in massive stars, which are the likely source of important elements such as oxygen, silicon and calcium. In addition, Arnett covers cosmological nucleosynthesis, thermonuclear and core-collapse supernovae and galactic chemical evolution. His approach is to convey the wisdom and physical insight he has gained from many years as a researcher without burying the reader under the weight of computer results. This is a computer-intensive field, and Arnett does present many results of nucleosynthesis network calculations, but the emphasis is on simplified models and analytical results. The presentation is a personal view of the field, and other researchers may well feel that their particular specialties are not adequately represented.

Although the book contains many illuminating discussions of classic results, there are some controversial views. For example, Arnett is an advocate of helium detonation on white dwarfs as the source of Type Ia supernovae. Although this model yields light curves with desirable properties, there may be a conflict with the supernova spectra. The book does not cover the large topic of supernova spectroscopy.

Arnett presents analytical arguments and computer results that have not been published elsewhere. Many of the computer results are presented in figures. The figures are useful, but the captions are rather cryptic, so the book is not suitable for readers who try to extract essential results by going through figures only. It will be a valuable resource, however, to any student or scientist who is planning research related to nucleosynthesis. It does not present derivations from first principles and is thus not suitable for use as a textbook on its own. However, it might be used to supplement Donald Clayton's *Principles of Stellar Evolution and Nucleosynthesis* (McGraw-Hill, 1968) in a graduate-level course on stellar interiors and evolution. Clayton's classic text is now out of date, and Arnett's book fills in much of the recent development of massive-star evolution and nucleosynthesis.

The final chapter of Arnett's *Supernovae and Nucleosynthesis* contains a demonstration that massive-star nucleosynthesis, combined with a plausible stellar mass function, can account for most of the observed abundances of nuclei in the atmospheres of old stars; the rapid evolution of massive stars makes them the dominant contributors to heavy elements produced early in galactic evolution. Despite the success of this demonstration, there remain major uncertainties in nuclear reaction rates and in the effects of mass loss, close-binary evolution, rotation and convective motions. There are still many problems for the next generation of researchers in this field, and Arnett's book provides a starting point for pushing back the frontiers.

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Gravity's Fatal Attraction: Black Holes in the Universe

Mitchell Begelman and Martin Rees
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There are several very fine popular accounts of the mind-boggling properties of black holes. But *Gravity's Fatal Attraction: Black Holes in the Universe*, by Mitchell Begelman and Martin Rees, may provide the best answer—for general as well as more sophisticated audiences as well—to the question, Do black holes actually exist? Step by step, fact by fact, this well-written and beautifully illustrated book makes a compelling case that these bizarre objects not only exist but have already been detected.

The authors are distinguished theorists who have worked at the forefront of black-hole astrophysics for many years. Rees is a renowned scientist and one of the founding fathers of the field; Begelman, a former student of Rees's, is one of the field's leading researchers. They have pooled their insights and their vast personal knowledge of the subject to tell a fascinating story of the black hole and the fundamental role that it plays in the cosmos.

The story begins with a brief historical account of the black-hole idea, but it quickly moves on to its main theme, the search for black holes in space. The authors show an unusual ability to sift through and assemble the hard observational evidence in support of the existence of black holes. These observational data are the product of many recent technological advances in optical, radio, x-ray and gamma-ray astronomy.

As the authors work their way through various properties of black holes and black-hole habitats, they show how astronomical observations at different wavelengths uncover black holes lurking in all sorts of places. The discovery of stellar-mass black holes in binary x-ray sources in our own Galaxy has been told before, but it is nevertheless compelling and worth retelling. What really sets this book apart, however, is its comprehensive discussion of massive black holes in the nuclei of active galaxies and quasars, the subject dearest to the hearts of Begelman and Rees. It is in these active galactic nuclei and quasars that black holes serve as the engines that power the most energetic sources of radiation in the universe. Cosmic jets, strong radio emission and superluminal expansion are all neatly tied theoretically to the accretion of magnetized plasma onto rapidly rotating, supermassive black holes. The book also offers one of the clearest and most compelling summaries of the "unified model" for radio galaxies in terms of relativistic jets. The authors delight in telling us how nature has thoughtfully furnished a minature stellar-mass model of a jet—called SS 433—in our own Galactic backyard.

By far the cleanest evidence for a supermassive black hole is NGC 4258, a spiral galaxy that harbors a disk of gas in Keplerian orbit about its center. The disk is viewed edge-on from Earth and is characterized by sharply defined maser molecular lines originating from various spots. By means of radio interferometry, a central black hole of 36 million solar masses is convincingly inferred.

Gravity's Fatal Attraction is about more than just black holes. It is also about neutron stars and white dwarfs (the other endpoints of stellar evolution), supernovae, jets, galaxies, quasars, dark matter, gravitational radiation and the big bang. It is observationally driven throughout, revealing the limitations of theory. Such unsolved mysteries as the origin of gamma-ray bursts are admitted candidly; more speculative topics, like pregalactic mini-black holes, are prudently left toward the end.

The book is similar in style to a typical article in *Scientific American*. Numbers abound, but actual equations are few. The color illustrations and photographs are magnificent and well integrated into the text; some sketch basic concepts, others are astronomical photographs and still others plot hard data or the results of computer simulations.

For whom is this book intended? Lay readers of popular science will certainly find it well worth the effort. Even specialists with technical expertise in the field will appreciate the book for its breadth and completeness. The book may be especially appealing to instructors of introductory physics and astronomy courses for nonscientists. One can well imagine an introductory curriculum based on black holes rather than the traditional survey of astronomy. For this purpose another book, Kip Thorne's *Black Holes and Time*

Warps: Einstein's Outrageous Legacy (Norton, 1994), with its rich historical insight and entertaining anecdotes by another renowned expert in the field, could provide a useful supplement.

