BOOKS

A Physicist's View of The Role of Philosophy in Science

Philosophical Concepts in Physics: The Historical Relation between Philosophy and Scientific Theories

James T. Cushing
Cambridge U. P., New York, 1998. 424 pp. $74.95 hc ($29.95 pb) ISBN 0-521-57071-9 hc (0-521-57823-X pb)

Reviewed by Sunny Auyang

When scientists in the course of the "science wars" criticize some extreme aspects of science studies, they should not simply flash the word "science" to assert their possession of absolute truth. That would lend substance to the caricature that portrays scientists as thinking naively outside their narrow fields of expertise. A better way for scientists to combat irrationality is for them to exercise the same rational attitudes they apply to scientific research: to understand their opponents and explain their errors clearly and to understand themselves by reviewing critically their own history and practice, analyzing the assumptions hidden in their beliefs and justifying their reasons for accepting a theory or preferring it to rivals. These are the tasks that James Cushing undertakes with the care characteristic of a good physicist in his *Philosophical Concepts in Physics*.

Cushing declares the central goal of the book to be the uncovering and explaining of the "essential and ineliminable role that philosophical considerations have played in the actual practice of science." Unlike most philosophical expositions, which argue in the vacuum, Cushing's book examines philosophical considerations in concrete historical and intellectual contexts. A large portion of the book is devoted to the presentation of major theories in the history of physics: the Ptolemaic and Copernican models; the Galilean and Newtonian revolution; the mechanical versus the electromagnetic world views; the special and general theories of relativity; quantum mechanics and its interpretations. In each case, the physics is presented both in the now-accepted form and as it was debated by the physicists when they struggled with it. Copious quotations of historical texts enable students to get a flavor of science in action and to appreciate the difficulty and hence the significance of a theory, which they can easily miss when they receive it fully cooked on a plate.

The historical accounts show that often there is more than one way to represent the same phenomenon. Why does a physicist think about a problem in a particular way? What are the criteria by which the physics community eventually accepts a specific theory? Through numerous case studies, Cushing argues that philosophical assumptions and social contexts influence scientific reasoning and the processes by which theory is accepted. "At times," he writes in his preface, "the term 'construction' may seem more appropriate than 'discovery' for the way theories have been developed and, especially in the later chapters, the question of the influence of historical, philosophical and even social factors on the very form and content of scientific theories is discussed."

Relativity and, especially, quantum mechanics receive particular emphasis. For example, a chapter on Walter Kaufmann's experiment on the electron mass and Max Planck's subsequent analysis shows that science does not always proceed in the simple schema of hypothesis, prediction, experiment, refutation. Even more philosophical lessons are drawn from a detailed account of the development of quantum mechanics, including the Copenhagen interpretation, the Bohr–Einstein debate, the Einstein–Podolsky–Rosen paradox, the Bell experiments, and the Bohmian alternative version of quantum mechanics. Is quantum mechanics complete? What is the notion of reality it implies? Does quantum mechanics explain, or does it merely predict? Do we understand it? Did historical contingency play a role in the form of quantum mechanics that physicists use today? These are some of the mind-teasing questions that the book confronts.

The book grew out of a one-semester interdisciplinary course that Cushing gave at the University of Notre Dame to advanced undergraduates in the arts, sciences, and engineering. It will serve well as a textbook for similar courses. Its clear explanations will make it accessible to anyone who has taken a course in physics.

SUNNY AUYANG *is a member of the faculty of the department of the history of science at Harvard University.*

The Feynman Processor: Quantum Entanglement and the Computing Revolution

Gerard J. Milburn
Helix Books (Perseus Books), Reading, Mass., 1998. 213 pp. $23.00 hc ISBN 0-7382-0016-6

The last 15 years or so have seen the publication of dozens of books that aim to explain the mysteries of quantum mechanics to a lay audience. The quality ranges from excellent (Nick Herbert's *Quantum Reality*, Anchor Press/Doubleday, 1985) to abysmal (better not identified). In Gerard Milburn's *The Feynman Processor*, which, despite its somewhat breathless style, ranks fairly high on the list, the peg on which the presentation is hung is the new field of quantum computing. This is a topic to which the author has himself made important contributions.

It is difficult for a reviewer already familiar with most of the subject matter of such a book to judge its comprehensibility to a reader approaching it from scratch. I have one particular worry in this connection: The author seems to have taken to heart, with a vengeance, the opinion attributed by Stephen Hawking to one of his advisers, that "each equation included in the book would halve the sales." No doubt this may be so, but, from any but a commercial perspective, a more interesting question is what effect each equation will have on the percentage of readers who will get out of the book the level of understanding intended. It is here that I think the author (who includes no equations at all) may be unduly pessimistic: Eschewing equations does not make the basic concepts of quantum mechanics any less subtle. I would suspect that any lay reader who is prepared to make the not inconsiderable mental effort necessary to grasp them is unlikely to balk at a half-dozen strategically chosen equations in the text, (particularly since the reader, on page 155, is assumed to have the mathematical background necessary to appreciate the fact that minus one raised to the power zero is plus one!).

