

Laudatio Lorentzmedaille P.G. de Gennes 1990

Mister Chairman, Ladies and Gentlemen,

The Selection Committee for the Lorentz Medal has asked me to present the motivation for awarding the 1990 Lorentz Medal to Pierre-Gilles de Gennes. I am honoured by this request and as a member of the Institute-Lorentz it is for me a particular pleasure to be assigned the task of presenting this Medal, which bears the name of our most distinguished Dutch theoretical physicist.

Lorentz had the reputation that he knew everything in physics in his time. If anybody now would have to be named with a similar grasp on condensed matter physics, it would be certainly you, Pierre-Gilles de Gennes. Because of your contributions, which in so many respects have led to a renaissance in condensed matter physics, you have been called the Landau of the West, after Lev Landau, the last of the heroes in physics, who made also such a profound impact on condensed matter physics.

Therefore I realize that it is an almost impossible task to do full justice to your scientific achievements. Rather than trying to be exhaustive, I would like to elucidate your discoveries with a number of highlights in your scientific work, the selection of which bears unavoidable a personal appreciation.

You started your research around 1955 at the Ecole Normale Supérieure and at the CNRS center in Saclay with the study of neutron scattering. The theory of neutron scattering had been formulated by Leon van Hove, one of the members of the Selection Committee for the Lorentz Medal, whom we lost so tragically due to his untimely death last August. Van Hove expressed the scattering intensity in terms of the time-dependent correlations of the scattering medium. A beautiful connection, which made neutron scattering into a tool to investigate these correlations. But at the time few means were available to calculate these correlations from the interparticle forces and so the theory was dormant for a while. In your paper in *Physica* you showed how frequency moments of the dynamic correlation functions can be expressed in static correlations, which are much more amenable to calculation. Thus you predicted and explained the narrowing of the diffraction peak with increasing wave number. This phenomenon is now known as the de Gennes' narrowing. This contribution signalled already your talent to revitalize an old field by subtle and transparent arguments and to translate theory into observable phenomena.

The second highlight, upon which I would like to focus, is your contribution to superconductivity, while you were professor at Orsay. Superconductivity is an old field. It started in 1911 with a number of Communications to this Academy by Heike Kamerlingh Onnes. Around 1962, when you gave an introductory course on superconductivity at Orsay, many important contributions were made and in fact some people considered the problem of superconductivity solved by the theory of Bardeen, Cooper and Schrieffer and the subsequent unification by Gorkov of the BCS theory and the description of the Russian school of Landau and Ginzburg. Your intention with the course at Orsay was, I quote from the preface of your book on superconductivity, "to set up basic knowledge of superconductivity both for experimentalist and theoreticians in a small group (including the lecturer) and from there on to plan experiments".

Rather than trying to set up a grand theoretical scheme, you continue, “we wanted in Orsay to start real experiments more urgently than experiments in teaching”. This attitude is unusual for a theoretician, but it has proven to be extremely successful. Indeed it has triggered beautiful experiments, but in retrospect, I think that your approach has been an even greater experiment in teaching. It is due to your teaching that in the West the real power and implications of the Landau-Ginzburg description have been appreciated.

Your interest focussed on the penetration of the magnetic field in a superconductor, which has been a most intriguing feature for a long time. Meissner showed that superconductors expel the magnetic field by a surface supercurrent, turning superconductors into ideal diamagnets. When the field approaches a critical value H_c , the field penetrates and destroys superconductivity. This simple picture applies to what is now called superconductors of the first type. In type II superconductors, the field can penetrate without destroying superconductivity in a range of fields between H_{c_1} and H_{c_2} . The existence of such a mixed state, with coexisting magnetic field and superconductivity was discovered by Lev Shubnikov. In your book you refer, unlike others, to the mixed state as to the Shubnikov state, giving credit to Shubnikov, this unfortunate physicist, who became victim of Stalin’s terror shortly after his discovery in 1937. He was sentenced and died in 1945 and he was removed from the Russian history. It is only recently that his physics department in Charkov could devote a book to the memory of this great physicist.

But you showed that the magnetic flux penetration is even more intricate than the existence of two boundaries H_{c_1} and H_{c_2} in the field-temperature plane. In a paper with Saint-James you demonstrated that superconductivity nucleates at the boundary of the specimen at an even larger field H_{c_3} , which you could calculate precisely from the Landau-Ginzburg equations. All this followed, because you were the first to formulate the boundary condition, which has to be imposed on the superconducting wave function. By studying the effects of the boundary conditions, you showed the richness of the Landau-Ginzburg description, pointing to new phenomena, which were subsequently discovered in Orsay.

Boundary superconductivity is particularly interesting because it is a realization of gapless superconductivity. Gapless superconductors were a shock to those who thought that the gap in the excitation spectrum was the hallmark of superconductivity in the BCS-theory. Along this line I would like to mention your beautiful calculation with Caroli and Matricon on the excitation spectrum in the core of a flux tube, showing that very low-lying excitations occur, which play a central role in the transport and relaxation phenomena at low temperatures. The dynamics of flux lines turns out to be *the* important ingredient in the technical applications of supercurrents, where the field is, of course, not permitted to destroy the superconductivity.

