Time-Dependent Effects in Disordered Materials

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PREFACE

This volume comprised the proceedings of a NATO Advanced Study Institute held in Geilo, Norway between 29 March and 9 April 1987. Although the principal support for the meeting was provided by the NATO Committee for Scientific Affairs, a number of additional sponsors also contributed. Additional funds were received from:

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This Study Institute was the ninth of a series of meetings held in Geilo on subjects related to phase transitions and was a natural successor to the 1985 meeting on Scaling Phenomena in Disordered Systems. Many of the subjects discussed at the latter meeting were revisited in 1987, with time dependence as an added feature. Often the common theme was the concept of fractals first introduced into statistical physics some six years ago. However, by no means all disordered systems can be forced into a fractal framework, and many of the lectures reinforced this lesson.

One of the main lines of research on fractals has been concerned with the study of the physical mechanisms responsible for the manifestation of fractal geometry in nature. The color plates at the front of this volume show two pertinent examples: fluid flow in a porous medium and electrodeposition. In the former case, the study is motivated by a practical concern to describe the displacement of a viscous fluid (oil) by a less viscous one (water) in a porous medium (rock). Under suitable conditions the patterns of displacement generated bear a remarkable resemblance to computer simulations of diffusion limited aggregation (DLA). The same remark applies to the color pictures of electrodeposition and to many other phenomena, suggesting the existence of universality among growth patterns. At Geilo, the emphasis was not on those patterns *per se* but rather on their time-dependent properties. The original DLA model involves a time-ordered sequence of (growth) events but is not explicitly time-dependent. However, the kinetics of this and other growth processes have been explored extensively by computer simulation and many of the results are discussed in this

volume. Experimental studies of growth kinetics are also reported for DLA-like systems in which the distributions of growth probabilities on the cluster surface can be described in terms of a multifractal distribution. Such distributions occur whenever a measure is placed on a fractal structure and have been used, for example, to analyze the onset of turbulence.

Both of the structures shown in the color plate involve growth in a field which obeys the Laplace equation. As for models which describe thermal or geometric critical phenomena, the Laplace equation insures that local fluctuations propagate over a much larger length scale. Although the analogy with phase transitions is still somewhat ephemeral, the properties of several variants of Laplace-equation growth have been studied in detail. This compilation is probably a prerequisite for the recognition of universal behavior. One model discussed at the meeting is that of dendritic growth, apt in view of the snowflake density at Geilo in March. It is quite clear both from the computer studies of this problem and from experiments on colloidal aggregation that the patterns formed depend sensitively on the local growth probabilities. The work on colloidal aggregation also demonstrates that the rate of accretion plays a crucial role in determining the ramification of resulting aggregates. In keeping with the "time-dependent" theme of the Study Institute, results for colloidal aggregation and electrodeposition were presented as films, allowing local details of growth processes to be observed first-hand. A real-time experiment involving a vertical Hele-Shaw cell in a slide projector nicely demonstrated viscous fingering of a "Newtonian fluid" of micron-sized polystyrene spheres in water.

The study of the dynamics of pattern formation, in which ordered structures develop from an initially disordered state, is by no means limited to models of aggregation. First order phase transitions involve kinetic processes such as nucleation and growth in addition to spinodal decomposition and coarsening. Universality classes for this dynamical behavior are imperfectly understood but the scaling behavior of several models has been determined. Computer situations presented at the Study Institute demonstrated that growth kinetics, microstructure and topology can be understood in terms of the Potts model.

The phenomenon of $1/f$ noise is ubiquitous: it can be associated with the flow of sand in an hour glass, with the spectral distribution of starlight and with the flow of water in the river Nile. It is generally argued that this diversity precludes a universal origin for the noise. Nevertheless, progress in localization theory seems to provide some insight and recent results were presented at the School. It was argued that a comparative study of magnetic and electrical noise might help in the understanding of the physics of spin glasses.

Various aspects of spin glass models were presented at Geilo and connection was made to the notion of hypermetricity and the study of neural networks. Although hypermetricity has

been a familiar concept to mathematicians since the turn of the century it only appeared in physics three years ago. In an ultrametric set there are no points intermediate between any pair of points. A classical example of this feature occurs in the taxonomy of living species. Such classifications are often represented as inverted hierarchical trees in which the branching points, representing the discrimination between two species, occur at successive times. Any natural definition of the distance between two extant species is proportional to the age of their most recent common ancestor, that is, to the time elapsed since branching occurred. This distance is found to obey the ultrametric inequality stated above for pairs of points. The fascinating lectures on hypermetricity presented at Geilo by Gerard Toulouse were based on a recent review of this subject by Rammal, Toulouse, and Virasoro (Rev. Mod. Phys., 58, 765-788 (1986)). We have chosen not to contribute to the proliferation of duplicated papers by including this article in these proceedings, but advise interested readers to consult the very well-written original paper.

