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Pierre-Gilles de Gennes (1932-2007)

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APPRECIATION

Pierre-Gilles de Gennes (1932–2007)

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Pierre-Gilles de Gennes, who died on 18 May 2007, was a giant in twentieth-century theoretical condensed matter physics. He was the winner of the 1991 Nobel Prize for physics, and the citation particularly mentioned his work in liquid crystals, as well as his work in polymers. All members of the liquid crystal community will have felt a vicarious pride in this specific act of recognition of the importance of our field of scientific endeavour.

Many Nobel Prize winners receive their prize for particular acts of scientific valour, for the discovery of *this*, or the invention of *that*. All who achieve this pinnacle of scientific recognition, of course, have achieved a special kind of greatness. However, there are some whose work is *so* outstanding that almost *any* selection from their scientific portfolio could have been cited in support of the award. In this regard, amongst twentieth-century theoretical condensed matter physicists, de Gennes can be compared with very few others, amongst whom one may particularly mention the American Philip Warren Anderson (b 1923) and the Russian Lev Davidovich Landau (1908–1968).

It is appropriate to recall Landau, for in liquid crystal physics, the names of Landau and de Gennes are often so closely bracketed that one is inclined to associate the well-known eponymous theory with a single double-barrelled multinational individual named Landau-de Gennes. The style of Landau was to go to the heart of the problem, make few but profound assumptions, and derive seemingly by magic some robust results. de Gennes' approach bore more than a passing similarity to that of Landau.

There was, however, one key difference, a stylistic distinction that places de Gennes in a more favourable light. For Landau was no writer. Just as Socrates required Plato to articulate his thoughts in ancient times, so Landau required the collaboration of Lifshits to transform his great insights into letters on the printed page of their classic series of textbooks. But de Gennes, by contrast, was a great writer, both in his native French and in the English[1] that he manipulated with such facility.

His scientific *oeuvre* was largely divided into short letters, and long reviews or books. There are much fewer standard intermediate length papers of the type that most workaday scientists write to establish their credentials. Those that there are, are often written with (and also, one suspects, by) collaborators. The letters seem to have been written in the hour or two immediately after finishing the piece of work in question. The scientific writing style is brief, concise and to the point. He explained the key features of the problem, but no more. Likewise he referenced a few vital papers, brutally omitting the long list of marginal experimental and theoretical contributors that good manners requires lesser individuals to include. The *gestalt* is that of a sketch, drawn just after the artist has left the scene, but while the view still remains in his short-term memory. Just as in the case of a master artist, the presence of a few key lines has transformed the paper into a living and breathing organism.

A whole range of obituarists have graphically recorded aspects of de Gennes' personality. There is little that I can add here. I want to concentrate on his scientific career, concentrating mainly, but not exclusively, on his contribution to liquid crystal science. He graduated from the elite *École Normale Supérieure* in 1955, before his 23rd birthday. The first scientific publication in his own list (although it was not quite his first) was a short note on spin waves in ferromagnets (*1*) in the *Comptes Rendus de l'Académie des Sciences* (CRAS, for short), submitted for the meeting of the French Academy of Sciences on November 12, 1956. His last, more than 600 papers and almost 53 years later, was published posthumously in the *Journal of Fluid Mechanics* in August 2008 (*2*).

In between, there was a roller-coaster of a career. By 1957 he had a PhD. de Gennes's first publications concerned the properties of magnets. Soon, however, his catholic interests began to show themselves. By late 1958 (at the age of 25) he was already submitting papers on ionic crystals, correlations in compressed gases and transport in disordered materials. When, in 1961, he returned from a postdoctoral period at Berkeley under the distinguished solid state physicist Charles Kittel to a post in France, he began studies in

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superconductivity. These led to a highly influential monograph, published in 1964 (*3*).

