(*Continued from page 1209*)
of the research itself with its limitations and implications while placing it in the particularly rich broader context surrounding the subject of symbiosis and its potential role in evolution. Symbiosis aficionados who may have wondered how their field found its place in the pecking order of biology will experience a satisfying sense of revelation as the undercurrents are exposed. The association of symbiosis with natural theology in the 19th century, with socialism as opposed to social Darwinism in the early 20th century, and with Lamarckism in the battle for the neo-Darwinian synthesis tended to keep it at the periphery. This was exacerbated by the rise of the 20th-century disciplines of biology, which dismembered symbiosis research and prevented its cohesion.

I noted one key omission in Sapp's account. The discovery of hydrothermal vent communities (in which geochemical energy is harnessed by endosymbiotic bacteria to support the dominant macrofauna) in the 1970s provided a major boost to symbiosis research and theory. As Sapp points out, the emphasis in the study of microorganisms on their role as agents of disease relegated symbiosis to the status of an interesting curiosity, not a fundamental biological theme. The discovery of communities in which bacterial endosymbionts play a central role jolted many biologists into re-evaluating symbiosis from many perspectives and helped to bolster the field's emerging legitimacy.

The book is well written and convincing, weaving many threads into a coherent whole. However, some readers may be a bit disappointed that the vivid personalities involved do not emerge in this account. For example, the intellectual contributions of Lynn Margulis are well described and placed in their proper context, but there is no question that the unique confluence of her personality and background with her ideas influenced the course of development and fate of the serial endosymbiotic hypothesis (the notion that eukaryotic cells are the result of multiple endosymbioses). A woman scientist in an era when serious barriers existed for women in conventional scientific careers, she was initially an outsider and in some sense had less to lose by advocating an unorthodox point of view. Her flamboyant personality and maverick style sometimes alienated more conservative scientists and were a barrier to acceptance of her ideas (some of which remain highly controversial). Nonetheless, her energy and intensity may have been critical to keeping the issue alive until the technology developed and evidence emerged to turn the tide.

Sapp's book is a fine piece of scholarship, whole and satisfying in itself. Nevertheless, we await yet another book, one that reveals the human side of the story.

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The Dressed-Atom Approach

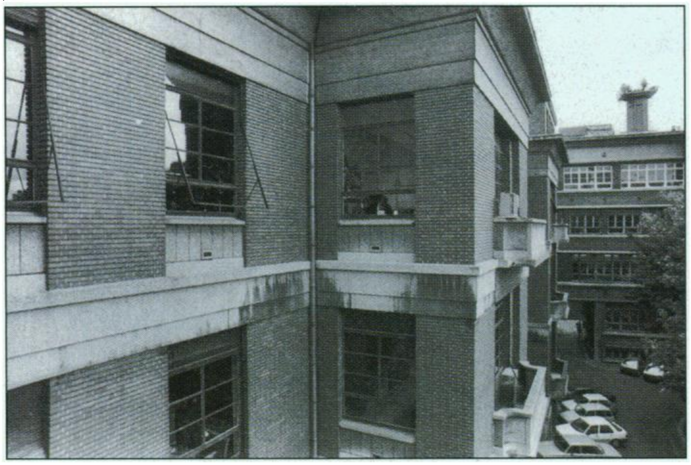
Atoms in Electromagnetic Fields. C. COHEN-TANNOUDJI. World Scientific, River Edge, NJ, 1994. xiv, 670 pp., illus. $108 or £85; paper, $53 or £42. World Scientific Series on Atomic, Molecular and Optical Physics, vol. 1.

Two years after Charles Townes had shared a Nobel physics prize with N. G. Basov and A. M. Prokhorov for the invention of the maser and the laser, the 1966 prize was awarded to Alfred Kastler alone for his origination—at the École Normale Supérieure, (ENS) in Paris, around 1950—of the technique of optical pumping (important to the operation of many masers and lasers). A graduate of the ENS in the 1920s, when French physics provided few opportunities for a research career, Kastler gradually worked his way up through positions at secondary schools and provincial universities, finally returning to Paris in 1941 as head the physical laboratory of the ENS. At war's end, determined to move his laboratory out of classical optical spectroscopy and into the exciting areas opened by the development of radio and microwave techniques during the war, Kastler sent his emissary, Jean Brossel, as postdoc to Francis Bitter at the Massachusetts Institute of Technology. Stimulated by the information Brossel funneled back to Paris, Kastler developed a distinctive perspective, which he then cultivated in conjunction with experimentalist Brossel: striving for a physical understanding of "atoms in electromagnetic fields" based on detailed analysis of cyclical processes of exciting the atom with light to higher energy states followed by decay through the emission of photons, with attention directed especially to the angular momenta of the photons and of the magnetically distinguishable sublevels of the atomic energy states and to the consequent alteration of the relative number of atoms in each of its possible energy states.

