books

Concentrated and illuminating: 25 years of lasers

Masers and Lasers: An Historical Approach

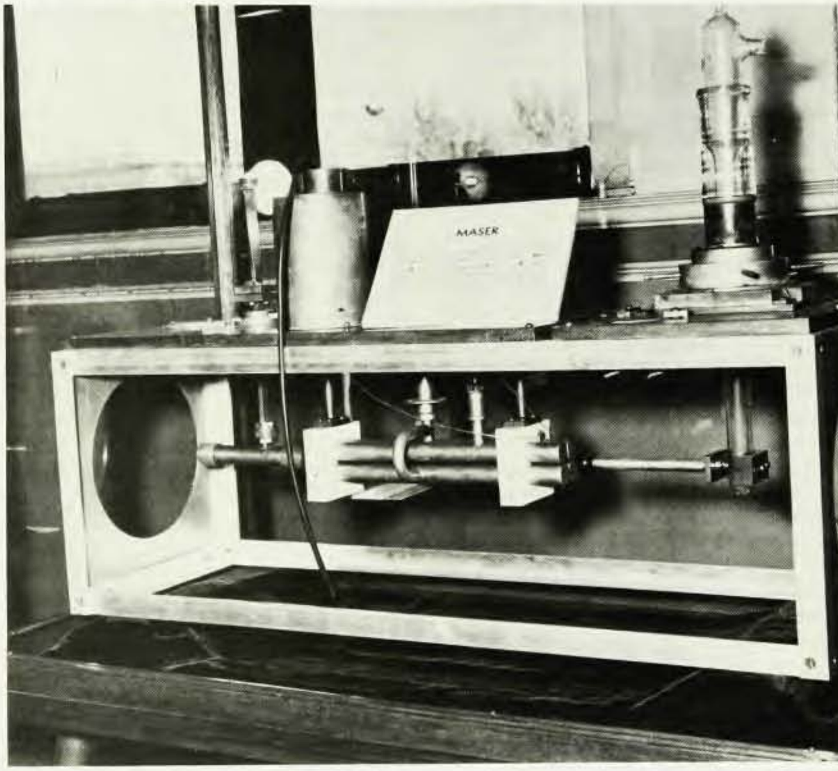
M. Bertolotti
268 pp. Hilger (US dist. Heyden, Philadelphia), 1983. $30.00

Reviewed by Peter W. Milonni

The construction of the first laser nearly a quarter of a century ago marked a turning point in the science and use of light. Mario Bertolotti's book traces the conceptual developments leading to masers and lasers. It is partly history, partly an introduction to the theory of operation of these devices.

Optical dispersion theory and the understanding of stimulated emission in "negative dispersion," played an important role in the formulation of quantum theory, especially in connection with the correspondence principle and matrix mechanics. A brief but lucid chapter ("Stimulated emission: Could the laser have been built more than 50 years ago?") is devoted to elementary dispersion theory and the experiments of Rudolf Ladenburg and others in the 1920s and early 1930s. It is followed by an intermezzo on magnetic resonance and optical pumping—Bloch equations, spin echoes and the Overhauser effect—and experimental evidence of population inversion. This work was concerned largely with the manipulation of energy-level populations, and in a sense the laser extends such manipulations to shorter wavelengths.

Research on the interaction of microwave radiation with matter in the 1940s and 1950s grew out of war-time radar research. A chapter on the maser begins with "the first public description of the maser principle (without a working device)" by Joseph Weber in 1952. In the spring of 1951 the operating principles of practical masers were worked out one morning by Charles Townes on a park bench in Washington. Townes was perhaps the first to understand the need for a resonant cavity. By 1953 the ammonia maser was built at Columbia by Townes's group; the acronym came with help from students when the group was unsuccessful in inventing a Latin or Greek name for the device. (Skeptics read it as a Means of Acquiring Support for Expensive Research.) Independently Nikolai Basov and Alexander Prokhorov were at work in the Soviet Union, and just a few months later Basov in his doctoral research built the first Russian maser.



The original maser, built by Charles H. Townes (on display at the Franklin Institute), began a new epoch in quantum electronics. (Photo by J. J. Barton, courtesy AIP Niels Bohr Library.)

One of the major problems in extending the maser principle to the visible was that a closed cavity of reasonable size would permit far too many modes to oscillate simultaneously. Arthur Schawlow had used a Fabry–Perot interferometer in his graduate studies in spectroscopy, and it occurred to him around the end of 1957 that a Fabry–Perot could be used as a mode-selective laser resonator. Earlier (1956) Robert Dicke had also suggested a Fabry–Perot, and he obtained a patent on this resonator in 1958. Schawlow and Townes described the basic theory of laser operation, and some possible pumping schemes, in an article published in December of 1958. (Townes at first could not arouse the interest of the patent office at Bell Laboratories, because "the invention had little bearing on Bell System interests.") Gordon Gould, a graduate student at Columbia, was thinking along somewhat similar lines but did not publish. Bertolotti also discusses Dicke's idea for a "coherence-brightened laser" (based on cooperative spontaneous emission) and the historically interesting work of V. A. Fabrikant in Russia, going back to as early as 1939.

A chapter on "The Laser: Further

Peter W. Milonni, associate professor of physics at the University of Arkansas, does work in quantum optics and electrodynamics.

Progress," begins with Theodore Maiman's construction of the first laser (ruby) in July of 1960; his paper, rejected by *Physical Review Letters*, was published in the 6 August issue of *Nature*. Most of the remainder of this chapter concerns the development of other lasers, particularly gas and semiconductor lasers.