Within this self- (or publisher-?) imposed constraint, Milburn has by and large done a first-class job in explaining in nontechnical terms the "weirdness" of quantum mechanics. If he has a fault, it is perhaps in aiming for a level of completeness that is not obviously necessary for his purpose and may on occasion be confusing to the intended readers (I would myself have settled for the oversimplification of a real but signed probability amplitude). But the exposition of the Bell–EPR results is as lucid as any I know, and, indeed, I somewhat prefer it to Herbert's, for example, in that it focuses more tightly on exactly how a quantum description enables one to evade John Bell's argument. Much of the discussion of the motivation for and nature of quantum computation is also first-rate. To be sure, by the time Milburn gets to Shor's algorithm, the going has become pretty heavy for a novice reader, but I suspect that is inherent in the material.

I have only two reservations of any substance regarding this book. The first relates to the author's enthusiasm, in chapter 4, for the notion of complete "simulability" by computer of physical reality—an attitude that I suspect will seem rather implausible to anyone dealing with any area of science (or even of physics) whose subject matter is less closely circumscribed than that of the author's primary field of quantum optics; in such fields, the problem lies not in the solution of the equations once obtained but in writing down the "relevant" equations in the first place.

My second reservation is the absence of any meaningful discussion of the quantum measurement problem—despite its obvious relevance to the interpretation of the "quantum randomness" on which the author repeatedly insists. On page 175, in the course of a discussion of decoherence, we read: "The mere fact that we can look at [the alien qubit] and decide which of two previously indistinguishable alternatives is realized destroys the superposition state." Who would guess that those three little words "can look at" conceal an issue over which some of the world's leading physicists, from Erwin Schrödinger to John Bell, have agonized for six decades?

Anthony J. Leggett
University of Illinois at Urbana-Champaign

Architectural Acoustics: Blending Sound Sources, Sound Fields, and Listeners

Yoicho Ando
AIP Press (Springer-Verlag), New York, 1998. 252 pp. $49.95 hc ISBN 0-387-98333-3

Acoustical design is an ancient art; some fundamental although subjective notions of sound-field evaluation and the linkage of acoustical quality to dimensional factors, concepts of reverberation, interference, echoes, and loudness go back to Vitruvius (ca. 25 BC). But for centuries little changed. From the Middle Ages until the beginning of this century, the design of theaters and concert halls, on which Yoicho Ando's *Architectural Acoustics* focuses, continued to be based entirely on empirical knowledge.

The first successful attempt to quantify the acoustic properties of the sound field was by Wallace C. W. Sabine, who, around the turn of this century, defined the sound decay in a hall in terms of reverberation time; he later derived a formula for its calculation based on the enclosure dimensions and sound-absorbing properties of the walls. Sabine also found that, for optimum listening conditions, there is an optimum reverberation time, which depends on the volume of the hall and nature of the acoustical signal (speech or music, for instance). Far into this century, the optimum reverberation time was the only acoustical criterion for concert hall and theater design.

Historically, concert hall and theater design has been dominated by architects, and acousticians have usually played only a secondary role. Nonetheless, some European concert halls designed around the beginning of the century have been subjected to sound-field studies using contemporary measurement and signal processing techniques and found to be acoustically outstanding. (Vienna's Musikvereinsaal and Amsterdam's Concertgebough are among them. The Boston Symphony Hall is also highly valued for its outstanding acoustical properties.)

It is now well known that optimal reverberation time is a necessary but not sufficient criterion for designing a good concert hall. What are the other essential sound-field properties required for an optimum listening environment? Architectural acousticians have been working on this problem for the last 50 years, but, compared to rapid developments in many other areas of physics, progress on concert-hall acoustics has been relatively slow.

This admittedly lengthy introduction helps to place in context the mission, importance, and potential impact of Ando's *Architectural Acoustics*, an outstanding book that provides deep insight into the subjects of its subtitle: blending sound sources, sound fields, and listeners. Ando summarizes his research and that of his collaborators. His approach to concert hall design dwells on psychological and physiological preferences for optimal values of a few sound-field descriptors to achieve optimal listening conditions. Using computer modeling for sound-field predictions of the selected field descriptors, the shape of the hall boundaries can be optimized and the work of the acoustician can be brought into harmony with that of the architect.

The book is divided into 12 sections that cover four principal areas. The first area covered involves those physical properties of sound sources and sound fields that are linked to sound perception. The source properties are examined in terms of their power spectra and autocorrelation functions. The important and relevant sound-field quantities include impulse waves that provide temporal information and the spatial cross-correlation that is essential for spatial–binaural criteria based on interaural cross-correlation.

The second area presents the results of the latest research into subjective preferences as an overall impression of the sound field. Here, the author discusses optimum delays and intensity of initial reflections and the need for a dissimilarity of the sound fields at each of the listener's ears, as expressed by interaural cross-correlation. Ando puts these topics into the context of the auditory–brain system. Based on his extensive research, he has created a model of the auditory–cognitive system in the brain and formulated a theory of subjective preferences.

The third area is devoted to practical matters of sound-field control by design, including the effects of wall and ceiling configurations, sound diffusers, lateral reflections from canopies, sound attenuation by seats, and interactions with the floor. The author ascribes great importance to individual listeners' subjective preferences and seat selection, which vary strongly from one person to the next, as Ando shows by many examples.

The remainder of the book is dedicated to case studies of acoustical design that demonstrate how the defined criteria for optimal listening can be achieved. The author also analyzes multipurpose auditoriums, round-shaped halls and auditoriums with movable walls and ceilings. Separate