INTRODUCTION

This volume contains a number of my lectures, given over the years at several schools and conferences, together with some research papers that are meant to complement them. The lectures are naturally grouped into three subjects that have been the main themes of my research: *Field Theory, Disordered Systems and Computer Simulations.*

Field Theory

The status of quantum field theory is now quite different from what it was when I started to work in physics. At that time, relativistic quantum field theory, with the exception of perturbative quantum electrodynamics, was considered to be an ill-defined and "dangerous" field. In the early seventies, the situation changed dramatically: theoretical and experimental progress demonstrated that quantum field theory is a necessary description for strong interactions. Moreover, the work of Wilson showed that the theory of strongly interacting fields can be controlled in the nonperturbative region, and that one can predict the critical exponents for second-order phase transitions.

The first lecture of the section devoted to field theory (originally written for Cargese 1973), "Field Theoretic Approach to Second-Order Phase Transitions in Two- and Three-Dimensional Systems," contains a full discussion of the method used to compute critical exponents using renormalization group ideas and the Callan–Symanzik equation. This paper is particularly interesting because it contains the first field theoretical computation of the critical exponents at fixed dimensions, without using the epsilon expansion in $4-\varepsilon$ dimensions. In the second paper, "On Nonrenormalizable Interactions," the methods described in the first are applied to the nonperturbative construction of nonrenormalizable interactions.

In "An Introduction to Scaling Violations," one finds a simple introduction to the theory of quantum chromodynamics and to the perturbative computations (based on the renormalization group) which can be done in the short-distance region.

"The Physical Basis of the Asymptotic Estimates in Perturbation Theory" is a presentation of some of the main results obtained in the study of the large-order behaviour of perturbation theory and related problems (e.g. Borel resummability). Perturbation theory is our main tool for studying field theory, and it is crucial to understand its limits and its convergence. "Critical Exponents and Large-Order Behaviour of Perturbation Theory" is an application of the techniques described in the previous paper to the computation of critical exponents using the renormalized perturbative expansion.

"The Borel Transform and the Renormalization Group," "Singularities of the Borel Transform in Gauge Theories" and "On Infrared Divergences" are, respectively, a short lecture and two papers devoted to the study of the large-order behaviour of perturbation theory (or equivalently of the singularities of the Borel transform) in renormalizable theories, where new phenomena are present. The case of asymptotically-free field theories is studied in detail.

"Quartic Oscillator" is related to the previous papers: it deals with the convergence problems of an asymptotic expansion in a quite different context: one studies the properties of the WKB expansion for a one-dimensional Hamiltonian with a potential equal to x^4. Finally "Trace Identities for the Schroedinger Operator and the WKB Method" is a short related paper in which one derives the trace identities for the same Hamiltonian.

Disordered Systems

My best contribution to physics is possibly the theory of broken replica symmetry that was first constructed in order to solve the spin glass model with long range interactions. This theory is rather complex and contains some points that are still not fully understood. The theoretical approach based on broken replica symmetry is quite general, and has been successfully applied to many other systems, like neural networks and interfaces in random media.

In "An Introduction to the Statistical Mechanics of Amorphous Systems," one finds a full discussion of the replica method as applied to spin glasses, to stochastic differential equations and to localization in disordered systems. The theory of broken replica symmetry is described in detail.

Stochastic differential equations are also the subject of the next paper, "Supersymmetric Field Theories and Stochastic Differential Equations." Here it is shown how some stochastic differential equations yield to relativistically invariant probability distributions.

"Spin Glasses and Optimization Problems Without Replicas" contains the reformulation of the broken replica theory in probabilistic terms using a self-consistent method (called cavity approach). The techniques used here are much more standard from a mathematical point of view: the replica method is not used and the dimensions of matrices is never smaller than 1.

While in "Spin Glass Theory" one finds a short technical review of spin glasses, in "On the Emergence of Tree-Like Structures in Complex Systems," the main results of the theory of spin glasses are presented using plain language; indeed this contribution was aimed at a nonspecialized audience.

The paper "On the Multifractal Nature of Fully Developed Turbulence and Chaotic Systems" has nothing to do with spin glasses. Rather, it contains a different, more geometrical, approach to some disordered systems, based on the new concept of multifractals.

Simulations

Computer simulations in physics play a role that is intermediate between experiments and theory. Indeed, when one wants to explain a new phenomenon in a complicated setting, one first proposes a simplified model which one tries to analyze theoretically. Computer simulations, when possible, are extremely useful for understanding the properties of a new model for many reasons.

- They allow a comparison between the predictions of the model and the experiments. In this way, it is possible to find out whether the proposed model is adequate in describing the experimental data.
- Theoretical predictions for the result of the computer simulations can be done in a rather simple setting where there are no doubts on the correctness of the chosen Hamiltonian. In computer simulations, every quantity is directly accessible to measurements, and this feature allows a more severe test of the theory.
- Sometimes the system is so complicated that no detailed theoretical predictions can be done for some quantities. This is the case of quantum chromodynamics (QCD), where quantitative predictions on the hadronic spectrum may be obtained only via numerical simulations.

The main subject of the remaining lectures is numerical simulations for QCD. This subject is studied from different points of view: general theory, real simulations and construction of dedicated hardware.

"Recent Progresses in Gauge Theories" is a simple introduction to gauge theory and numerical simulations, written at the time of the first numerical computations for lattice gauge theories.

"The Strategy for Computing the Hadronic Mass Spectrum" and "Prolegomena to Any Future Computer Evaluation of the QCD Mass Spectrum" are two lectures written when first generation simulations were already done and the people involved were examining, with a critical eye, all possible sources of systematic errors and trying to find the best strategy for reducing the statistical error.

"A Short Introduction to Numerical Simulations of Lattice Gauge Theories" and "Principles of Numerical Simulations" are two lectures in which the general principles of numerical simulations are exposed; some of the more recent results for lattice gauge theories are also presented.

In "The APE Computer: An Array Processor Optimized for Lattice Gauge Theory Simulations," one finds a description of the APE computer (hardware and software). The results that have been obtained using this very powerful computer (10^9 floating point operations per second) have been presented in some of the previous papers.

"The APE–100 Computer: (I) The Architecture," contains the description of the architecture and the general principles of software for the new generation APE–100 computer that should reach the speed of 10^{11} floating point operations per second. At this time, a prototype of a section of APE–100 has been constructed; it reaches the speed of 6×10^9 floating point operations per second.

The list of people to whom I have been scientifically indebted in this twenty-year period is too long to be inserted here. I thank all of them warmly. I also thank the organizers of the congresses and schools where I have presented the material collected here. In particular, I am grateful to the organizers of Cargese and Les Houches, who have been so kind as to invite me so many times.