QED

Even the best of theories can get a hard time now and then

by Dietrick E. Thomsen

The great virtue of classical physics was determinism. In a Newtonian world a given set of conditions at the beginning of an action leads to one and only one result. Newton's laws may not be able to tell you which way the cat will jump, but they will tell you which way the ball will fall and how high it will bounce.

The determinism of physics had a profound influence on other intellectual realms. Its influence in philosophy and theology almost drove orthodox Christianity underground among the intellectual classes and produced such famous 18th-century notions as the God as watchmaker, who wound up the universe and then let it run. Determinism invaded other sciences. Indeed it became hard to see things as scientific if they weren't deterministic: Darwinian biology is a kind of Newtonism applied to the evolution of species, and nowadays we even have a deterministic school of psychology. B. F. Skinner might very well tell you that you can indeed predict which way the cat will jump.

Meanwhile, however, when physics reached the innards of the atom, determinism came to a screeching halt. The theory that works in describing subatomic activity is nondeterministic. Quantum theory, as it is called, does not generally tell you the unique outcome a given set of starting conditions will yield. It usually tells you that there are several possible outcomes, and all it gives you is the probability with which each of them is likely to occur. Quantum mechanics has been very successful as a theory goes.

Yet in this business success does not guarantee that you will make friends and influence people. Many physicists are uncomfortable with the theory. Even those who helped originate it seem at times as if they did so against their own will. Max Planck, who brought the idea of the quantum into physics, spent 40 years of his life thereafter trying to find ways around it. Albert Einstein, who won the Nobel Prize for his explanation of the photoelectric effect as a quantum effect, is remembered for remarking that God does not throw dice.

Quantum electrodynamics (QED) is the branch of quantum theory that deals with electromagnetic phenomena. It has been the most spectacularly successful branch of the theory. It lies, or should lie, at the basis of all electric, magnetic and optical phenomena. Yet, here, when one talks to people doing day-to-day work in optics, one finds that the general philosophic malaise is reinforced by conceptual and computational problems of the do-we-really-need-all-this variety. The question has led to the presentation of rival, deterministic theories for serious consideration. A discussion of the state of the question was undertaken at the Eighth International Quantum Electronics Conference in San Francisco.

Quantum electrodynamics "is one of the greatest achievements of science," says Stanley J. Brodsky of the Stanford Linear Accelerator Center. It has been tested at distances ranging from 10^{-15} centimeter (one one-hundredth of the radius of an atomic nucleus) to several earth radii, and its predictions have all been verified except a very few points.

And yet, after 70 years of development, says Leonard Mandel of the University of Rochester, "the validity of quantum electrodynamics is being called into question in optics." The critique rests partly on dissatisfaction with the mathematical calculation the theory requires and partly on its conceptual framework. The need for a quantized theory is questioned by those whose work seldom deals explicitly with quanta. To them the quanta, called photons, the little bundles of energy on which the theory depends, seem more and more transcendent and elusive. "Optical photons are rarely in the real world," says Mandel. "They cannot be real altogether."

In fact to get someone to praise the successes of QED, you have to get a particle physicist like Brodsky. Particle physicists love QED. In their bailiwick photons are important. The theory gives predictions that experiment supports with razorfine accuracy. Let us review a few of Brodsky's points.

The latest experiments to test QED involve high-energy collisions of electrons and positrons. It is these that test QED down to lengths of 10^{-15} centimeter accuracy. Results of electron-positron experiments in which the electron and positron are transmuted into muons indicate that electrons, muons, positrons and photons all have no internal size, or at least that their size is less than 10^{-15} centimeters.

The magnetic moment of the electron, the quantity that measures its response to a magnetic field, has a so-called anomalous part resulting from the modern theory's correction of an older simpler model. QED predicts the anomalous part as 0.0011596519. Famous experiments by Polycarp Kusch of Columbia University have yielded 0.0011596567, agreement to the tenth significant figure, a truly fantastic agreement.

QED calculation of the Lamb shift, a small correction to the frequency of light emitted in certain atomic transitions, predicts a value of 1,057.91 megahertz; experiment yields 1,057.90. Study of the splitting of lines in the spectrum emitted by muonium, an "atom" consisting of an electron and a muon, can determine the fine-structure constant, the figure that measures the intrinsic strength of electromagnetic forces. QED predicts 137.03631; experiment gives 137.03608.