Over the last four decades Claude Cohen-Tannoudji has been the most talented and consistent prosecutor of Kastler's research program. Born in Algeria in 1933, Cohen-Tannoudji was himself schooled at the ENS in the late 1950s and has since worked in close collaboration with younger researchers coming up through that laboratory. Continually deepening the theoretical foundations of that distinctive perspective and widening its experimental applications, he was awarded the 1992 Lilienfeld Prize of the American Physical Society for "his unique contributions to the understanding of atomic systems in electromagnetic fields and for his expository skills" (*Physics Today* **45**, no. 6, 94 [June 1992]; the statement continues: "He has made singular contributions to the theory of 'dressed atoms,' optical pumping and cooling, and resonance fluorescence and has experimentally verified some of his predictions.") A member of the Paris Académie des Sciences and foreign member of the U.S. National Academy of Sciences, Cohen-Tannoudji holds—since 1973—one of the 50-odd personal teaching chairs that constitute the Collège de France.

World Scientific has performed a service for all with an interest in the most recent history of physics by inducing Cohen-Tannoudji to bring together—and by reproducing photographically in so well-produced a volume—this selection of his scientific papers. The 39 papers here included (only two are in French) are distributed with remarkable uniformity over the 31 years separating the first (Cohen-Tannoudji's 1961 doctoral thesis) from the last (1992, on laser cooling of atomic motion). They are grouped in seven topical sections, with introductions of a few lines to a couple of pages provided by Cohen-Tannoudji for each paper and each section. As the dates of publication of the papers in each section have relatively small temporal dispersion and the ordering of the sections is essentially chronologic, the volume gives the trajectory both of Cohen-Tannoudji's attention and of the development of his field. In this it is an effective complement to his recent systematic exposition: Claude Cohen-Tannoudji, Jacques Dupont-Roc, and Gilbert Grynberg, *Atom-Photon Interactions: Basic Processes and Applications* (Wiley, 1992; translated from the French edition, 1988).

The first section is concerned with the work that first made Cohen-Tannoudji's name, the small shifts in the energy levels of atoms resonantly absorbing photons from, and being stimulated to emit photons back into, an intense radiation field. This discovery—Cohen-Tannoudji theoretically predicted and then experimentally demon-



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strated this "light shift"—received immediate attention, as it introduced a serious obstacle to the prospect of highly accurate atomic clocks based on optical pumping (R. H. Dicke) and optical detection of microwave resonance (H. G. Dehmelt).

The second section introduces—here, first, in the radiofrequency domain—Cohen-Tannoudji's characteristic "dressed-atom approach" to a proper quantum-mechanical treatment of an atom immersed in an electromagnetic field. Instead of treating the field as an exogenous entity driving the internal dynamics of the atom, the field is considered the atom's "raiment": atom and photons are treated as a single system, and the total Hamiltonian is diagonalized to obtain the energies of the dressed states. Only in the later 1970s, however, when applied to atoms in laser fields—sections 3 and 4 of the book—did this physical point of view stand out as especially distinctive and powerful. At a 1978 Royal Society colloquium, R. K. Bullough remarked: "I have been particularly delighted by his demonstration both here and on previous occasions, that a driven atom problem can, by changing to the dressed atom basis, be treated as a spontaneous emission problem in which the dressed atom cascades down its own sequence of Bohr energy levels emitting fluorescence photons as it does so" (p. 374).

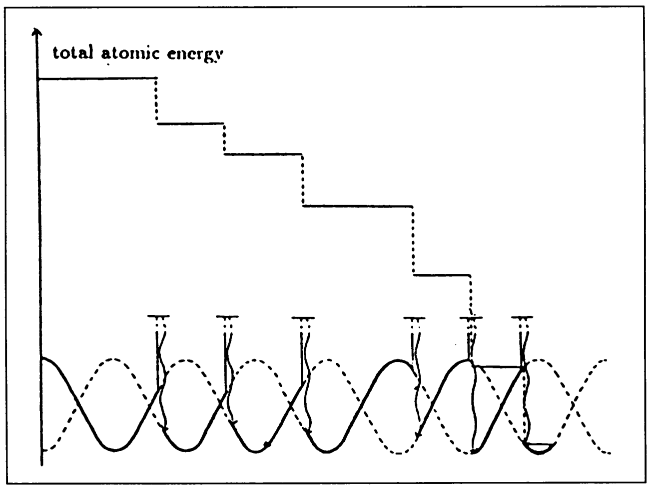
Section 5 contains four papers from the 1970s and '80s in which Cohen-Tannoudji endeavors to provide simple physical pictures for the most fundamental processes of quantum electrodynamics, particularly vacuum fluctuations and radiative corrections.