The theory of neural networks was invaded by physicists about five years ago and the subsequent emphasis has been on the application of techniques of statistical mechanics to memory nets which perform pattern recognition tasks. Various models for memory have been proposed with different learning rules and degrees of error tolerance. The ultimate memory capacity of a neural system of a given size depends on the model, as does the occurrence of such tragedies as the confusion catastrophe. In spite of its deficiencies, statistical mechanics has contributed to a wider understanding of neural networks and has provided surprising insight related, for example, to the existence of spurious states and phase transitions. Correspondingly, neural-network theory has broadened the scope of traditional statistical mechanics by spurring interest in non-Hamiltonian systems, multi-valley analysis, sizes of attraction basins, etc. Von Neumann's forty-year-old prediction that the theories of computing would move closer to thermodynamics seems to be verified.

Although the relationship between spin glasses and real (window) glass is not at all clear, the dynamics of both systems are relevant to a school on time-dependent effects in disordered systems. The glass transition itself is not limited to special systems since any class of materials can be prepared in amorphous form if the cooling rate is adjusted to the dynamics of the material. In this proceedings, a discussion of the glass transition in polymers is presented with particular emphasis on an understanding of the Vogel-Fulcher law, which describes the relaxation time in such systems. The subject of polymer dynamics is also treated in relation to the sol-gel transition and the dynamics of sol clusters. In this field, light-scattering measurements have provided detailed data which can be compared with scaling predictions. The combination of inelastic light scattering and dielectric relaxation measurements also yields information on the non-linear response of dipolar glasses, once again yielding the ubiquitous Volker-Fulcher behavior.

At this school, there was an unprecedented number of contributed papers, most of which were presented as posters in order to respect the allotted 10 day schedule. In many cases, these shorter contributions served to illustrate or amplify points made by invited lecturers, and they have been included in this volume.

The organizing committee would like to take this opportunity to thank the invited speakers and participants for contributing so enthusiastically to yet another successful and thought-provoking Geilo school.

R. Pynn
T. Riste

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Examples of uniformly sized microspheres used for model studies of disordered materials. (A) Slow diffusion-limited aggregation of $1.1\text{-}\mu\text{m}$ spheres in a plane producing a “snowflake”-like crystal with dendrites after several months. (B) $1.1\text{-}\mu\text{m}$ spheres dispersed in water (gray) packing into a planar polycrystalline lattice. The different shadings in blue indicate different orientations of the grains. This systems may be used for model studies of annealing and interfacial melting. (C) Ramified fracture pattern resulting from a uniform contraction of $3.5\text{-}\mu\text{m}$ polystyrene spheres in a plane. This process takes place as a regular lattice of water-dispersed spheres dries out. (D) Colloidal flow of $1.9\text{-}\mu\text{m}$ water-dispersed spheres induced by gravitation in a vertical Hele-Shaw cell (glass plates separated by $25\text{ }\mu\text{m}$). This exemplifies a chaotic process for fluid flow in the case of zero interfacial tension between two fluids. (A.T. Skjeltorp)

(E) Ramified growth in electrodeposition of silver at high ion concentration. The change in morphology in the middle of the growth pattern is resulting from an increase in voltage between the electrodes. (F) DLA-like growth patterns in electrodeposition of silver at low ion concentration. (G. Helgesen)

Fig. 1. A spanning percolation cluster (light blue) on a lattice of 147×147 bonds. The cluster shown consists of 6261 sites. The concentration of occupied sites is $p_c = 0.593$, but only sites on the spanning cluster are shown. Occupied neighboring sites are connected by conducting bonds. The backbone of the spanning percolation cluster is shown in white, and consists of 3341 sites.

Fig. 4. A digitized version of the “fast” experiment shown in Fig. 3. The backbone is black. The sites added during the time interval between two consecutive pictures are colored differently. The masses are 30, 86, 213. The center of injection is marked by a light blue point.

Fig. 5. A digitized version of the “slow” experiment at $1 \text{ ml/h} \sim 0.33 \text{ pore/sec}$. The backbone is black. The sites added during the time interval between two consecutive pictures are colored differently. The masses are 145, 379, 543. The center of injection is marked by a light blue point. The mass at breakthrough is 753.

Fig. 7. A sequence of growth stages in a typical computer simulation at the same aggregate masses as in Fig. 4.

Fig. 8. The “fast” experiment of Fig. 4 and the simulations from Fig. 5 superimposed. The backbone is black, the experimental result is yellow, the result of a simulation is red. The overlap, i.e., sites found both in the simulation and in the experiment, is white. The cluster mass is 213.

Fig. 10. Simulation of “slow” flow with $\eta \rightarrow 0$. The backbone is black. The sites added during later growth stages are colored differently. The masses are 145, 379, 543. The center of injection is marked by a light blue point. (U. Oxaal et al.)