (quantum chromodynamics) and the partially unified electroweak theory. Its use in studying cosmology and the early universe has brought much of contemporary physics into the domain of quantum field theory.

Steven Weinberg, who contributed to the development of quantum chromodynamics and shared the Nobel Prize in physics for his contributions to the electroweak theory, has written a definitive book on the physical foundations of quantum field theory. His book differs significantly from the long line of previous books on quantum field theory going back to Gregor Wentzel's *Einführung in die Quantentheorie der Wellenfelder* (Franz Deuticke, 1943) and including *Quantum Field Theory* by Lowell S. Brown (Cambridge, 1992) and *Quantum Field Theory: A Modern Introduction* by Michio Kaku (Oxford, 1993). (Brown's and Kaku's books were reviewed in PHYSICS TODAY, February 1994, page 104.) The difference is that Weinberg does not start with quantum fields as a given object. He argues instead that quantum fields are the only construct that allows the union of quantum mechanics with the notions of special relativity (excluding string theory, which has an infinite number of particle species).

Two conditions are essential for this union. First, experiments that are widely separated in space at a given time must be independent of each other. This leads to the "cluster decomposition" requirement that, for scattering experiments that are widely separated in space, the S -matrix element for the total process must be the product of the S -matrices for the individual experiments. Even in nonrelativistic quantum physics, the simplest way to satisfy cluster decomposition is to use quantum fields to describe the scatterings. Secondly, the S -matrix must be Lorentz invariant. This requires the Hamiltonian density at x to commute with itself at y whenever the points are separated by a spacelike distance (at least in the simplest case). The combination of these two requirements can only be satisfied using quantum fields, and these fields themselves must either commute or anticommute at a spacelike separation. Weinberg dismisses the case of parafields (that do not obey this last requirement but do

lead to a Lorentz invariant S -matrix) as equivalent to a set of ordinary fields with an internal symmetry.

Weinberg's *Foundations* differs from several recent field-theory books, such as Brown's, mentioned above, and Pierre Ramond's *Field Theory: A Modern Primer* (Addison-Wesley, 1989) that take the Feynman path integral as the basic object in field theory. Instead, Weinberg introduces the canonical formalism first and considers the path integral as an efficient device to derive Feynman rules for a given theory, rather than as the fundamental object in quantum theory. His arguments for doing this are that, unlike the canonical formalism, the path integral does not allow a proof of unitarity and that the path integral based on the canonical formalism allows a straightforward treatment of nonlinear theories.

Foundations, the first volume of Weinberg's planned *The Quantum Theory of Fields*, treats other topics in the context of Abelian theories, particularly quantum electrodynamics. These other topics include radiative corrections, renormalization theory, infrared phenomena and bound states, among others. More recent advances in quantum field theory, in particular non-Abelian theories, will be treated in Volume II.

To summarize, *Foundations* builds the structure of quantum field theory on the sure footing of physical insight. It is beautifully produced and meticulously edited (I found only one misprint, and that only in the spelling of the name of an author of a cited article), and it is a real bargain in price. If you want to learn quantum field theory, or have already learned it and want to have a definitive reference at hand, purchase this book.

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About Time: Einstein's Unfinished Revolution

Paul Davies
Simon and Schuster, New York,
1995. 294 pp. \$24.00 pb
ISBN 0-671-79964-9

Elementary geometry has an intuitive quality. As Plato believed, it seems to express what we knew all along. This has never been true of the way physics represents time. The time line of Aristotle and Galileo leaves out essential elements of time as we experience it—in particular, the distinctions among past, present and future, and what we call the "passage" of time.