The final chapter, on "The statistical properties of light," makes up about a fourth of the book. This is quite appropriate, for the statistical and coherence properties of laser light are what distinguish it from thermal radiation. There is a clear and concise summary of the work of Albert Einstein and Satyendra Nath Bose on the wave–particle duality and photon statistics of thermal radiation. Bertolotti considers the Hanbury Brown–Twiss (or "photon bunching") effect in some detail, and quotes R. Hanbury Brown at length about the difficulty many physicists had in accepting the effect. ("These difficulties about photons troubled physicists who had been brought up on particles and had not fully appreciated that the concept of a photon is not a complete picture of light.") He also discusses the quantum theory of optical coherence, including the Glauber–Sudarshan P-representation, and experiments on the photon statistics of laser radiation.

This attractively slim and highly readable book, written by a leading contributor, should appeal to researchers and students of laser physics and quantum optics, especially those interested in the evolution of ideas in these broad subjects.

Probabilistic and Statistical Aspects of Quantum Theory

A. S. Holevo

312 pp. North-Holland, New York, 1982. $85.00

This book, which constitutes Volume 1 of the North-Holland Series in Statistics and Probability, was originally published in Moscow in 1980. It has been translated by the author, Aleksandr Semenovich Holevo, who is a member of the Steklov Institute of Mathematics in Moscow. (Curiously the author's name is spelled "Kholevo" in the Library of Congress catalog.)

Most approaches to quantum mechanics from the side of mathematics emphasize either the arcane properties of unbounded operators or the "quantum logics," neither of which seems to reveal the physical essence of the subject. While unbounded operators and their domains are very much in evidence here as calculational tools, the emphasis in this book is on the statistical description of measurements. This keeps the subject matter fairly close to observations and makes this book more useful to physicists than are most mathematical approaches to quantum mechanics.

The author begins by defining "statistical model" so as to be able to treat classical and quantum models uniformly within one formalism. A model consists of two sets of elements, "states" and "measurements." A state is naturally associated with a preparation procedure, and thus with the potential ensemble of systems that may be subjected to the preparation. Thus Holevo effortlessly avoids the conceptual pitfalls that characterize the approaches that deal with a quantum state as a property of an individual system. A state is associated with a statistical operator S; a measurement with a family of projection operators $\{M_u\}$, where u is one of (or a subset of) the possible outcomes. The probability μ_s of the outcome u is given by $\mathrm{Tr}(SM_u)$. In a classical model, all of these operators are simultaneously diagonal; in a quantum model, S and M_u need not be.

Holevo expresses the results of this analysis in the language of mathematical statistics, and it is his objective to generalize many theorems of classical statistics to quantum statistics. From the physicist's point of view, the results provide sometimes a different view of familiar territory and sometimes one entirely novel.

Holevo shows how any statistical model is equivalent to a "hidden-variable" model. He points out that his assertion does not contradict the "no-go" theorems of Simon Kochen and E. P. Specker and of John S. Bell because those require more of such models than he does. No doubt he is correct, but an illustration of those differences by a simple example would have been welcome.

An essential property of the projection operators associated with a measurement is that they form a "resolution of the identity," $\Sigma_u M_u = I$. By allowing not only the familiar orthogonal resolutions of identity, but also nonorthogonal resolutions (provided by overcomplete sets such as the coherent states of the harmonic oscillator), Holevo is able to generalize the theory to treat several cases that do not fit into standard quantum measurement theory. These include joint measurements of coordinates and velocity (not violating the uncertainty principle), measurement of a time observable (for which no canonical operator exists), and measurement of rotation angle variables.

The book has a bibliography of 147 items, in addition to a brief subject index. The quality of the translation and of the printing are excellent, and the price is correspondingly high. Both mathematicians and physicists should find something of interest in this book.

LESLIE E. BALLENTINE
Simon Fraser University
Burnaby, British Columbia

Direct Nuclear Reactions

G. R. Satchler

833 pp. Oxford U.P., New York, 1983. $110.00

Our present comprehensive knowledge of nuclear structure largely comes from studies of direct reactions. Direct reactions in nuclear physics are scattering reactions with a peaked angular distribution for the scattered particle and a small energy transfer to the target nucleus. There are many useful kinds of direct reactions: Elastic scattering, inelastic scattering and particle-transfer reactions all provide different kinds of information about nuclear structure.

G. Raymond Satchler, a theorist who pioneered in the application of direct reactions to nuclear studies, has written a treatise on direct reactions covering practically all aspects of the subject.

Although Satchler is concerned with details of theory and the great variety of experimental phenomena, he has taken pains to provide a broad perspective of the subject. The introductory chapters are very readable, presuming only a knowledge of elementary quantum mechanics. Satchler explains in physical terms how direct reactions occur, as projectiles interact with the surface region of the nucleus. Illustrating his discussion with some well-chosen cross-section data, Satchler shows the evidence for the classification of varieties of direct reactions and the geometric origin of the peaked oscillatory angular distributions.

At a more technical level, his book invites comparison with the monograph written by Norman Austern in 1970, *Direct Nuclear Reaction Theories*. The theoretical framework was in place in Austern's earlier work, which used the distorted-wave Born approximation and its generalization into the coupled-channel method. At that time, however, the scope of the theory was unclear, and the experimental picture was much sketchier. Satchler brings the subject up to date with recent data that illustrate new successes of the theory as well as limitations. The inelastic scattering reactions have revealed the existence of new giant vibrations: Reaction theory enables their intrinsic properties to be measured. On the subject of particle-transfer reactions, new experimental tools have allowed the study of the reaction under a greater variety of conditions. With spin-polarized projectiles and heavy-ion projectiles one can measure the