No sooner had he achieved fame in superconductivity, than he was off again. In 1966 there was a paper on turbulent flow (as well as six other papers on superconductivity). In 1967, we find more papers on superconductivity, his first papers on polymers, together with papers on the denaturation of DNA and the vibration spectra of hydrogen bonds. On 18 December 1967 came his first output in the liquid crystal field: a short note at a *Séance* of the Academy of Sciences in Paris (in French) entitled 'Orientational fluctuations and Rayleigh scattering in a nematic crystal' (*4*). This short two-page note is the first to show that director fluctuations are essentially long-ranged. They decrease with distance R only very slowly, as R^{-1} in fact. A finite correlation length is only introduced in the presence of a magnetic field. This paper is also marked by its slightly contemptuous tone. 'Orientational fluctuations in a liquid crystal', it begins, 'have been most often discussed in terms of "swarms", whose meaning remains rather vague'. The swarms, he tells us, had been invoked by Gray, Chistyakov and Chatelain, but never again. In a couple of lines the swarms had been summarily eliminated from scientific literature forever.

de Gennes' *Liquid Crystal Period*, if we can call it that, was extremely short – just 41 papers, covering the period from 1968 to 1976. In addition, there was the overwhelmingly influential *The Physics of Liquid Crystals*, written so fluently (in English to reach the maximum audience), and published by Oxford University Press in 1974 (*5*). The fading yellow cover can still be found on academic bookshelves the world over, even if it is sometimes supplemented by the red and blue cover of Prost's 1993 revision. However, even during this period, he was not fully focussed on liquid crystals. In addition to his liquid crystal work, there was ground-breaking work in polymer dynamics, a widely cited renormalisation group calculation of the critical exponents of a self-avoiding walk (one case where he did allow himself some difficult mathematics, if only to confirm the results of a back of the envelope calculation), and some collaborative work on the then hot topic of superfluid He^3. However, after 1976 his attention was fully taken by other matters, and subsequent papers on liquid crystals always contained polymer or gel aspects. At least from our point of view, there was a puff of smoke, and the magician was gone.

His subsequent work ranged over different aspects of what the de Gennes group called 'Soft matter': the physics of different kinds of gunge. The studies of polymers were joined by wetting and surface problems, which in turn gave way to granular materials, adhesion, friction, and finally in the years preceding his death, a number of studies in biology. New subjects required a new view on old material, and he produced a number of ground-breaking monographs, including *Scaling Concepts in Polymer Physics* (1979), *Simple Views on Condensed Matter* (1998), and *Capillarity and Wetting Phenomena: Drops, Bubbles, Pearls, Waves* (2002).

Although the pioneers in liquid crystals were almost all German, many of the major advances in the interwar period were made in France. The basic paradigm (and indeed much of the terminology), that the *nematic* phase is an oriented liquid, and the *smectic* phase is a layered phase such that within the layers the molecules contain no positional ordering, is due to Georges Friedel (1866–1933). Friedel was a scion of one of the most famous French scientific families; his grandson Jacques Friedel (b 1920), later president of the French Academy of Sciences, was one of de Gennes' early advisors. Friedel's groundbreaking 1922 article *Les états mésomorphes de la matière* (*6*) was compulsory reading for de Gennes as he began to think about liquid crystal problems. His 1974 textbook shows that he had read all of the early works carefully. The highly developed tradition of liquid crystal studies in France served as a stimulus for further progress.

The influence of de Gennes's work in liquid crystals has been massive. His most highly cited liquid crystal paper (*7*) was published in *Molecular Crystals Liquid Crystals* in 1971 and originally presented as a talk at the International Liquid Crystal Conference in July 1970. This paper, which establishes what has come to be called the Landau–de Gennes Theory, is an exemplar of the de Gennes method. He defines the order parameter, and then uses the general Landau method to introduce a free energy expansion in terms of the order parameter close to the nematic–isotropic transition. A pedestrian theorist might then stop, or concentrate on higher-order terms in the expansion, or otherwise stray from the central theme, but de Gennes focuses in a broad-brush way on the experimental consequences of his model. Spatial correlations are linked to optical scattering above T_{NI}. The elastic theory is linked to a baby theory of the nematic–isotropic interfacial boundary conditions and surface tension. By using the ideas of Onsager, he was able to make a minimal sketch of the dynamical theory. Then he can addressed flow birefringence and inelastic light scattering, as well as the coupling of flow with order parameter relaxation modes[2] (*8*). Not content with this, he continues by generalising the theory to cholesterics (now, as I understand, it a forbidden term), treating Bragg scattering and optical rotation in the pretransitional regime.

