sometimes useful to start an argument without knowing the end of it." The book should be useful to students entering the field. Much work remains to be done, and there will undoubtedly be more books on this subject.

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Newton Tercentenary

Three Hundred Years of Gravitation. S. W. Hawking and W. Israel, Eds. Cambridge University Press, New York, 1987. xiv, 684 pp., illus. $69.50.

This volume is a collection of 16 solicited contributions published in association with a Newton Tercentenary Conference held last summer at Trinity College, Cambridge, and summarizing the state of gravitation 300 years after the publication of Isaac Newton's *Principia*. The initial essays by Stephen W. Hawking and Steven Weinberg discuss Newton's greatest achievements. These include his development of the laws of mechanics, the universal inverse square law of gravitation, and the calculus. Weinberg feels that at the heart of the greatness of the Newtonian achievement is the fact that "mankind for the first time saw the glimpse of a possibility of a comprehensive quantitative understanding of all of nature." Hawking points out that the Newtonian universal law of gravitation is inconsistent with the idea held in Newton's time that the universe is filled with a static and nearly uniform distribution of stars extending infinitely in all directions. As Hawking shows, Newton used a fallacious argument to justify a static universe. When Einstein first published his theory of general relativity (which includes Newtonian gravitation as an important limit), his equations did not permit a static universe. In order to allow a static universe, Einstein in 1917 modified them by introducing the cosmological constant. He later called this modification his worst blunder. It is remarkable that two such great minds as Newton and Einstein missed an opportunity to predict a nonstatic universe.

Roger Penrose's essay is interesting because of his unconventional view of why Newton doggedly maintained his belief in his corpuscular theory of light and because of Penrose's conviction that the gravitational field is instrumental in the reduction of the wave packet—a profound idea. In any volume purporting to survey research in gravitation, a review of experiments is essential. A. H. Cook and Clifford M. Will admirably survey the status of current experimental and observational tests of theories of gravitation. Cook concentrates mainly on laboratory experiments, whereas Will's discussion also ranges over the motion of the planets, the moon, light, and stars in binary systems. One of the most important systems for testing general relativity is the binary pulsar PSR 1913 + 16, which consists of a pulsar in close orbit about an unseen companion. General relativity is essential for determining the orbital parameters of this system. As Will points out, the rate of loss of orbital energy can be attributed to gravitational radiation and is consistent with the quadrupole formula of general relativity and inconsistent with dipole formulas predicted by a class of alternative metric theories of gravitation. The discovery of the binary pulsar has encouraged much recent theoretical work on the general relativistic two-body problem. Thibault Damour reviews the current status of this problem.

Werner Israel gives a carefully researched and readable historical sketch of the development of the idea of black holes. He starts with the work of John Michell, who speculated in 1783 on the possibility that there might exist bodies so dense that "their light could not arrive at us," continues through the history of white dwarfs and neutron stars, the final states of gravitational collapse, and the thermodynamics of black holes, and ends with the discovery in 1974 by Hawking that black holes produce black-body radiation through gravitational effects. This historical sketch is particularly good because of the author's insight as an important contributor to the field. He states that as the narrative "moves nearer to the present, the perspective inevitably becomes more subjective. Others, located at diverse research centres around the globe, will have experienced the events recounted here in their own very different ways." This reviewer is one case in point. The quantum field theoretical method of treating particle production in gravitational fields, which was applied in deriving the black-hole radiation, was originally developed by me in the 1960s to investigate particle production by the expanding universe. The method was further applied in 1971–72 by Stephen Fulling in his Ph.D. dissertation to a situation involving event horizons. My work and the work of Fulling played an important role in the development of the ideas that led to Hawking's definitive calculation of the spectrum of particles created by a black hole, although it is not included in this historical sketch. Furthermore, the assertion that skepticism about Hawking's 1974 paper was "prolonged and virtually unanimous" is not entirely correct. (I, for one, immediately recognized the result as correct.)

Astrophysical black holes occurring as the end state of stellar gravitational collapse are sufficiently massive that their temperature is negligible. However, they act as sources of energy through the heating of infalling matter, which radiates as it spirals gradually inward. R. D. Blandford gives an up-to-date survey of astrophysical black holes, including a good discussion of observational evidence for their existence, which appears strong in at least three cases. In the next one or two decades gravitational wave astronomy will open up a key new window on the universe. One of the most important contributions in this volume is a complete review of gravitational radiation research by Kip S. Thorne. This includes a particularly good discussion of astrophysical sources of gravitational waves and methods for detecting them. The Newtonian dynamics of bound groups of galaxies seems to imply that much of the matter in the universe is in a nonluminous, unobserved form. An interesting discussion of dark matter and the large-scale structure of the universe is given by Martin J. Rees. Alexander Vilenkin gives a clear exposition of the basic physics involved in deriving the gravitational properties of cosmic strings, one of the candidates for explaining the large-scale structure of the universe.

The cosmological constant introduced by Einstein has regained significance in recent work. Certain elementary particle theories imply that at very early times there may have been a large cosmological constant caused by vacuum energy, which would have produced a very rapid early expansion of the universe. These "inflationary" models are of considerable interest because they offer a possible explanation of several observed facts, such as the homogeneity of the cosmic background radiation and the near spatial flatness of the universe. Steven K. Blau and Alan H. Guth offer a well-written, comprehensive review of inflationary models. This is followed by Andrei Linde's discussion of chaotic inflation, in which inflation is produced by an initial nonequilibrium distribution of a scalar field. Some of the deepest issues in cosmology are addressed in the essay by Hawking on quantum cosmology. These include the choice of the initial quantum state of the universe and the question why the observed universe shows an asymmetry between the future and the past. The leading candidate for a unified theory that includes gravitation is superstring theory, in which the elementary constituents are strings rather than point particles. John H. Schwarz, one of the key developers of the theory, gives an overview. Finally, Cedomir Crnković and Edward Witten in a clearly written essay show how to express the foundations of the canonical formalism of Yang-Mills theory and general relativity in a manifestly covariant way.

