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NEWS

Tutorial school a festival on optics

Optics has a fine tradition in India, from the days of C. V. Raman. Rapid developments have taken place in the subject in recent years and it has been divided into many new areas. A two-week-long tutorial school ('Modern developments in optics', Indian Institute of Science, Bangalore, 18 to 30 June 1990), probably the first such all-India school, supported by the Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore, and the Centre for Theoretical Studies of the Indian Institute of Science, took note of these developments. The school was planned at three levels: courses of lectures on several important and interesting areas; specialized individual seminars, both experimental and theoretical; and special evening survey lectures by some of the distinguished senior scientists presently leading research and development programmes, to educate young scholars about the technological spin-offs that could arise from their work. It was emphasized throughout the school that optics is no longer just the curiosity of a theorist or an experimentalist, but also a technologist's dream. In the words of Herman Haken, 'There is hardly any other field of physics in which a profound understanding of the fundamental physical processes is so intimately interwoven with technical and physical applications of great importance as in modern optics.' This connection makes optics particularly attractive and rewarding for scientific study.

Many of the courses given at the school were grouped around major themes while a few covered special areas. Thus, there was a course on group-theoretic methods in optics and a companion on squeezed states, generalized coherent states and geometric phases. Then there were three inter-related courses on optical processes in multilevel atoms, QED of atoms in cavities, and single-atom spectroscopy and quantum jumps. Another related pair were X-ray lasers and Free-electron lasers. The 'singletons' were photon-counting statistics, speckles and scintillations, phase-conjugation optics, and chaos in optics. These titles convey the range of ideas covered—truly a festival on optics.

N. Mukunda's (IISc) lectures on group-theoretical methods in optics were a journey beginning with Fermat's principle in classical ray optics, through the development of the machinery of the symplectic groups Sp $(2,\mathbb{R})$ and Sp $(4,\mathbb{R})$ to deal with ray optics, to a smooth transition to wave optics. This procedure is quite elegant, it uses the machinery of quantum mechanics and group theory in carrying the simplicity of the ray description over to the wave theory. This novel way of presenting the ideas of classical optics has intrinsic appeal. For a practising 'optician', this formulation allows the freezing of an optimal design for an optical system right at his desk, before being given for fabrication. The relevance of this flexible approach to futuristic optical computers need hardly be emphasized. While Mukunda's lectures essentially involved scalar optics, the seminar on analogy between light optics and electron optics by R. Jagannathan (Institute for Mathematical Sciences, Madras) adequately supplemented and covered the vector and spinor aspects of the problem.

R. Simon (IMSc) introduced the concepts of squeezed states and generalized coherent states and their properties. He showed that the group-theoretic machinery set up in Mukunda's lectures comes in very handy in treating the properties of these states. He also used group theory to introduce and discuss the geometric phase in optics and to distinguish Berry's phase from the Pancharatnam phase. In the first seminar of the school, V. Srinivasan (University of Hyderabad) had already talked on geometric phases, covering the basic ideas and his own work, and prepared the way for Simon's course.

S. P. Tewari (University of Hyderabad) gave a flavour of optical processes in two- and three-level atoms induced by driven coherent fields, borrowing extensively from the book by Allen and Eberly.

R. R. Puri (BARC, Bombay) outlined the quantum-electrodynamic behaviour of atoms in cavities. Experimental studies in this area are carried out by two groups in the world—Walther's group in Munich, and Haroche's group at the École Normale in Paris. The ideal experimental situation for observation of QED effects is Rydberg atoms placed in microwave cavities. One finds interesting effects basically arising from the sole fact that the photon annihilation and creation operators do not commute ($[a, a^\dagger]=1$), such as vacuum-field Rabi oscillations, and collapses and revivals of these oscillations. These effects are observable in principle in microwave cavities of high Q factor, in the range 10^8–10^{10}, being developed in Germany and France. Both single-atom and multi-atom effects can be studied. Puri also discussed the possibility of chaotic behaviour arising when cavity detuning and decay are taken into account. The experiments also indicate new ways of producing fields having purely quantum properties like antibunching and squeezing.

The third in this group of connected courses was an extensive discussion of quantum jumps, experimental as well as theoretical, and the recent observation of the quantum Zeno effect in induced optical transitions (see also *Curr. Sci.*, **59**, 897), by S. V. Lawande (BARC). High-resolution spectroscopy, using ions trapped in quadrupole fields and then optically cooled, has made it possible to conduct many fundamental physics

Prof. R. Rajaraman of the Indian Institute of Science knew J. S. Bell, the distinguished 'philosopher' of quantum physics and had also collaborated with him. We publish below the invited article he wrote for us in memory of this outstanding savant.

—Ed.

John Stuart Bell—The man and his physics

R. Rajaraman

With the shocking and untimely death of Professor John Stuart Bell on 1 October 1990, the world has lost not just a very distinguished physicist but an exceptional human being. For nearly three decades he was a moral presence in the world of physics, maintaining high standards of intellectual clarity and professional integrity, while making a series of important contributions to his field. His path-breaking work on the foundations of quantum theory, acclaimed of course by the physics community, had also made him famous in a larger world—a celebrity status that he handled with quiet dignity and gentle amusement. As a person, he was kind and soft-spoken, yet commanded much respect, sometimes bordering on awe.

I cannot claim the privilege of having known John very intimately, or for long. I met him for the first time in early 1983 when he visited our Centre for Theoretical Studies in Bangalore, and I never saw him again after bidding goodbye to him at CERN, Geneva, in late 1985. During those three years, however, we did have a fair bit of contact at both the professional and social levels. We also collaborated on and co-authored a couple of research papers. In the process I, like many others before me, grew to admire and respect him. I was also a recipient of his kindness in several ways.