There are 662 citations of this paper recorded by the Web of Knowledge. Mere mortals would of course be pleased by such a high citation count. It is likely that de Gennes did not concern himself with such trivial indicators of excellence. Bureaucrats require indicators of excellence because (like computers) they have no criteria with which to recognise its intrinsic meaning. Be that as it may, mortals also take an interest in these stellar details, which are the scientist's replacement for the glossy staged pictures of *Hello* magazine.

It turns out that the 662 citations (of which 11 occurred in 2008) place it a mere seventh in the list of de Gennes' papers. It transpires in fact that the period 1971–1972 was a bit of an *annus mirabilis* for de Gennes. A further 611 citations (no. 10 on de Gennes' pantheonic list) are recorded for his 1972 paper (*9*) noting an analogy between the smectic A phase and superconductors. The analogy arises from the existence of a local phase, which may describe either the position of the smectic layers or the phase of the macroscopic superconducting wave function. Meanwhile, his work in other areas was also steaming ahead. His 1972 paper in *Physics Letters A* on the renormalisation group approach to the critical exponents (*10*) of the self-avoiding walk has attracted 746 citations (no. 6 on the list) and a 1971 paper in the *Journal of Chemical Physics*, introducing the idea of *reptation* (the wriggling necessary for a polymer to escape the cage imposed by its neighbours) (*11*) and creating a paradigm for polymer dynamics, has been cited a massive 2620 times (no. 2 in the list).

Several other papers during de Gennes' liquid crystal period had lasting influence. A paper with Brochard in 1970 introduced the idea of *ferronematics*: magnetic colloids in a nematic matrix (*12*). The idea was to amplify the (normally rather weak) coupling between the liquid crystal director and a magnetic field through the intermediary of magnetic colloidal particles, which couple sterically to the nematic. There has been a certain amount of success in making this effect work with lyotropic liquid crystals, while in thermotropics, the field remains very active. A number of papers were concerned with topological defects, either in smectics or in nematics, a field that retains interest to this day, given that both mathematical and experimental methods have become more sophisticated. It was de Gennes who famously proclaimed that he was 'disinclined to be disinclined', and in so doing changed forever Charles Frank's 'disinclinations' into the 'disclinations' that they seem to remain. A paper on the correct description of viscous flow in smectic liquid crystals kept the applied mathematicians busy for years. Finally, two late papers with Dubois-Violette (*13*) in 1975 and 1976 discussed surface anchoring driven not by steric effects, but rather by longer-range van der Waals interactions. Interestingly, very recent experimental work seems to bear out this idea.

Charles Frank's death in 1998 called for a re-evaluation of his liquid crystal work. A key point is that almost all of his work was done in fields remote from liquid crystals, but that the catholicism of his interests enabled him to contribute significantly all the same. Likewise, in the case of de Gennes, the liquid crystal community only borrowed the talents of a maestro for a brief period, but the period was long enough for him to infuse the community with an enthusiasm from which, fortunately, it has yet to recover. We salute the master's talents and grieve at his premature death[3] (*14*).

Notes

1. There is a (perhaps apocryphal) story of de Gennes arriving in Rome to give a talk, and offering to give it in English, French, or Italian. The audience chose English. de Gennes was subsequently questioned by a fellow conferee as to his competence in Italian. He admitted that his Italian was insufficient to sustain the conference talk, but that good manners required him to offer nevertheless.
2. The flow-order parameter relaxation coupling, pioneered in an earlier paper in collaboration with Parodi and Dubois-Violette, is an alternative way of viewing the backflow of the Leslie–Ericksen theory. The opposing viewpoints led to some considerable dispute in the late 1960s and early 1970s. With the passage of time, it is interesting from the point of view of the history of science to compare the approaches of the intuitive theoretical physicist de Gennes with that of the rigorous applied mathematician Leslie. In the end it turned out that the two were more or less equivalent.
3. A list of de Gennes' publications can be found in the preface to the *J. Phys. Chem.* de Gennes special issue: http://pubs.acs.org/doi/full/10.1021/jp9011894. This list includes 609 research publications and 10 books.

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