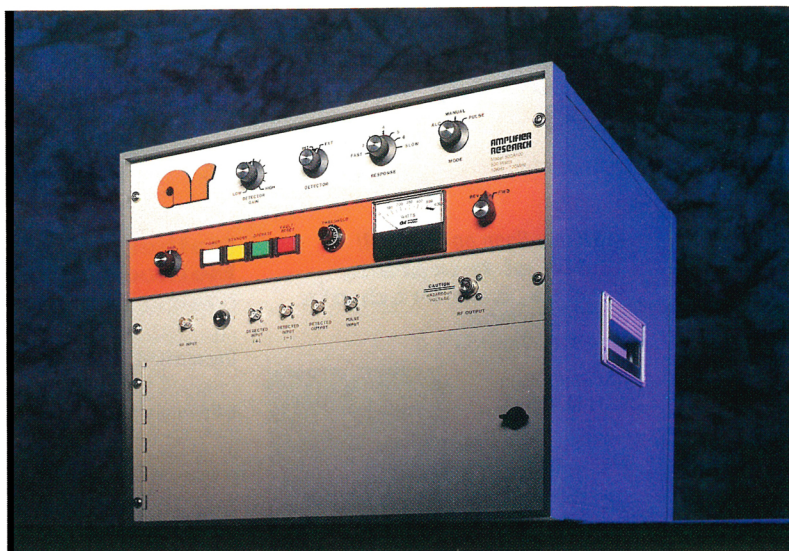
Still, if we extrapolate from these subjective elements we are left with something that makes intuitive sense: the uniform rotation of an idealized Earth.

Einsteinian time—Paul Davies calls it “flextime”—puts a much greater strain on intuition and common sense. A cosmonaut returning from intergalactic space flight finds that she is now the same age as her twin sister’s grandchild. Identical clocks at different heights run at different rates. For someone falling into a black hole, time itself will (very soon) have an end. For the universe, time had a beginning in the finite past; it makes no sense to ask what happened before that.

In *About Time*, Davies has set out to demystify these and other mysteries for the general reader. It is a formidable task, and no one, so far as I know, has accomplished it more successfully—or more entertainingly. Davies succeeds because he deeply understands and is genuinely excited about his subject, because he has mastered the difficult art of simplifying without oversimplifying, because he deploys a large stock of fresh and interesting examples and because he is a first-rate storyteller.

Flexitime, however, is only half of Davies’s story. In spite of brilliant successes, relativistic cosmology seems to be in trouble: Old stars (once again) seem to be older than the universe, time’s arrow still lacks a widely accepted explanation and delayed-choice experiments reveal ever more astonishing instances of quantum “telepathy” (Einstein’s term). Meanwhile back at the drawing board, quantum cosmologists seek to generate time from nontime. And what about time travel? Is it really as crazy as it sounds? Davies has carefully prepared the way for a discussion of all these issues, and his handling of them is notably clear and evenhanded. His opinions on controversial topics do occasionally show through, but he doesn’t press them.

Two more features of this splendid book deserve mention, even in so brief a review. The first (pages 184–185) is a response to the negative reaction of what Davies calls the “British chattering classes” to Stephen Hawking’s *A Brief History of Time* (Bantam, 1988), a reaction that Davies attributes to a combination of arrogance and ignorance. “Science, to the extent that it is considered at all by British opinion-formers,” he writes, “is regarded as at best a necessary evil required to propel money-spinning technology, and at worst a technocratic conspiracy.” The second feature worth mentioning is the author’s



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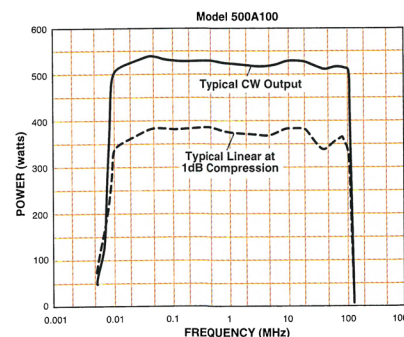
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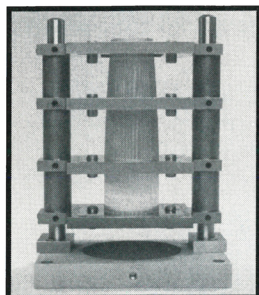
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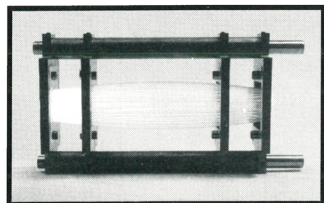
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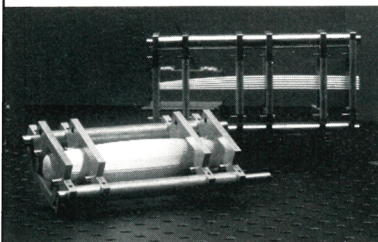
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characteristically clear and insightful, but all too brief, concluding discussion of the philosophy and psychology of time perception. The reader is left hoping that Davies will find or make the time to develop his ideas on these topics at greater length.