In the early 1980s, Cohen-Tannoudji returned to the analysis of atomic motion in laser light, initially theoretically, and then experimentally in collaboration with researchers—particularly A. Aspect—at the ENS. At first—section 6—stimulated by the early efforts at cooling trapped atoms *with* laser beams and trapping cooled atoms *in* laser beams, Cohen-Tannoudji directed his attention to the alteration of the translational motion of atoms through photon interactions. Laser cooling, as introduced in the late 1970s, makes use of the natural width of an atom's resonance-fluorescence lines: by detuning of the laser toward the red, the atom is forced to use its translational kinetic energy to make up the energy difference between a photon emitted at the center (intensity maximum) of such a line—where, by definition, most are emitted—and a photon absorbed out on its "red" side. Consequently, such "Doppler cooling" cannot slow the atom very far below a temperature-equivalent of the energy-equivalent of the spectral line width, $h\Delta\nu = kT$, that is, not much below a millidegree Kelvin. Moreover, the mechanism fails if the intensity of the laser is too high, for Doppler cooling requires that the atom's emission of photons be spontaneous, not stimulated by the light of the cooling laser. Two or three orders of magnitude below the limiting Doppler cooling temperature, at some microdegrees Kelvin, lies the fundamental limit set by the far smaller energy an atom gains recoiling (to conserve momentum) on the emission or absorption of a photon in any process of laser cooling.

Cohen-Tannoudji's first advance (1985–86) was the recognition that in a standing light wave a moving atom is slowed "due to a correlation between the spatial modulation of the dressed-state energies and the spatial modulation of the spontaneous departure rates from these dressed states. As a result of this correlation, the moving atom is, on average, running up the potential hills more often than down" (p. 526). Appropriately named "Sisyphus cooling," this effect becomes the stronger the more intense the laser beam, but, owing to the heating resulting from statistical fluctuations, this first Sisyphus mechanism to be recognized has a limiting temperature even higher than "Doppler cooling."

The spectacular results—section 7—came in 1988 and after, through combining with the dressed-atom approach to these questions of cooling and trapping the same close analysis of the repopulation of atomic energy states through optical pumping cycles that Cohen-Tannoudji had carried forward in his doctoral thesis almost 30 years before. The reconsiderations leading to these advances arose from the experimental discovery by W. D. Phillips at the National Institute of Standards and Technology, with whom the ENS researchers have worked closely, that laser cooling can in fact produce temperatures below the theoretical Doppler cooling limit.

Through a closer study of the spatial dependence of the optical pumping of a trapped atom by the standing light wave, Cohen-Tannoudji was able to explain the unexpected success as yet another form of Sisyphus cooling. Further, he established the conditions—and confirmed them by experiment—under which Sisyphus mechanisms could carry atoms even below the limit set by an atom's recoil momentum on emission and absorption of a laser photon: as the atom's motion is slowed, its deBroglie wave lengthens, becoming considerably longer than the length of the standing light wave in which the



"Sisyphus cooling" of atomic motion by a laser standing wave. The two sine waves represent the "light shift" variation of the energy of an alkali atom in its ground state—two possible orientations of the spin of the valence electron—over a distance of two wavelengths in the beam of the cooling laser. A hypothetical atom moving from left to right traverses the solid portions—including up the straight vertical line representing optical pumping to an excited state and down the wavy vertical line representing spontaneous decay of that state. Because of the spatial modulation of the transition rates between the ground and the excited state, a moving atom sees on the average more uphill parts than downhill parts of the two sinusoids and consequently its velocity is gradually damped—as indicated by the descending stair-like trace, above. [From *Atoms in Electromagnetic Fields*; Y. Castin, J. Dalibard, and C. Cohen-Tannoudji, 1991] atom is trapped and thus overlapping the deBroglie waves of atoms trapped in neighboring potential minima of that standing wave; consequently the atoms form a coherent state and the recoil momentum is no longer absorbed by the emitting atom alone but distributed over all. (At these low velocities the kinetic energy of an atom is less than the variation in its internal energy with position in the laser standing wave, so that the atom becomes trapped in one of the valleys in the figure.) Cohen-Tannoudji relates in a brief epilogue (1994) that creating extensive arrays of laser trapped and cooled atoms in coherent states and investigating their properties is the exciting program in which he is now engaged.

