RETROSPECTIVE

Samuel Frederick Edwards: Founder of modern polymer and soft matter theory

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This year marks the 50th anniversary of the seminal paper by Sam Edwards on the statistical mechanics of a single polymer chain in dilute solution, a paper that in one stroke founded the modern quantitative understanding of polymer matter, and vaulted soft condensed matter on to the stage of theoretical physics (1). Sir Samuel Frederick Edwards, universally known as "Sam," was a giant of theoretical physics; he passed away in Cambridge, England on May 7, 2015. The problem solved in his 1965 paper (1) addresses the simplest question that one can ask at a fundamental level about polymeric matter: given the number of monomers in a chain, how big is the polymer itself in 3D space? It is also an extraordinarily difficult problem: a polymer chain is almost a random configuration in space, yet it has to respect the constraint that atoms cannot overlap, restricting the positions of the monomers in a nonlocal way and generally resulting in a polymer chain that is somewhat expanded compared with a random walk. Paul Flory, the great polymer chemist, had provided an ingenious heuristic solution to the problem of one chain, but a detailed and systematic understanding remained out of reach. Edwards formulated the problem in terms of path integrals, and solved it in an excellent approximation using self-consistent field theory. Edwards' method would, in time, become the basis for a complete attack on all phases of polymeric matter, not only single chains but dilute and concentrated solutions, disordered phases such as rubber and gels, charged phases such as polyelectrolytes, and even dynamical properties. A decade after Edwards' work, Pierre-Gilles de Gennes would show that Edwards' ideas could be extended to take into account critical fluctuations using renormalization group ideas (2). This approach would be refined in great detail by subsequent studies, allowing accurate computation of universal scaling functions governing the physical chemistry of all polymers in solution and providing excellent agreement with experiment. de Gennes would be awarded the 1991 Nobel Prize in physics for his many contributions to soft matter, but many believed that Edwards' contributions, so frequently linked with de Gennes', deserved similar recognition.

Samuel Frederick Edwards. Image courtesy of the Cavendish Laboratory.

In establishing the deep connections between quantum field theory and the configurations of a polymer chain, Edwards inaugurated a new and sophisticated way of looking at matter that was not simply point-like but extended. He was fond of telling prospective students that "polymers are their own Feynman diagrams," a single sentence that both entranced and bewildered the listener. Indeed, the Edwards style was articulated in an interview given in 1973: "If you can manage to study several subjects, you find there are fruitful relations between them … and you can solve the same problems in a different subject… One can be a very good entrepreneur in this business" (3). Edwards' acts of intellectual arbitrage brought powerful methods from many-body theory, statistical mechanics, and quantum field to bear on a multitude of "dirty" problems that had previously been unjustly dismissed by physicists as outside their purview and perhaps not worthy of consideration. Edwards did not have any such delicate sensibilities. During his career, through courageous and sometimes prodigious efforts, Edwards would make seminal contributions to our understanding of such systems as granular materials, liquid crystals, polymer melts, glasses, turbulent fluids, disordered electronic phases of matter, colloids, gels … even the physics of food! The breadth of his interests was so wide that workers in different fields would sometimes express amazement that "their Edwards" was one and the same person as another Edwards in a completely different field. However, all of his contributions showed a common touch: a dazzling mastery of functional methods, which he wielded with abandon and scarce respect for rigor, a powerful intuition

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for the right and physically correct answer, and a seemingly boundless mathematical creativity.

Of Edwards' many contributions, arguably the most enduring is his theory of the viscoelasticity of polymer melts, delivered as a series of papers (and eventually a book) with Masao Doi. The Doi–Edwards theory was based on the notion that a polymer in a melt is effectively confined by a "tube" formed by the other polymers in its vicinity, and explored the dynamical consequences of this seemingly innocuous idea with great precision and detail. The tube idea originated in Edwards' work on rubber (4), and had been famously adopted by de Gennes in his groundbreaking work on reptation (5), which established the background to the Doi–Edwards theory.

For a different community, Edwards' most influential work was perhaps the formulation and mean field solution of the statistical mechanics of disordered magnets (or spin glasses as they came to be known) (6) using the replica method that he had invented to solve the problem of rubber elasticity. Both problems were difficult because of the presence of hard constraints—random impurities in the former and random cross-links in the latter—but could be treated as the "$N \to 0$ limit" of the thermodynamics of N copies of the original system. This idea has been used in fields as diverse as disordered metals, combinatorial optimization, and theoretical neuroscience.

In another famous paper (7), Edwards initiated the study of growing interfaces, deriving the general statistical properties of interfacial fluctuations. Near the end of his career, Edwards developed statistical mechanical formulations for the properties of granular materials, introducing a characteristic temperature that bears his name despite considerable initial skepticism.

Edwards began his career as a student of Julian Schwinger, working on quantum electrodynamics and the high energy physics problems of the day. Following a postdoctoral year at the Institute for Advanced Study in Princeton, his first academic position was at the University of Birmingham, where he was part of a distinguished group around Sir Rudolph Peierls. Later Edwards moved to Manchester, before joining the University of Cambridge, where he eventually held the Cavendish Chair.

During the 1970s Edwards became increasingly active in scientific policy and administration in the United Kingdom, eventually heading up the Science Research Council, the United Kingdom counterpart to the National Science Foundation in the United States. Edwards received many awards and honorary degrees during his lifetime, including the Boltzmann Medal, the Davy Medal, and the Royal Medal of the Royal Society (of which he was a Fellow). Edwards was knighted by Queen Elizabeth in 1975. Despite the administrative demands on his time, Edwards remained defiantly active and creative in science, deftly wielding his apparatus, "a pencil and paper, and a telephone," and supervising graduate students on the Cambridge-London train.

Sam Edwards leaves behind a remarkable legacy. His students rank among the leaders of condensed matter physics in Europe, the United States, and Japan, many of whom are perpetuating his virtuosity and free-wheeling approach to applying theoretical physics in unconventional areas of science. Edwards' penetrating and creative insights into science remain a dazzling inspiration to those who would expand the domain of theoretical physics, without condescension, into practical problems with an underpinning of deep intellectual challenge.

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