Superconductivity could not keep your attention very long, since your interest developed towards the field of liquid crystals, a subject that was shunned by most physicists, because the liquid crystal systems are composed of non-trivial chemical compounds. Moreover the study of liquid crystals requires the knowledge of several disciplines as chemistry, optics and mechanics. But you

seem to have a particular pleasure in comparing the theories of different fields. Lecturing on a subject is for you a way to develop it. Thus you demonstrated that liquid crystal theory is not a dull and complicated subject but a very rich and spectacular field.

A highlight in this pursuit is certainly your discovery of the close connections between superfluidity and superconductivity on the one hand and liquid crystal behavior on the other hand. In both fields, the key is the identification of the order parameter of the system. In superfluids this is the condensate wave function. For liquid crystals the director field plays the central role. Now you noted that in the smectic-A to smectic-C transition one has a transition from an uni-axial to a bi-axial system and this can be described by a two-dimensional rotation, which is equivalent to a complex number. A rotation in the director field is directly observable and in fact can be made visual by optical methods. This means for instance that spatial correlations in the director field can be measured optically, allowing to determine critical exponents which are more difficult to measure in the superfluid transition in superfluid Helium. In fact with a magnetic field one can force a rotation of the molecular axis and near the transition the system becomes singularly sensitive to such influences, which makes the associated critical exponent directly accessible to experiment.

But you discovered an even more elegant analogy between superconductors and liquid crystals. The superconducting order parameter is the wave function of the Cooper pairs. This complex field is coupled to the electromagnetic field since electrons are charged. You noticed that the free energy expression for a liquid crystal near the transition of the smectic-A to the nematic phase has a form which is similar to the Landau-Ginzburg expression for the free energy of a superconductor. Smectic liquid crystals have a layered structure, which makes the density a periodic function of the position. The phase of the Fourier components of the density is a measure for the smectic order parameter, indicating the position of the layers. Again this is a complex field and it is coupled to the director field in the same way as the superconducting wave function is coupled to the vector potential.

This correspondence prompted you to introduce the notion of a coherence length and a penetration depth for liquid crystals. Even the notion of type-II superconductors can be carried over to liquid crystals. The magnetic field for a superconductor corresponds to a bend deformation of the director field. So if a liquid crystal is deformed at the boundaries, one can have a finite penetration, shielding the bulk from the deformation, or even a Shubnikov phase may appear, where a network of dislocations forms itself. The flux quantization is also realized in liquid crystals, since the contour integral of the director field is necessarily an integer.

No wonder that, after the discovery of such beautiful analogies, the physics community became interested in liquid crystals! Thus the liquid crystals display the richness of both superconductors and superfluids. It takes however your courage and insight not to be scared off by many possible complications and pitfalls that occur in liquid crystal physics.

Your third big scientific endeavour is the study of polymers. Again an old field which did not appeal to much to the imagination of physicist, until you

became interested. Your interest was aroused by two experimental developments:

- the possibility to do neutron scattering on polymer solutions;
- the self-beat technique for inelastic light scattering due to the availability of lasers.

Neutrons can detect correlations on a temporal and spatial scale which were inaccessible before. In principle X-ray diffraction would reveal the same spatial correlations, but polymers become completely transparent at these wavelengths of electromagnetic radiation. Increasing the contrast by substitution of the polymer atoms by heavy atoms, destroys the motion and the space filling of the polymers, often leading to spurious separation between labeled and unlabeled species. The neutron scattering contrast, however, can be increased by mild substitution of the hydrogen atoms by deuterons.

The advent of the laser opened the study of polymer motion in a frequency range from 1 to a million Hertz, which is precisely the range of the overall motion of polymer chains. Zooming in on these frequencies by the self-beat method, eliminates also the signals of the omnipresent dust, which contribute due to their immobility only to the elastic scattering and had hitherto spoiled the scattering from polymers.

You suggested that the polymer chains move like a reptile through its environment. In entangled polymers a chain is hindered strongly in its motion by its surroundings, which you visualized as a tube around the chain. The main motion is to crawl through the tube as a reptile. By simple argument you could show how long it takes to have a complete renewal of the tube and this time is the scale for the cross-over from elastic to viscous behavior. Thus you provided with the idea of reptation a transparent understanding of the visco-elastic behavior of polymers.

The main theme of your work on polymers is the introduction of the concept of scaling in polymer theory. It was noticed before by Flory that properties of polymers may depend in a singular way on the length of the chain or the number of monomers out of which the chain is composed. Following a polymer in space is like performing a random walk, with the important complicating feature: the polymer never intersects itself, so the random walk is self-avoiding. The mean square displacement is a strange power of the number of steps and so is the end-to-end distance a strange power of the number of its number of monomers. Such powers are reminiscent of critical singular behavior. At the time that you became interested in polymers, the theory of critical phenomena witnessed a breakthrough and you have carried over the machinery of critical phenomena to polymer physics.