There are points where QED does not do so well: the X-rays emitted by atoms in which a muon has replaced an electron, the radioactive decay of positronium (an "atom" consisting of an electron and a positron) and electron-positron collisions in which particles other than electrons and muons are produced. On the whole, however, it comes through rather well.

But, meanwhile, back at the optical ranch, theorists have found that they can explain a number of supposedly quantum results, including some of the early observations out of which QED developed, by nonquantum theories. Mandel reviewed some of these neoclassical explanations, concentrating especially on the theory put forth by E. T. Jaynes of Washington University in St. Louis, because it makes some predictions that differ from QED. Other attempts are content to provide alternate explanations for the various phenomena that QED also explains.

That grand example of the textbooks, the photoelectric effect, which led Einstein to invoke quanta, it turns out can be quite well explained by a nonquantum theory, one based on waves and classical fields. The necessity of using Bose-Einstein statistics in electrodynamic calculations, a consequence of the tendency of photons to come in bunches, can also be explained neoclassically. If one splits a beam of light with a half-silvered mirror so that part of the light comes off at a 90-degree angle and the rest goes on straight and one then puts photon counters at the ends of the two beams, there should be no coincidences between the counts. Individual photons are not split, so different ones go off in the different directions. Strangely enough, this too can be explained neoclassically.

However the neoclassical theory tends to fail when it postulates extended time in something like the emission of light, where QED predicts an instantaneous occurrence. It also fails in predicting the width of lines in the spectra of scattered light and in certain experiments with polarized light. Altogether, though, Mandel says, nonquantum theories can account for more than most people think. Nevertheless he concludes that none of the non-quantum offerings is likely to replace QED.

Was the effort of devising them then wasted? Not at all, says Mandel. "We've been obliged to critically confront evidence and reopen questions long thought settled." The activity may help put electrodynamics on a firmer conceptual foundation, and it goes to show that in physics nothing is sacrosanct. No theory, however successful, is beyond criticism. □

New Books

New Books is an editorial service for readers' information. To order any book listed or any U.S. book in print, please remit retail price, plus 25¢ handling charge for each book to **BOOK ORDER SERVICE**, Science News, 1719 N Street, N.W., Washington, D.C. 20036. All books sent postpaid.

BEHOLD MAN: A Photographic Journey of Discovery Inside the Body—Lennart Nilsson with Jan Lindberg; text by David H. Ingvar et al., transl. from Swedish—Little, 1974, 9x11, 254 p., 350 color photographs, drawings by Bernt Forsblad, $25. Presents Nilsson's remarkable record of internal electron micrographs revealing the workings of cells, blood, organs, nervous system and senses.

BIOLOGICAL CONTROL BY NATURAL ENEMIES—Paul DeBach—Cambridge U Pr, 1974, 334 p., photographs, tables, $14.95; paper, $5.95. Authority on the subject outlines the fascinating potentialities of biological control of pests for the general reader and student of environmental phenomena, and shows how pesticides disrupt the ability of natural enemies to control pests.

CHILDREN OF THE DESERT: The Western Tribes of Central Australia—Géza Róheim, introd. by Werner Muensterberger, Ed.—Basic Bks, 1974, 282 p., $8.50. Psychoanalyst tests widely held psychoanalytic concepts against his own anthropological fieldwork on the desert people's kinship system, food quest, hierarchy, sexual code and child-rearing practices.

CLIMATES OF THE STATES, Vol. I: Eastern States plus Puerto Rico and the U.S. Virgin Islands. Vol. II: Western States including Alaska and Hawaii—Officials of the National Oceanic and Atmospheric Administration—Water Info Center, 1974, 9x11, 1,000 p., 395 tables, 310 maps, $39. Practical reference containing basic climatological data of the United States.

EIGHTEENTH CENTURY INVENTIONS—K. T. Rowland—B&N, 1974, 9x11, 160 p., illus., $10. Describes more than 130 inventions, each illustrated, grouped by sections such as iron & steel, steam power, textiles, electricity, and maritime.

IN SEARCH OF THE RED APE—John MacKinnon—HR&W, 1974, 222 p., color plates, photographs by author, maps, $8.95. An absorbing account of trailing the elusive orang-utan through the jungle forests of Sumatra and Borneo, studying the habits of this solitary ape.