This volume is unusual because of the clarity with which many of the essays are written. The less technical contributions may be read with enjoyment by nonspecialists and students interested in learning about the state of gravitation 300 years after the *Principia*. They will see that gravitation is a healthy and vital area of research, which may yet hold the answers to many of the unsolved fundamental problems of physics. Many of the more technical contributions will be of value to advanced students and researchers in the field. I heartily recommend this volume.

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A Natural Resource

Georges Bank. RICHARD H. BACKUS, Ed. MIT Press, Cambridge, MA, 1987. x, 593 pp., illus., + chart in pocket. $225.

Georges Bank is situated to the east of Cape Cod and Nantucket, between the Gulf of Maine and the edge of the continental shelf. The bank, as defined by its 60-meter depth contour, measures approximately 200 by 100 kilometers with a minimum water depth of less than 3 meters on modern charts. European explorers marked Georges Bank on maps as early as the 1520s. However, the region first became famous as a fishing ground, initially for cod in the 18th century and then for mackerel, halibut, and haddock as new fishing techniques and markets were developed in New England in the 19th century.

The fishing continued into the present century, surviving various crises as stocks of particular species were reduced. As a result, marine biologists began to consider why fish production should be so high on Georges Bank. Through the pioneering works of Henry Bigelow (1879–1967), who was the first director of the Woods Hole Oceanographic Institution, Gordon Riley (1911–1985), to whom this book is dedicated, George Clarke, and others, new ideas about the marine food chain were developed, including early models of the effects of light, nutrients, and grazing on phytoplankton growth. However, it was the severe depletion of fish stocks by East Bloc trawlers in the 1960s and 1970s and events leading up to the exploratory drilling of the first deep holes for hydrocarbons in 1981–82 that really drew political and public attention to Georges Bank.

With the announcement of leasing plans for drilling sites in 1974, the establishment of a 200-mile Exclusive Economic Zone, and the dispute over the international boundary between the United States and Canada (settled in 1984), there grew an urgent need for information on all aspects of Georges Bank that could only be met through new research. One result is this admirable book, edited by Richard Backus of the Woods Hole Oceanographic Institution, covering the physical science, biology, fisheries, and uses of Georges Bank. Although intended for a general audience, the 57 chapters have been written and carefully reviewed by well-known scientists; together they form an outstanding reference book on exploration, exploitation, and scientific knowledge up to 1984.

"Henry Bigelow aboard the U.S. Fish Commission schooner *Grampus* during the pioneering cruises of 1912–1916." [From *Georges Bank*; Museum of Comparative Zoology, Harvard University]

The account of subsurface geology (chapter 5) traces the various phases of sedimentation in the Georges Bank basin since the Triassic period at the early stages of the formation of the Atlantic Ocean. The Jurassic sequence, consisting of up to 5 kilometers of calcareous rocks, sandstones, and mudstones, became overlain by thinner Cretaceous and Tertiary deposits as the rate of basin subsidence declined. Despite ample evidence for potential hydrocarbon traps (chapter 50), the two deep exploratory drill holes were dry and showed only low levels of organic material. But on the basis of past exploration on the Mid-Atlantic and Scotian shelves, it is estimated that a further 10 to 15 years' work would be needed to establish whether commercial quantities of hydrocarbons (with gas most likely) exist in the sedimentary basin. A discussion of the politics of oil drilling (chapter 55) considers the problems of communication among federal and state agencies, industry, and scientists and concludes that it is unlikely that "fish and oil" can coexist on Georges Bank.

The possible effects of petroleum on benthic and pelagic ecosystems are discussed with particular reference to larval recruitment in summer months (chapter 53). The speculative approach may not meet with everyone's approval, but low-level contamination by fossil fuels, as well as by PCBs, has already occurred on Georges Bank (chapter 19). Good observational data on fluxes of such materials from land, via rivers and the atmosphere, and on their fate within shelf waters are still lacking despite adequate technology for appropriate chemical measurements.

The reasons for the abundance of fish on Georges Bank is one theme in a fascinating account of scientific exploration (chapter 1). That problem remains essentially unsolved. However, physicists have recently provided a much more rigorous picture of the hydrodynamic environment, thus opening the way to new interdisciplinary studies. Observations and models have defined four main physical regions (chapter 11) and shown the importance of tidal and shelf-edge fronts in determining seasonal circulation patterns. Various factors contribute to reducing the exchange of water between the bank and surrounding areas, but residence times for bank waters are extremely difficult to define, let alone estimate, for open boundary conditions (chapter 14).

The account of phytoplankton production (chapter 21) compares mixed and stratified waters and considers the various mechanisms by which nutrients are supplied to the phytoplankton. An explicit treatment of respiration yields an annual upper limit of 272 grams of carbon per square meter for net primary production. An important criticism, however, is that there is a lack of consistency in the interpretation of these data in relation to those in chapter 22 for nitrogen budgets (for example, table 22.2 implies twice as