1991 NOBEL PRIZE IN PHYSICS

# Mesoscopic Systems Back into Focus

**J. Friedel, formerly Professor at the Université de Paris-Sud, appraises the significance of the 1991 Nobel Prize in Physics, awarded to Professor Pierre-Gilles de Gennes for the discovery that "methods developed for studying order phenomena in simple systems can be generalized to more complex forms of matter, in particular to liquid crystals and polymers".**

It is a great pleasure for me to present this appreciation of the 1991 Nobel Prize in Physics. Professor Pierre-Gilles de Gennes is, of course, a Frenchman, but he is also a former co-worker and a friend. But, more profoundly, the award recognizes this time, I believe, remarkable achievements in original thinking and in opening new ways to progress science.

P.-G. de Gennes was born in Paris in 1932 into a family with a strong medical tradition. Because of a serious illness, he spent part of his youth during World War II in a small Alpine village before finally entering the Ecole Normale Supérieure, Paris, after taking the entrance exam which normally leads to studies in the biological sciences. This beginning did not prevent him from switching to physics for his "Agregation" competition, which he passed brilliantly, and from starting research in the fundamental physics department of the recently created Commissariat à l'Energie Atomique at Saclay near Paris. I think de Gennes' career shows that a broadly based education need not be a hinderance: in his case, it certainly accounts for a permanent interest in chemistry and biology, a characteristic which was reinforced by his being persuaded to do research by Edward Bauer, a physical chemist having exceptional teaching and human qualities.

### Magnetic Phenomena

When I first met de Gennes, he was preparing a theoretical thesis on the scattering of neutrons by magnetic fluctuations near a critical ordering temperature $T_c$. This was a natural subject as his department was launching experiments in the field under the overall guidance of Yvon, a well-known but very shy thermodynamician. De Gennes applied the Born approximation to an analysis of magnetic fluctuations which had just been developed by van Hove. This was well before one became interested in critical scattering and Wilson's work on renormalization. The work was useful, being applicable as soon as one was not too near $T_c$: I think he developed it by himself, with no intervention by a "patron" as is usually understood for a Ph.D. dissertation.

I used to visit Saclay at the time as a consultant, and took the habit of dropping in to see de Gennes every week. It was clear that he was very attuned to developments and was interested in many questions in solid state physics. He became involved in percolation, a field he was to work on much later, and persuaded a local mathematician to compute approximately the critical concentration in an alloy. De Gennes himself calculated for A. Abragam the part played by spin diffusion in the coupling of nuclei in NMR experiments. I mentioned to him one day that the low resistivities of rare-earth metals had convinced me that the large ff correlations led to a weak exchange scattering of the valence electron by localized magnetic f shells. Could one apply this interpretation to the results he was obtaining for neutron scattering? A few weeks later, de Gennes presented me a paper on this topic, and he politely asked me to co-sign. There soon followed his celebrated paper on the indirect magnetic coupling of f shells by valence electrons *via* their orbital moments,

*Pierre-Gilles de Gennes, the 1991 Nobel Laureate in Physics. Born in 1932 and educated at the Ecole Normale Supérieure, Paris, he joined the theoretical physics department of the Commissariat à l'Energie Atomique, Saclay, in 1955 before taking up a postdoctoral position at the Unversity of California, Berkeley, followed by an appointment at the Université de Paris-Sud, Orsay. He was Professor of Solid State Physics at the University from 1961 to 1971, becoming Professor of the Collège de France in 1971 and Director of the Ecole Supérieure de Physique et Chimie Industrielles de la Ville de Paris in 1976.*

an extension of the analysis by Ruderman and Kittel for a similar coupling of the spin moments of nuclei.

After spending more than two years on military service in the Navy, de Gennes, at my suggestion, was invited by Charles Kittel for a postdoc stay at the University of California, Berkeley, where he did more work on magnetic couplings between f shells.

### Superconductivity

Shortly after de Gennes returned to Saclay at the end of the 1950's, Abragam telephoned me about a post of *Maître de Conférences* which had recently become available at the burgeoning science centre at the Université de Paris-Sud, Orsay, where I myself had recently moved. We decided that I would propose Pierre-Gilles, who was accepted despite severe competition. There followed 10 years of common effort, together with A. Guinier and R. Castaing and a rapidly increasing number of young collaborators, in building up what, I think, was one of the most lively centres for solid state physics at the time.

P.-G. de Gennes' contribution was central. He first convinced me that we should extend our skills to experiments on the electronic structure of solids. He soon switched from magnetism in the rare earths to superconductivity. Very characteristically, he and his group did not work on the microscopic features of the phenomenon, but on its possible spatial variations. Topics included vortex lines in Type II superconductors in an applied magnetic field, the effect of free surfaces (where he obtained a higher critical field $H_{c3}$), superconductivity induced by contact, and tunnel effects between superconductors. The work of the "Orsay group" with C. Caroli, J. Matricon, J.P. Burger, E. Guyon, G. Deutscher, and many others, together with the experimental and theoretical work he inspired at Saclay, his teaching, and his book *Superconductivity of Metals and Alloys* (1966) dominate the field. The approach he adopted derives more from the one of Landau, Ginzburg and Abrikosov than from that of Bardeen, Cooper and Schrieffer, and on a more philosophical level, reminds us of Louis Néel's mesoscopic view of magnetism, or of the kind of approach which had been developed shortly before in the field of crystal dislocations. Finally, there is a very strong analogy between van Hove's description of magnetic fluctuations and the Landau equations for order in superconductors.