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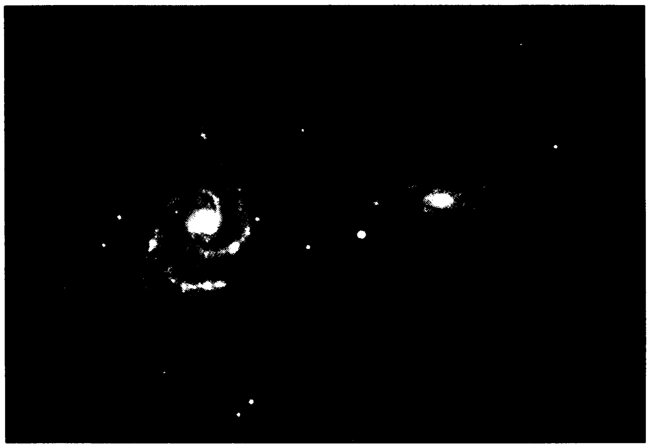
Galaxies

Carnegie Atlas of Galaxies. ALLAN SANDAGE and JOHN BEDKE. Carnegie Institution of Washington, Washington, DC, with the Flintridge Foundation, 1994. In two volumes. viii, 750 pp., illus. $95.

In 1936 Edwin Hubble wrote, "We know our immediate neighborhood rather intimately." "Immediate" and "intimate" are odd words to apply to a region a hundred million light years across. Now *The Carnegie Atlas of Galaxies* makes Hubble's statement seem eminently reasonable. The atlas is a work of art. Nowhere are the grandeur and aesthetic appeal of the cosmos more elegantly displayed. The images of the galaxies are mesmerizing—it is easy to spend hours paging through the two exquisite volumes.

The authors, Allan Sandage and John Bedke, describe the atlas as a guide to the classification and detailed properties of more than a thousand nearby galaxies. From the nearly featureless elliptical galaxies to spectacular spirals to the messes called irregulars, the verbal descriptions of the galaxies are clear and concise. The photographs are so cleanly reproduced that the salient features of any particular galaxy are obvious even to the uninitiated. The choices of contrast, scale, and positive or negative images masterfully enhance the clarity of the verbal descriptions. For the researcher, the atlas is an invaluable aid in developing research projects on nearby galaxies. Perhaps these volumes will inspire a solution to the nagging puzzle What causes the range of morphologies of galaxies?



NGC 5426/5427. Both these galaxies "have normal Sbc morphologies. They evidently form a physical pair. . .The only evidence for a close tidal encounter are the two thin straight strands of the multiple outer arms of NGC 5426 that overlap the outer thin spiral arms of NGC 5427, which are of the grand design." [From *Carnegie Atlas of Galaxies*]

The *Carnegie Atlas* is the culmination of an ambitious project with a distinguished pedigree. From 1919 to 1948 Hubble used the 60-inch and 100-inch telescope on Mount Wilson to photograph bright galaxies to explore and to define their "family traits." Hubble was unable to complete his atlas before his death in 1953. In 1961 Allan Sandage completed the now classic *Hubble Atlas of Galaxies*, which includes famous photographs of galaxies by Hubble and by Sandage himself. The *Carnegie Atlas* builds on (and includes) the *Hubble Atlas*. The photographs are a unique historical record of the exploration of the nearby universe—of people and of telescopes.

NGC 1187. The inner-arm pattern of this galaxy "is composed of three high-surface-brightness grand design spirals. Each begins near the small central nucleus. . .The two principal arms of the inner triad pattern can be traced for about three-quarters of a revolution outward before they abruptly decrease in surface brightness." [From *Carnegie Atlas of Galaxies*]

Taking the photographic plates at the telescope was only the crucial first step in the production of the new atlas. Many of the photographic plates are as large as 20 by 20 inches (51 by 51 centimeters), and a specially equipped lab is necessary to print the images for wide accessibility. John Bedke met the challenge of organizing and directing a photolab at the Space Telescope Science Institute where the extraordinary requirements of the atlas could be met. The crisp image of single spiral galaxy filling the 17 by 13½ inch printed page is simply awe-inspiring.

The authors write, "The intent is that volumes reach the hands of the young astronomers who will produce the coming spectacular developments in the next century." Perhaps this goal is too modest. Because of the generous subsidy provided by the Flintridge Foundation, the first printing is available for a small fraction of the commercial cost of such high-quality printing. The *Carnegie Atlas* should be in art museum shops along with other collections of famous photographs. For the professional or amateur astronomer the atlas is a must. Copies in high school libraries would inspire any imaginative young person, science-oriented or not. In fact, a brief, informal guide for young people (and their teachers) would be a valuable companion to the atlas.

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Millennia of Star Study

The Norton History of Astronomy and Cosmology. JOHN NORTH. Norton, New York, 1995. xviii, 697 pp., illus. $35 or $C45; paper, $18.95.

Almost a half-century after the Dutch astronomer Antoine Pannekoek published the last widely disseminated single-author general history of astronomy (translated into En-