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Principles of Condensed Matter Physics

Paul M. Chaikin and Thomas C. Lubensky
Cambridge U. P., New York, 1995.
665 pp. \$49.95 hc ISBN
0-521-43224-3

What is the material world around us made of? The answer depends on whom and when you ask. A century ago the strongest answer would have come from the chemists. For them the world was made of atoms, those 98 elementary entities newly organized into the periodic table. Through the first half of this century the physicists were developing a competing view based on quantum mechanics. For them matter was made of Schrödinger waves coursing through space and confined by one another. The ascendancy of the quantum view was marked by the 1953 publication of Charles Kittel's famous *Introduction to Solid State Physics* (Wiley).

Kittel's textbook expanded the notion of what it meant to understand matter. But its scope was limited; it aspired to describe matter only insofar as matter could be viewed as a periodic lattice. Thus it necessarily left out phenomena as basic as the freezing, boiling and flowing of a drop of water. Curing this deficiency has been a major preoccupation for condensed matter physics ever since. This effort, like the quantum paradigm before it, has now reached a level of comprehensive understanding.

Paul Chaikin and Tom Lubensky's *Principles of Condensed Matter Physics* marks this development. Chaikin is a distinguished condensed matter experimenter; Lubensky is a distinguished theorist. Their 700-hundred-page work, in progress since 1986, is an important achievement. It brings into focus a new approach to the question, What is matter made of? For Chaikin and Lubensky, matter is *phases*—organizations of indefinitely large amounts of matter with a well-defined broken symmetry.

Phases are solids, liquids, liquid crystals or quasicrystals. Phases also define electronic organizations of matter such as the ferrimagnetic or the

superconducting states. By extension, fractal aggregates, surfactant membranes and flexible polymers are also viewed as phases. To understand matter in this approach is to explain the structure, thermodynamics and types of motion distinctive to a particular phase or to a transition between phases.

Among the book's pedagogical features are a wealth of daunting problems, a pithy glossary of intimidating terms and concrete descriptions of experiments and technological applications. At some points the charm of a gifted teacher shines through, as in this playful aside: "[Polymerized membranes] have a negative Poisson ratio . . . , i.e., when stretched in one direction, they expand rather than contract in the other. This effect can be seen with a crumpled piece of paper—try it." Still, for all but the most dedicated and sophisticated doctoral students, learning from this book will be tough going. There are long stretches of unmotivated manipulation and occasional confusing misstatements.

Like any unified discussion of a broad field, this one has its limitations. As announced in the preface, the book is not about the behavior of individual electrons or ions in matter. It leaves out important cooperative phenomena like the origin of metallic and insulating behavior and the consequences of quenched disorder. Thus the book complements traditional solid-state textbooks; it doesn't supersede them. It also leaves out conformal invariance, the powerful symmetry that fixes the values of many critical exponents in two dimensions. Likewise, collective phenomena far from equilibrium, such as turbulent flow or material fracture, go unmentioned. Given the real scope of the book, it might be better titled "Principles of Phase Behavior in Condensed Matter." In this important domain the book represents a great advance in unification. It will strengthen the understanding by students and researchers for a long time to come.

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Diagrammatica: The Path to Feynman Diagrams

M. Veltman
Cambridge U. P., New York, 1994.
284 pp. \$29.95 pb
ISBN 0-521-45692-4

On the whole, *Diagrammatica* is a masterful introduction to quantum