In this brief homage to John Bell, I shall first refer to his physics, and give an introduction to two of his major contributions. I will then hazard a few personal impressions of John Bell the man, recalled with affection and respect.

Over the years, John worked on a wide range of subjects in physics. Not many physicists of the current generation may know, for instance, that one of the first review articles on the theory of nuclear matter was written by him, co-authored with E. J. Squires in 1961 when that field was still in its infancy. He made important contributions to such widely different areas as accelerator physics and neutrino scattering from nuclei. My own work with him in the mid-eighties was on the mysteries of fractional charge in polymers and

one-dimensional field theories. But of his numerous contributions, perhaps the two that are most famous are what have come to be known as Bell's theorem (on the foundations of quantum theory), and the Adler–Bell–Jackiw anomaly in quantum field theory.

Bell's inequality

Bell's theorem or Bell's inequality, deals with the foundations of quantum theory. In order to appreciate why this work evoked so much interest even beyond the world of physics, I must first say a few words about quantum theory itself. Quantum theory is more than just the theoretical basis of modern physical science. It is one of the most profound constructs of the human mind, whose significance transcends the scientific discoveries galore that it has led to, spectacular though these are. This is because, underlying its working rules, quantum theory carries a conceptual structure radically different from that of all the 'classical' science that

R. Rajaraman is in the Centre for Theoretical Studies, Indian Institute of Science, Bangalore 560 012.

preceded it for centuries. It has demanded fundamental changes in our ideas of scientific predictability, of determinism and indeed of the whole nature of physical reality. These aspects of quantum theory, to which Bell's theorem was addressed, have fascinated not just physicists but the larger intelligentsia, including philosophers, theologians and even litterateurs.

To begin with, the predictions of quantum theory are probabilistic. But unlike the use of probability and statistics in classical physics or in the social sciences, the probabilistic feature of quantum theory is meant to be intrinsic, not due to limitations of available data or our calculational stamina. Quantum theory demands an unavoidable influence of the very act of measurement on its result. If we measure the position of a particle, knowledge of its momentum becomes totally uncertain, and vice versa. Similar statements are true for many pairs of 'simultaneously incommensurate' observables. Quantum theory also forces us to accept situations in which a system consists of, say, two spatially well-separated components where, while the results of measurement cannot be precisely predicted in either component, yet, given any specific result in one of the components the result in the other is fully determined! These are examples of the famous EPR paradox, to which we shall return shortly.

Is the real world actually so bizarre? Or are these vagaries of a very successful but nevertheless incomplete description called quantum theory, while 'actually there is an objective reality out there', with simultaneous and precise values for positions, momenta, etc.? Is it even meaningful to ask such questions about the nature of 'true reality' within the purview of science, unless one can identify measurable criteria which can answer them objectively?

Such issues have bothered people ever since the inception of quantum theory. The great Albert Einstein had serious reservations about quantum theory because of its conceptual features and in 1935 he wrote (with B. Podolsky and N. Rosen) a seminal paper constructing the EPR paradox mentioned earlier, to give focus to what worried him. The debates between Niels Bohr and Einstein ('God does not play dice'—this from Einstein) on these questions are legendary. Inspired by Einstein, several people tried to construct a more fundamental theory which is deterministic and consistent with classical ideas of objective reality. Constructing such theories in a responsible manner is not at all easy. It must not only reproduce all the experimentally confirmed predictions of quantum theory, but also suggest other concrete measurable consequences that could distinguish it from quantum theory.

Not surprisingly then, this field of study progressed slowly and inconclusively, with occasional carefully thought out papers by very serious thinkers mixed in with relatively superficial hidden-variable alternatives which did not carry conviction, not to mention missives from a variety of nuts, cranks, and malcontents.

Into this somewhat confused scenario with a heterogenous literature came John Bell's work, cutting through it like a beacon of crisp cold light. Given a class of EPR type of experiments, Bell constructed explicit measurable criteria which could distinguish between the quantum and classical pictures of reality. His criteria were in the form of simple mathematical inequalities. To paraphrase (a potentially dangerous step in this subject), his inequality in such an experiment would involve a combination (let us call it C) of quantities that can be objectively measured by these experiments. If the experimental results were fully in accord with the standard predictions of quantum theory, then the value of C, suitably normalized, would have to be less than one. On the other hand, if the system were governed by some deeper 'classical' type of theory, (where all particles did simultaneously 'possess' specific values for all their physical attributes, such as their positions, momenta, all spin-projections, etc., governed in turn by some deterministic rules) then the value of C would have to be greater than one! This is regardless of the specific mechanisms and the details of the underlying classical candidate theory. The important feature of Bell's ingenious criterion was that it was based solely on objectively measurable experimental numbers. It elevated the forty-year-old debate over the quantum versus the classical nature of reality from being a perennially inconclusive controversy involving metaphysical or subjective preferences, to something that could be objectively decided.

Subsequently, Alain Aspect and collaborators at Paris conducted a practical version of such thought-experiments. On applying Bell's inequality to the data, quantum theory was vindicated. More importantly, the possibility of some deeper classical explanation of the data was ruled out. Of course all this does not diminish the bizarre nature of the quantum view of reality, which continues to violate our intuitive notions based on day-to-day experience. But, as Bell's work has established, it nevertheless seems to be unavoidably true, and we just have to live with it.

The ABJ anomaly

In 1969, John Bell and Roman Jackiw, another distinguished theoretical physicist now at MIT, discovered the phenomenon of 'anomalies' in four-dimensions. Stephen Adler at Princeton had also discovered the same thing around the same time, independently and by different methods. Anomalies refer to the violation, upon quantization, of some symmetry of a system (and the associated conservation law) present at its classical level. Generally speaking,