books

Making the best of the *gruppenpest*

Group Theory

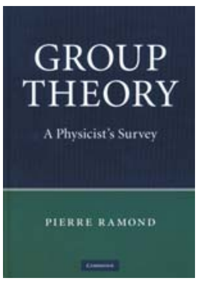
A Physicist's Survey

Pierre Ramond
Cambridge U. Press, New York, 2010. $70.00 (310 pp.). ISBN 978-0-521-89603-0

Reviewed by Robert Gilmore

In 1928 Paul Dirac gave a seminar at Princeton University. In the discussion that followed, Hermann Weyl protested Dirac's assertion that he would derive his results without using group theory. Dirac replied, "I said I would obtain the results without previous knowledge of group theory." His response was priceless, but not timeless.

The ensuing years saw diminishing returns on efforts by some physicists to slay the *gruppenpest* created by Weyl and Eugene Wigner. Those efforts were effectively laid to rest in the 1960s by numerous successful applications of group theory to particle physics. During that period, and especially following, there has been a deluge of books on group theory: by mathematicians for mathematicians, by mathematicians for physicists, and by physicists for physicists. Most books in the third category attempt to summarize the applications of group theory in one or a few corners of the field, for example, spectral and structural details in atomic and molecular physics, nuclear physics, condensed-matter physics, and particle physics. So it would be fair to assume that theoretical physicist Pierre Ramond's *Group Theory: A Physicist's Survey* would lay out the group-theoretical foundations of the standard model, to which he has made significant contributions. It does not, nor was that his intent.



Robert Gilmore is a professor of physics at Drexel University in Philadelphia. He is the author of several books, including *Lie Groups, Physics, and Geometry: An Introduction for Physicists, Engineers and Chemists* (Cambridge University Press, 2008) and, with Christophe Letellier, *The Symmetry of Chaos* (Oxford University Press, 2007). He contributed to the paper that first described how to construct atomic coherent states and has developed the most general framework for the construction of coherent states for Lie groups.

The book's construction is straightforward. It first introduces a mathematical description of some physical problem—for example, the isotropic harmonic oscillator, the Bohr atom, the Elliott model, the Eightfold Way, or the standard model. Next it provides a brief indication of how group theory has been useful in understanding the underlying physics and points out computations that could be carried out without overburdening the reader. The latter discussion is used as a jumping-off point to introduce material that should, or could, be useful in models yet to come.

Not surprisingly, the most extensive presentation devoted to a single area of physics is Ramond's chapter on the standard model. But it is not a chapter to turn to for instruction in carrying out anything but the most elementary computations. Rather, it gives prescriptions for constructing models that go beyond the standard model but remain within the constraints of various prescribed symmetries and their breakings. Those prescriptions inch inexorably toward ever more exceptional or exotic groups: E_6, E_7, E_8, $E_8 \times E_8$, and finite subgroups of $SO(3)$ and $SU(2)$. In fact, the closing chapter is given over entirely to the presentation of exceptional structures, which are poorly known to physicists. As a result of that emphasis, Ramond's book is not directly comparable to any "Group Theory and (fill in the details) Physics" text.

Group Theory: A Physicist's Survey contains a few small disappointments. Irreducible representations of the simple Lie groups are labeled in various ways, but never through Young partitions. That omission makes it difficult to compare results developed in the book with those available in most research papers. The other disappointment is in the correspondence between infinitesimal generators of some Lie groups with creation and annihilation operators. Ramond describes the Hilbert spaces generated by k independent fermion operators; those spaces are of use in constructing antisymmetric representations of many groups. But there is no mention of the extension to many-boson modes, which is relevant to the symmetric representations. In particular, missing is the restriction to two-boson modes and bilinear products that involve one creation and one annihilation operator; that scheme was introduced in a beautiful way by Julian Schwinger to provide a simple and direct description of the properties of both the angular momentum algebra and the $SU(2)$ representations.

Despite those minor disappointments, and an index far too small, *Group Theory: A Physicist's Survey* successfully introduces physics model builders to the most likely tools of choice for future constructions. Ramond's underlying belief is that any future fundamental theory will be beautiful and exceptionally elegant. The trouble is that we don't yet know what kind of mathematics it will involve. Lie groups? Supergroups? Kac–Moody algebras? Finite groups over fields unfamiliar to physicists? Each case has regularities and exceptions, and there are some regularities among the exceptions. Many particle theorists, including Ramond, share the prejudice that when the dust settles and we have a "final theory," it will be understood through the facet of some exceptional structure. After all, isn't the universe in which we live itself exceptional?