An ambitious instructor might wish to use these books to design an upper-level physics or astronomy course in which the text is supplemented everywhere by simple, back-of-the-envelope mathematical derivations of the key ideas. Designing such a course might pose a challenge, but it is my hunch that it would be very well received.

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Broken Symmetry: Selected Papers of Y. Nambu

Edited by T. Eguchi and K. Nishijima
World Scientific, River Edge, N.J., 1995. 467 pp. $86.00 hc ISBN 981-02-2356-0; $35.00 pb ISBN 981-02-2420-6

From the revolutions of relativity and quantum mechanics in the first quarter of our century, physicists attained both a more refined description of nature and an appreciation that events can be influenced by unexpected, novel and sometimes paradoxical processes having no analogue in the earlier, classical physics. Examples include the mixing of time and space, mass–energy transmutation, tunneling and modification of dynamics in force-free regions.

In the years that followed the invention of relativity and quantum theory, these two disciplines were combined into relativistic quantum field theory, which has been successful at energy and distance scales far removed from the original solar and atomic applications. Although much technical development accompanied this expansion, very few new physical principles emerged, beyond those already present in the initial formulations of relativity and quantum mechanics. One notable instance of new physics that accompanied the development of quantum field theory concerns the absence of observed symmetry in natural phenomena, even though the equations that govern our theories possess a high degree of symmetry. Yoichiro Nambu is a principal contributor to this subject, and in his recently published selected papers, aptly titled *Broken Symmetry*, one can follow very nicely the fascinating, if winding, flow of these ideas.

Physicists widely agree that the ultimate laws of nature enjoy a high degree of symmetry, that the formulation of these laws is unchanged when various transformations are performed. However, it must also be recognized that actual physical phenomena rarely exhibit overwhelming regularity. Therefore, at the very same time that we construct a physical theory with intrinsic symmetry, we must find a way to break the symmetry in the physical consequences of the model. Progress in physics can frequently be seen as the resolution of this tension.

In classical physics, the principal mechanism for symmetry breaking, already realized within Newtonian mechanics, is through boundary and initial conditions on dynamical equations of motion. But for quantum theory, which does not need initial conditions to make physical predictions, other mechanisms of symmetry breaking must be found.

The mechanism of spontaneous symmetry breaking presents itself as one resolution to our problem: Equations of motion are symmetric, but if the ground (lowest energy) state is degenerate, with copies related by a symmetry transformation, a solution necessarily selects one ground state, thereby breaking the symmetry. (A double-well potential, with left–right symmetry, illustrates the mechanism: In the ground state, a particle must be at the bottom of one of the two wells, and left–right symmetry is broken.) Spontaneous symmetry breaking evidently occurs in classical mechanics (as the previous example illustrates); it does not occur in quantum mechanics, with its finite number of degrees of freedom, because tunneling lifts the ground-state degeneracy. However, in the infinite volume limit—the thermodynamic limit with the infinite number of degrees of freedom that is appropriate for relativistic quantum field theory—tunneling disappears and spontaneous symmetry breaking can occur.

It was Werner Heisenberg who realized that, for a many-body system like a ferromagnet, the large number of degrees of freedom suppresses tunneling, and spontaneous symmetry breaking ideas are applicable. Moreover, he proposed in 1959 to use them in particle physics but did not construct a phenomenologically viable model. Heisenberg's work inspired Nambu, who had earlier understood the Bardeen–Cooper–Schrieffer theory of superconductivity in these terms (1960 paper **28**), to suggest a "superconductor" model of elementary particles (1960 paper **33**) and to elaborate the idea with collaborators (1961–62 papers **34–38**). This resulted in the accepted theory for pions: With the approximation that their small mass is neglected, they are viewed as the massless particles that accompany spontaneous symmetry breaking. Ironically, even though Nambu's analysis of BCS theory was complete, when it came to particle physics he did not appreciate the generality of a gapless mode—massless particle—accompanying infinite vacuum degeneracy; when Jeffrey Goldstone produced a simple example suggesting this generality, Nambu, according to the collection's introduction, "felt as if a prize catch had been stolen from under [his] nose." (Nevertheless, Nambu did receive several other distinguished prizes, which are listed in a useful *curriculum vitae* included in the book.)

By researching the Heisenberg-type model rather than one containing a gauge field, as in the BCS theory, Nambu could "not know whether a finite observed [gauge-field] mass can be compatible with [gauge] invariance" (1960 paper **33**). (That it can be was argued for particle physics by Julian Schwinger and Philip Anderson in 1962 and 1963, but the physics community did not respond until these results reappeared—when many people introduced gauge fields into Goldstone's example, thereby making possible the present-day standard model for elementary particles.)

Nambu has contributed significantly to physics in other areas as well, and this is reflected by the other papers in the collection. There is his three-triplet model of hadrons, which gave us an early suggestion for the "color" degree of freedom (1965 paper **54**). The semiclassical expansion for quantum field theory is derived (1968 paper **71**). String theory—touted by some as the new paradigm for particle physics—owes its action formulation to Nambu (1970 paper **78**). The remainder of the book comprises interesting papers that deal with subjects that did not blossom (infinite component wave equations), or were superseded (dispersion relations), or have not yet found a wide audience (generalized Hamiltonian–Nambu dynamics, field theories defined on finite sets of integers, nonparticle physics applications of supersymmetry).

While I regret that the publishers did not reset the papers in a uniform typeface, the modest price ($35 for the paperback) makes up for the sometimes illegible reproduction. The book benefits from the inclusion of previously unpublished material, informal lectures and conference-summary talks that are not widely available. These, together with the selected research papers, provide an excellent scientific biography of Nambu and of the Japanese physics tradition, which he describes