The theory of critical phenomena has its origin in the thesis of Johannes Diederik van der Waals on the "continuity between the gaseous and liquid state" in 1874. Landau put the van der Waals theory in a more general context by introducing the idea of an order parameter. This was a perfect theory with only one shortcoming: that it did not match with the observation. The breakthrough, to which I alluded, came from Kenneth Wilson in 1971, who showed

how the Landau theory could be corrected by taking the fluctuations of the order parameter into account. Within a few months you showed how to extend this to polymer theory.

The charming aspect of critical phenomena is that a number of properties is independent of the molecular interactions. Such universal quantities are determined by the long-wavelength fluctuations and are therefore not sensitive to the precise short-range interactions between the particles.

From critical phenomena to polymers is a long way, amongst others because the critical singularities come out only sharply in the thermodynamic limit of infinitely large systems, while polymers may be long, but are always finite in length. The clue for the connection that you gave, was the observation that a finite polymer is nearly critical in the same way as a magnetic system close to its Curie point is nearly critical. This would in itself be sufficient to use the scaling concepts in polymer theory, but you showed that the analogy with magnetic systems runs even deeper. The order parameter in a magnetic system is the magnetization, which tells how much the magnetic moments align with each other. The magnetic moment is a vector and the order parameter has three components. Not always are the three components equally important. Anisotropies may reduce the order parameter to two or even one component. As I mentioned earlier, liquids crystals, superfluids and superconductors may be described by a two-component order parameter. You came to the bold conclusion that the order-parameter field for polymers must have zero components! I do not think that anybody can visualize a field with zero components. The way to understand the statement is to consider the general theory for an n -component order parameter and its graphical representation. Then the limit $n \rightarrow 0$ selects precisely the graphs which are self-avoiding random walks and therefore qualify as non-intersecting polymers. This seemingly academic theorem has been extremely fruitful in the study of polymers. It means amongst others that one has the whole machinery of hamiltonian field theory available for the study of polymers.

In your beautiful short Physics Letter in 1972, you showed not only that one has to take the limit $n \rightarrow 0$, but also how the polymer exponents can be obtained from the ϵ -expansion and that Flory's value, which was conjectured to be exact, is accurate but still approximate. And this was published a month after the ϵ -expansion had appeared in the literature and without any advertising jargon of being "important", "novel" or "breakthrough", that nowadays seems necessary to have something printed in prestigious journals.

Bringing the polymers in the family of critical systems has enriched the critical theory, but more importantly, it has brought ordering and perspective in polymers physics. In phase transitions the critical point is an exceptional point, which is difficult to reach. Respectable polymers are long and so all polymers are nearly critical and their dominant behaviour is indeed given by scaling laws. In your book on the scaling concepts in polymers, which appeared in 1979, you have achieved an admirable degree of coherence for a work of such scope, summarizing a decade of fruitful research by you and your associates in Paris, Saclay and Strassbourg. By keeping steadfastly your eyes on the on the universal features and striving always for simple and transparent expla-

nations for basically complex phenomena, you have made the field accessible to many physicists.

Your position at the Collège de France requires that you give each year a new course on a subject of your choice. You have used this opportunity to regularly change your interest in physics. Recently you have been lecturing on colloidal systems, solid-fluid interfaces, random media, polymers at interfaces, wetting and the mechanism of adhesion. Lecturing means for you also developing and organizing a field, and every time your interest in a field has led to a renewed interest in the physics community of that area.

Mister Chairman, as I said in the beginning it is impossible, within the proper limits of time, to do full justice to our Laureate's achievements in all these fields. Allow me therefore to close with a few general remarks on the style of his work, which struck me in going over his papers.

The mainstream of physics seems to put more value on abstract reasoning and exotic phenomena. You, however, seem in your later work to have more pleasure in unraveling the physics closer to daily life. After having invented such abstract notions as zero component order parameters, you can write with equal enthusiasm on the intricacies of such common features as the spreading and shape of droplets!

Nowadays industrious people, wanting to measure the impact of scientific contributions, have developed subtle tools to rate the journals on their impact. In your choice of scientific journals, you do not show any preference for so-called high-impact journals; if you have any preference, it is definitely for European journals. You have certainly not suffered from the fact that your papers remained unnoticed. It shows that quality is the only criterion for real impact.

In our country, as in many places, we have a continuing debate in the universities whether teaching or research should be our main concern. Your scientific style shows that teaching and research do not have to compete, but can be brought into perfect harmony. The same is true for the distinction between theory and experiment. Although both have their own methods and require different skills, your work has shown that strong interaction between theory and experiment is very fruitful. In the preface of your book on liquid crystals you call yourself a semi-theorist, indicating your role as intermediary between theory and experiment. This is presumably the ideal position, but it is reserved for only a few of your stature.

Your contributions to superconductivity, to liquid crystals and to polymers, of which I have sketched only a few highlights, would be each ample reason to award you the Lorentz Medal. Therefore it is a triple satisfaction for me to present to you, on behalf of the Royal Netherlands Academy of Science, the Lorentz Medal.

J.M.J. van Leeuwen