Dark Energy

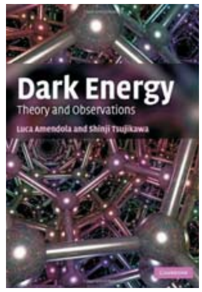
Theory and Observations

Luca Amendola and Shinji Tsujikawa
Cambridge U. Press, New York, 2010. $75.00 (491 pp.). ISBN 978-0-521-51600-6

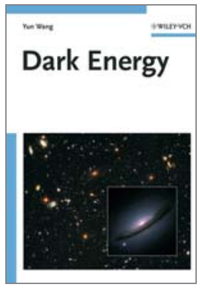
Dark Energy

Yun Wang
Wiley-VCH, Weinheim, Germany, 2010. $79.00 (244 pp.). ISBN 978-3-527-40941-9

Two teams of astronomers studying distant type Ia supernovae presented evidence in 1998 that the expansion of the universe is speeding up. From the time of Edwin Hubble, cosmologists had been trying to measure the slowing of the expansion due to gravity, so the discovery of cosmic acceleration instantly became one of the field's most important developments. Subsequent observations, including more detailed studies of supernovae, along with independent evidence from clusters of galaxies, large-scale structure, and the cosmic microwave background, have now firmly established this remarkable finding.



Unraveling the physical origin of cosmic acceleration will be an important goal for fundamental physics in the coming years. Is the acceleration caused by dark energy, a new form of stuff that dominates the mass–energy of the universe, or does it indicate that on cosmic scales, Einstein's theory of general relativity must be replaced by a new theory of gravity? If the answer is dark energy, is it the energy of the vacuum—or, equivalently, Einstein's cosmological constant—or something else, perhaps an ultralight scalar field sometimes called quintessence? Weirder still, could the observations be telling us that despite the near-isotropy of the cosmic microwave background, the universe is inhomogeneous on large scales and our Milky Way galaxy is located near the center of a very large void?



Although dark energy has been the subject of several excellent review articles in recent years, until now this young and rapidly maturing field has lacked a focused textbook. Two recent graduate-level texts by experienced practitioners go a substantial way toward filling that hole: One of those books is *Dark Energy: Theory and Observations* by Luca Amendola of the University of Heidelberg and the National Institute for Astrophysics in Rome and Shinji Tsujikawa of Tokyo University. The other is *Dark Energy* by Yun Wang of the University of Oklahoma.

Dark Energy: Theory and Observations is the more comprehensive of the two. It begins with chapters about the basics of physical cosmology, measures of large-scale structure, the evolution of cosmological perturbations, and the current observational evidence for cosmic acceleration. The bulk of the book focuses on theoretical models for acceleration, including the cosmological constant, quintessence and its variations, modified-gravity models, and void models. The final segment of the book covers the impact of dark energy on the evolution of cosmological perturbations, discusses statistical analysis methods for cosmological surveys, and gives an overview of techniques that will be used by upcoming surveys to probe dark energy.

One strength of Amendola and Tsujikawa's book is the level of detail it provides on dark-energy models. The authors do a good job of describing the theoretical challenges to incorporating dark energy into the framework of elementary-particle physics. The discussion, though, is not always self-contained; for example, the authors assume a familiarity with supersymmetry and supergravity models. However, the book would have grown too unwieldy had the authors tried to present that supplementary material at the requisite level.

My main quibbles with *Dark Energy: Theory and Observations* are that the authors missed the opportunity to cover increasingly standard analysis techniques such as Markov Chain Monte Carlo and omitted discussing sources of systematic errors in the major techniques for probing dark energy. And a brief survey of the landscape of current and upcoming experimental projects in the field would have been helpful to provide context for students considering observational dark-energy research.

Many of those shortcomings are addressed in Wang's *Dark Energy*. Although Wang also covers the basic cosmology background and includes a short chapter on models to explain cosmic acceleration, her book focuses much more on the major observational methods for probing dark energy—supernovae, large-scale structure, weak lensing, and clusters. As an example, Wang goes into substantially more detail on the nuances and systematics of estimating supernova distances. Her book will therefore be of more practical interest to those contemplating or involved in analysis of cosmological data. It also includes a chapter on instrumentation for dark-energy experiments and a brief discussion of ongoing and future projects. My main concerns with Wang's book are that it is rather compact for a standalone text and that the choices of subtopics and references to the literature are occasionally idiosyncratic.