INTERSTELLAR COMMUNICATION: Scientific Perspectives—Cyril Ponnamperuma and A. G. W. Cameron—HM, 1974, 226 p., illus., paper, $5.95. Provides a readable version, for student and general reader, of lectures designed to cover every aspect of the problem, from the question of the origin of the universe to that of origin of life, origin of intelligence, and the means of communication.

LEARNING BASIC FAST—Claude J. DeRossi—Reston Pub Co, 1974, 220 p., diagrams, $8.50. Computer programming language presented informally in nontechnical terms, suitable for self-teaching.

LOGIC OF THE LIVING BRAIN—Gerd Sommerhoff—Wiley, 1974, 422 p., illus., $15.95. Addressed to the intelligent layman, the book takes a fresh look at fundamental concepts, issues and assumptions about the special capabilities of the human brain.

MARIE CURIE—Robert Reid—Sat Rev Pr, 1974, 349 p., plates, $8.95. A newly researched biography of both the woman and the scientist who became the first winner of two Nobel Prizes.

THE METALSMITHS—Percy Knauth and the Editors of Time-Life Books—Time-Life Bks, 1974, 160 p., color plates, photographs, maps, $7.95. About the technique of metal working, early copper mining and smelting, the impact of iron axes and shields, the Asian mastery of bronze, and the gold-working craftsmen of the pre-Columbian empires.

METASTABLE LIQUIDS—V. P. Skripov, transl. from Russian by R. Kondor; D. Slutzkin, Ed.—IPST (Halsted Pr), 1974, 272 p., diagrams, $30. Deals with the physics of the metastable state of matter, with special emphasis on the thermodynamics and kinetics of spontaneous formation of vapor-phase nuclei in superheated liquids.

MINDS, BRAINS AND PEOPLE—T. E. Wilkerson—Oxford U Pr, 194 p., $11.25. Examines two philosophical accounts of the concept of a person, a traditional "descriptive" account, and a physicalist "revisionary" account yielded by the Identity Theory (the claim that psychological states are identical with states of the brain and nervous system.)

MODE OF ACTION OF ANTIBIOTICS ON MICROBIAL WALLS AND MEMBRANES—Milton R. J. Salton and Alexander Tomasz, Ed.—N Y Acad of Sci, Annals, Vol. 235, 1974, 620 p., photographs, diagrams, paper, $40. Papers deal with structure, chemistry and biochemistry of walls and membranes, their functional interrelationships, wall biosynthesis and penicillin action, inhibitors of synthesis, and membranes as targets for antibiotic action.

THE MYTH OF MENTAL ILLNESS: Foundations of a Theory of Personal Conduct—Thomas S. Szasz, M.D.—Har-Row, 1974, rev. ed., 313 p., $8.95. Revision eliminates technical language and excessive documentation of first edition, text partially rewritten for readability, with new preface and summary added.

POWER FROM THE WIND—Palmer Cosslett Putnam—Van Nos Reinhold, 1974, 224 p., illus., $9.95. Originally published in 1948, book describes from beginning to end the development and testing of a 175-foot, 1,250-kilowatt experimental wind-turbine installed on a Vermont mountain.

STAYING ALIVE—Maurice and Maralyn Bailey, foreword by Sir Peter Scott—McKay, 1974, 192 p., photographs, drawings, maps, $6.95. The day-to-day diary record of a resourceful couple, nearly four months adrift in a rubber dinghy in the Pacific Ocean.

TIME AND THE SPACE-TRAVELLER—L. Marder—U of Pa Pr, 1974, 208 p., diagrams, paper, $3.95. Gathers together all the material on the clock paradox and examines the arguments in a unified way, with clarity, humor and the necessary mathematics.

THE ULTIMATE STRANGER: The Autistic Child—Carl H. Delacato—Doubleday, 1974, 238 p., $6.95. Based on 20 years of successful work with brain-injured children, the author contends that these children suffer from sensory distortions and that perception-oriented therapy can produce dramatic results.

VIOLENCE AND AGGRESSION IN THE HISTORY OF IDEAS—Philip P. Wiener and John Fisher, Eds.—Rutgers U Pr, 1974, 284 p., $15. Seventeen essays with comments, from discussions of warfare in the cosmos to myth and fact in Marxist theory.