### Liquid Crystals

By the end of the 1960's, de Gennes had somewhat exhausted the originality of his approach and was looking for something else. He considered high energy physics, in which Orsay was active at the time, and biology, that was becoming fashionable for physicists. In the latter context, he followed some lecture courses at the Institut Pasteur and we came into contact with the biophysics laboratory C. Sadron had built-up in Strasbourg and was then moving to Orleans. P.-G. de Gennes even started some studies of random walks of chains on a lattice, as a schematic description of polymer or DNA molecules in the entangled conformation.

However, G. Durand, a young polytechnician working in a neighbouring laboratory, had just returned from a postdoctoral stay with N. Bloembergen at Harvard University in the USA, where he had undertaken some optical investigations of liquid crystals. This was the time when industry was starting to investigate the potential use of these materials in optical displays, exploiting the fact that small perturbations in these relatively unstable mesophases produce large distortions, where the characteristic penetration lengths are of optical dimensions. Durand quickly convinced de Gennes of the importance of research in the area and came to lead one of the experimental groups. Meanwhile, a number of theoreticians and experimentalists followed de Gennes in this new venture — at Orsay, Saclay and several other places — and, as before, many foreign visitors participated.

Pierre-Gilles was quick to grasp that, here again, studies on mesoscopic scale were essential, and that many features could be transferred from Type II superconductors: a master equation again described the long-wave distortions from perfect order; line and point defects reminded one of vortex lines; surface conditions and the rôle of applied fields were all-important. Finally, optical experiments and theoretical analyses describing order fluctuations in liquid crystals near a phase transition represented, in a certain sense, direct extensions of de Gennes' work at Saclay on electron or neutron scattering by magnetic fluctuations.

A major advantage of this new venture was the collection around one central focus of a large spectrum of experimental and theoretical abilities. The ensuing book *The Physics of Liquid Crystals* (1974) remains the central reference of a field which was opened up by Lehman, Grandjean and my grandfather G. Friedel in the first quarter of the century, but then lay dormant for nearly 50 years.

### Hydrodynamics and Entanglements

It is now quite clear that the cooperative interactions between elongated organic molecules leading to long-range order with many possible distortions provide a good starting point for configurational and cooperative phenomena such as those observed in biological entities (*e.g.*, membranes and chromosomes). But de Gennes has so far avoided these fields. His more recent interests have mostly been in a number of fields which can be considered as industrial developments of earlier liquid crystal work.

Two major themes can be identified. One concerns hydrodynamic instabilities. His interests here started with the early experimental work of his student E. Guyon at Orsay on Bénard instabilities in liquid crystals, first under thermal gradients, and later under electric fields. This work, together with subsequent work by Rondelez and the theoretical interpretations developed at Orsay, represented one of the first programmes resulting in the application of liquid crystals in displays. It can also be seen as the seminal work leading to the use, by French groups of physicists (Libchaber at the Ecole Normale Supérieure, Bergé at Saclay), of optical means to follow paths to chaotic hydrodynamic instabilities. Subsequent work initiated in the area by de Gennes treats hydrodynamic instabilities in the kinetics of wetting.

The other and, in a way, more important development involves de Gennes' returning to the study of polymers. This time the issues were the statics and kinetics of entanglements of more or less random, long, organic chains, resulting in deviations from pure random walk (since the chains repel at short ranges) and in the very significant influence of solvents. In developing Flory's simple ideas, P.-G. de Gennes has developed a clearer understanding of the various situations, depending on the concentration of polymer molecules. Together with S.F. Edwards, he was the first to introduce the concept of "reptation" to describe how one chain can move out of its entanglement with others without moving them. De Gennes, along with Benoit from Strasbourg and Janninck from Saclay, was for many years a leading spirit in French research in the field, especially in relation to neutron scattering by molecules labelled with isotopes. It now seems well established that the reptation concept is an important feature of many experimental situations, although a more refined description must take into account deformation of the "cage" created by the other chains and the possible rôle of short-range order.

De Gennes has switched, in recent years, to mainly surface problems such as the propagation of plastic cracks in polymers, the rôle of a solid boundary on the disorder of polymeric chains, and the adhesion mechanisms of polymeric glues. Here again, a book *Scaling Concepts in Polymer Physics* (1979) highlights his new interests, which have been pursued in Paris at his laboratory in the Collège de France, where he was appointed Professor of Condensed Matter Physics in 1971, and in laboratories in the Ecole de Physique et Chimie, the celebrated engineering school where Curie and Langevin taught and which he has directed since 1976.

I think what strikes me most about de Gennes' remarkable research effort is the extent to which it has succeeded in tracing a coherent and original path through a succession of new fields — fields he was able to open up or at least broaden very significantly. His successive changes of interest have been a powerful stimulus to younger people who made the effort to follow him (they may have depressed somewhat those he left behind!). In any event, under P.-G. de Gennes, new fields of condensed matter physics have been created and the mesoscopic scale of classical physical chemistry brought back into a focus. Of course this does not mean that fields with either purely macroscopic or microscopic scales should be abandoned.

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