Our best tools for understanding the fundamental physics driving cosmic acceleration are measurements of the history of the expansion rate and of the growth of large-scale structure. If general relativity plus dark energy is the correct paradigm, there is a definite correlation between the expansion rate and the growth of structure. Moreover, if dark energy is vacuum energy, then the expansion rate and structure will each have a specific dependence on cosmic time that can be tested. Currently, the data are consistent with a universe comprising about 71% vacuum energy, 25% dark matter, and 4% ordinary matter, but we need more precise measurements to draw definitive conclusions about the nature of dark energy and the consistency of the paradigm of general relativity plus dark energy.

Ongoing, planned, and proposed experiments will employ several complementary techniques to make greatly improved measurements of expansion and structure growth and thereby help uncover the cause of cosmic acceleration. For those needing a useful introduction to this exciting area of research, these two textbooks, taken together, provide just that.

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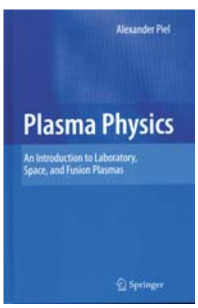
Plasma Physics

An Introduction to Laboratory, Space, and Fusion Plasmas

Alexander Piel
Springer, New York, 2010. $79.95 (398 pp.). ISBN 978-3-642-10490-9

"Plasma physics is at the cusp of a new era." So began the National Research Council's most recent decadal survey, *Plasma Science: Advancing Knowledge in the National Interest* (National Academies Press, 2007). On the energy front, the laser-based National Ignition Facility came online two years ago and the magnetic-confinement ITER project in France is on track for first plasma in 2019 (see the news stories in PHYSICS TODAY, March 2011, page 26, and April 2010, page 20). In the space-physics arena, several solar satellites, including *Hinode*, *STEREO*, and the *Solar Dynamics Observatory*, have been launched in anticipation of the upcoming solar maximum; they are expected to yield spectacular images and data. In the lab and in the electronics manufacturing industry, low-temperature plasmas are used to fabricate complex electronics and large-scale displays such as plasma TVs.



Progress has also been made in the availability of undergraduate physics texts. Until 15 years ago, there was only one: Francis Chen's *Introduction to Plasma Physics and Controlled Fusion* (2nd edition, Springer, 1984). Then two excellent texts emerged and have become the standards for senior elective and first-year graduate school courses in plasma physics: Robert Goldston and Paul Rutherford's *Introduction to Plasma Physics* (Taylor & Francis, 1995) and Paul Bellan's *Fundamentals of Plasma Physics* (Cambridge University Press, 2008). Other more specialized texts focus on the theory and application of plasma in such areas as astrophysics, diagnostics, or fusion devices.

A welcome addition to this growing suite of excellent texts is Alexander Piel's *Plasma Physics: An Introduction to Laboratory, Space, and Fusion Plasmas*. As the title suggests, *Plasma Physics* offers a broad and modern introduction to the many aspects of plasma science, but it also gives a rigorous treatment of important topics. It complements the books by Chen and Bellan, being much more up-to-date than the former and less rigorous than the latter. The text will be accessible to undergraduates with only a background in electrodynamics.

Plasma Physics does a fine job with the standard subjects, including single-particle motion, dispersion relations for the various waves that exist in cold, magnetized plasma, and plasma instabilities. The text includes several useful parenthetical "Application" sections on Hall thrusters, the Parker spiral, ion beams, anisotropic etching of silicon, and other topics. Also interesting are some historical asides such as on the terminology "gas discharge," which arose from early Leyden jar experiments that sounded like a gunshot.

Particularly useful is the author's emphasis on and presentation of low-temperature plasma experiments and diagnostics. Piel provides an exceptional discussion of the implementation of Langmuir probes—a technique that practicing plasma scientists have used for decades—and an analysis of Langmuir probe data. A curious student or interested researcher could track down laboratory notes, older monographs, and obscure papers describing Langmuir probe operation, but it is satisfying to have a complete description in an introductory plasma text. The final two