Photorefractive Nonlinear Optics, Pochi Yeh has drawn on his many years of contributions to the field to provide a well-organized, advanced textbook intended for a course in modern optics for electrical engineering and applied physics students. A general knowledge of electromagnetism, solid state physics and differential equations is assumed. The book should also find immediate acceptance with researchers entering the field of photorefractivity, because it treats in detail many of the most fascinating and most subtle beam-coupling properties that arise from the nonlocal phase shift of photorefractive holograms.

Yeh successfully builds a foundation for many applications in several introductory chapters that review electromagnetism in crystals, the coupled-mode theory in periodic media and the physical mechanisms that lead to photorefractivity. Such topics often require entire books for a full exposition (for example, *Optical Waves in Crystals* by Amnon Yariv and Yeh; Wiley, New York, 1984), but the presentation here is still lucid and reasonably complete.

To describe the variety of applications resulting from beam-coupling effects and nonreciprocality, Yeh begins with explanations of how oscillation can occur in photorefractive resonators, paying particular attention to the role of the photorefractive phase shift and the oscillation conditions. To make the strange effects that can occur with self-pumped and multiple-pumped phase conjugators physically reasonable, Yeh effectively presents three theoretical explanations based on four-wave mixing, resonator theory and hologram sharing, respectively. The storage capacity of volume holograms is calculated as the number of "uncertainty volumes" that can be placed in the wavevector phase space of a given material. This discussion could have included an example of the application of uncertainty volume to specific storage architecture.

The book pays particular attention to the nonreciprocal nature of optical elements formed from photorefractive materials. Yeh correctly realizes that to understand what is different about photorefractives used in interferometric applications, the reader must first understand the Stokes relationships for a normal lossless beam splitter. This background greatly helps the reader appreciate the subsequent descriptions of ring cavities and Michelson interferometers containing photorefractive materials, as well as the optical computing applications based on amplitude subtraction and addition, reconfigurable optical interconnection, and dynamic neural networks.

Only a few small enhancements would have improved this already excellent text. The general introduction briefly describes the early days of photorefractive nonlinear optics, but no references are listed for the early measurements until the later chapters. A list of variables and nomenclature would have assisted the researcher in translating specific results to other naming conventions. On the whole, however, this book is an important contribution to the field, worthy of the attention of anyone serious about understanding the novel properties of photorefractive materials.

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Quantum Measurement

Vladimir B. Braginsky and Farid Ya. Khalili (Edited by Kip S. Thorne)
Cambridge U. P., New York, 1992. 191 pp. $39.95 hc
ISBN 0-521-41928-X

Even before humans were human, we learned to predict, with only a quick glance at a moving animal, where it would be a few seconds later. Now, not so long afterward, a small group of experimental physicists has sharpened this skill by a factor of 10^{16}—to catch not rabbits but gravitational waves.

When a gravitational wave shines on an aluminum bar or a pair of interferometer mirrors, a differential force stretches or compresses the bar or the separation between the mirrors by a fraction of an atomic diameter. One makes two or more measurements of position and then predicts the future position in the absence of the wave. If a subsequent measurement differs from the prediction, the apparatus has caught a gravitational wave.

The gravitational wave—containing frequencies below a few kilohertz and a large number of coherent quanta—can be described classically. Its interaction with the bar or interferometer is also classical, as is the subsequent motion. Only the position measurements are quantum mechanical.

The problem of measuring the position of a particle in the absence or presence of a very small force is simple, general and elegant. Although the bar or interferometer with which gravitational measurements are done is really a harmonic oscillator, for small amplitude changes the position of one end of the bar or of one mirror can be approximately described as a free particle. At a time t seconds after the initial position and velocity have been measured, the uncertainty in the predicted new position is the root mean square sum of Δx_0 and $\Delta p_0 t/m$.

Because Δp_0 is related to Δx_0 by $\Delta p_0 = \hbar/2\Delta x_0$, Δx_0 can be chosen to minimize the uncertainty of the new position. The resulting minimum uncertainty in the predicted position, the standard quantum limit, is $(\hbar t/2m)^{1/2}$. Thermal fluctuations make measurements at the SQL hard to achieve, but Vladimir Braginsky has built a tiny system that works at the SQL even at room temperature.

Although a real detector of small forces, such as a bar or pair of mirrors, is not a free particle but a harmonic oscillator, the SQL of a real detector is, within a factor of 2π, that of a free particle with the time t replaced by the oscillator period.

The surprise is that, for classical forces, the standard quantum limit can be beaten. One can get far below the SQL by measuring a combination of position and momentum that responds to the force while leaving the quantum state of the oscillator unchanged. This quantum non-demolition measurement extracts information but does not destroy the original state. One candidate for a quantum nondemolition measurement is the oscillator energy. This measurement gives no information about the oscillator phase. Another candidate is one of the oscillator's two quadrature amplitudes. This measurement, similarly, gives no information about the other quadrature amplitude. In each case, the cost of measuring one variable more and more accurately is that the measuring apparatus must throw more and more energy into the conjugate variable to increase its uncertainty. The oscillator is put into a state in which the measured variable with the small uncertainty is squeezed, while its conjugate variable is inflated. The limit is eventually set by the amount of energy available, or the robustness of the oscillator.

A more accurate title for this book, by Braginsky and Farid Khalili of Moscow State University, might have been *Quantum Measurement of Classical Forces*. The book applies all the tools of classical and quantum measurement to the measurement of small forces. The tools include time evolution operators, eigenstates, density matrices, correlation functions, noise spectral densities and hetero- and homodyne detection. By focusing on this practical but previously little-studied aspect of quantum measurement, the authors show a simple way to understand the limits that quantum mechanics places on classical measurements of force, energy, displacement and velocity. As in Braginsky's previous book, *Systems with Small Dissipation* (U. of Chicago P., Chicago, 1985), the ideas, all subtle, fundamental and useful, are the original work of the authors. The material is accessible to graduate students and can be interpreted for undergraduates. *Quantum Measurement* will provide easy-to-understand examples for the quantum mechanics texts of the future, and it will influence the direction of research in quantum measurements.

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Theory of Quanta

Iwo Bialynicki-Birula, Marek Cieplak and Jerzy Kaminski
Oxford U. P., New York, 1992. 494 pp. $49.95 hc ISBN 0-19-5-7157-3

Topics in Advanced Quantum Mechanics

Barry R. Holstein
Addison-Wesley, Redwood City, Calif., 1992. 436 pp. $48.50 hc ISBN 0-201-50820-6

Some time ago, quantum mechanics found its way into elementary physics at the college level. It is nonetheless common for advanced undergraduates or beginning graduate students to take a "serious" quantum mechanics course—two semesters, sometimes three, in length—that surveys the subject from the beginning. What should such a concentrated introductory course in quantum mechanics include, and what should be presented at the next level? To these problems the books under review—*Theory of Quanta*, by Iwo Bialynicki-Birula, Marek Cieplak and Jerzy Kaminski of the Polish Academy of Sciences and Warsaw University, and *Topics in Advanced Quantum Mechanics*, by Barry R. Holstein of the University of Massachusetts, Amherst—offer thoughtful resolutions.

It is to the beginning audience that *Theory of Quanta* is directed. In this volume the authors restrict themselves to Schrödinger's wave mechanics, promising extensions to matrix mechanics in a sequel. This self-