

A Report on the Woods Hole Conference on

TRANSPORT THEORY

By Sigi Ziering

A SMALL topical conference on transport theory took place on September 13, 14, and 15, 1962, at the Little Harbor Farm, Woods Hole, Mass. The conference was sponsored by the National Academy of Sciences and the Air Force Office of Scientific Research. Its broad aims were to bring together researchers in the various fields related to transport theory, and to discuss common interdisciplinary areas of research as well as problem areas more specific to a given area of research.

By far the largest representation was in statistical mechanics and kinetic theory, with some representation of solid-state, neutron transport, aerodynamics, astrophysics, and mathematical physics by fields of interest. The small size of the conference (25 attended) and the pleasant surroundings allowed for an informal and congenial atmosphere.

The first day was mainly concerned with mathematical questions related to the Boltzmann equation and, not necessarily by choice, restricted to linearized theory. The second day dealt with foundations of transport theory, while the third day's program consisted of special topics. As many of the topics discussed are available in the literature (or will be shortly), only a brief summary will be given.

The conference participants were welcomed by G. E. Uhlenbeck of the Rockefeller Institute, who also acted as chairman for the first day's sessions. The initial talk by K. M. Case of the University of Michigan concerned the mathematical methods found useful in soluble problems in transport theory. The starting point is the linearized Boltzmann equation with a degenerate type of kernel. To illustrate the usefulness of representative techniques, Prof. Case considered the adoption of distribution theory (density distribution in the exosphere), the theory of singular integral equations

and the related Cauchy problem (longitudinal oscillations), and, finally, group theoretical considerations (to find the invariance group for cross sections in a kinetic equation).

In a talk entitled "Approximate Statistical Equations and Approximate Methods of Solution", E. P. Gross of Brandeis University surveyed briefly such methods as various polynomial expansions and integral methods in linearized transport theory. He also discussed the construction of "model" equations, and the nonanalytic behavior of boundary-value problems in the neighborhood of physical boundaries. A number of questions were raised by Prof. Gross regarding the validity of linearized theories in general. In particular he questioned nonlinearities peculiar to an Eulerian description (for instance, the crossing of particle trajectories in a klystron), or nonlinear effects connected with trapped particles. These nonlinearities arise from the streaming term, that is, the left-hand side of the Boltzmann equation. Equally serious, however, are questions arising out of comparisons of the linear versus nonlinear relaxation spectrum due to the collision terms (e.g., the right-hand side of the Boltzmann equation). For inverse fifth molecules the spectrum is discrete and unbounded, varying as the fourth root of the principal number for the linear case. For the same molecular law of force in the nonlinear case, however, Prof. Gross pointed out that the first nonlinear decay frequency is twice the smallest linear frequency, but is smaller than the next linear one. This questions seriously the validity of the higher linear decay frequencies.

The second day was concerned with the foundations of macroscopic equations and was chaired by J. M. Burgers of the University of Maryland. Prof. Uhlenbeck, who talked on "Foundations in Transport Theory", was mainly concerned with the question of what constitutes a macroscopic theory. A number of fundamental questions, inadequately described by present theories, provide a strong impetus towards a critical

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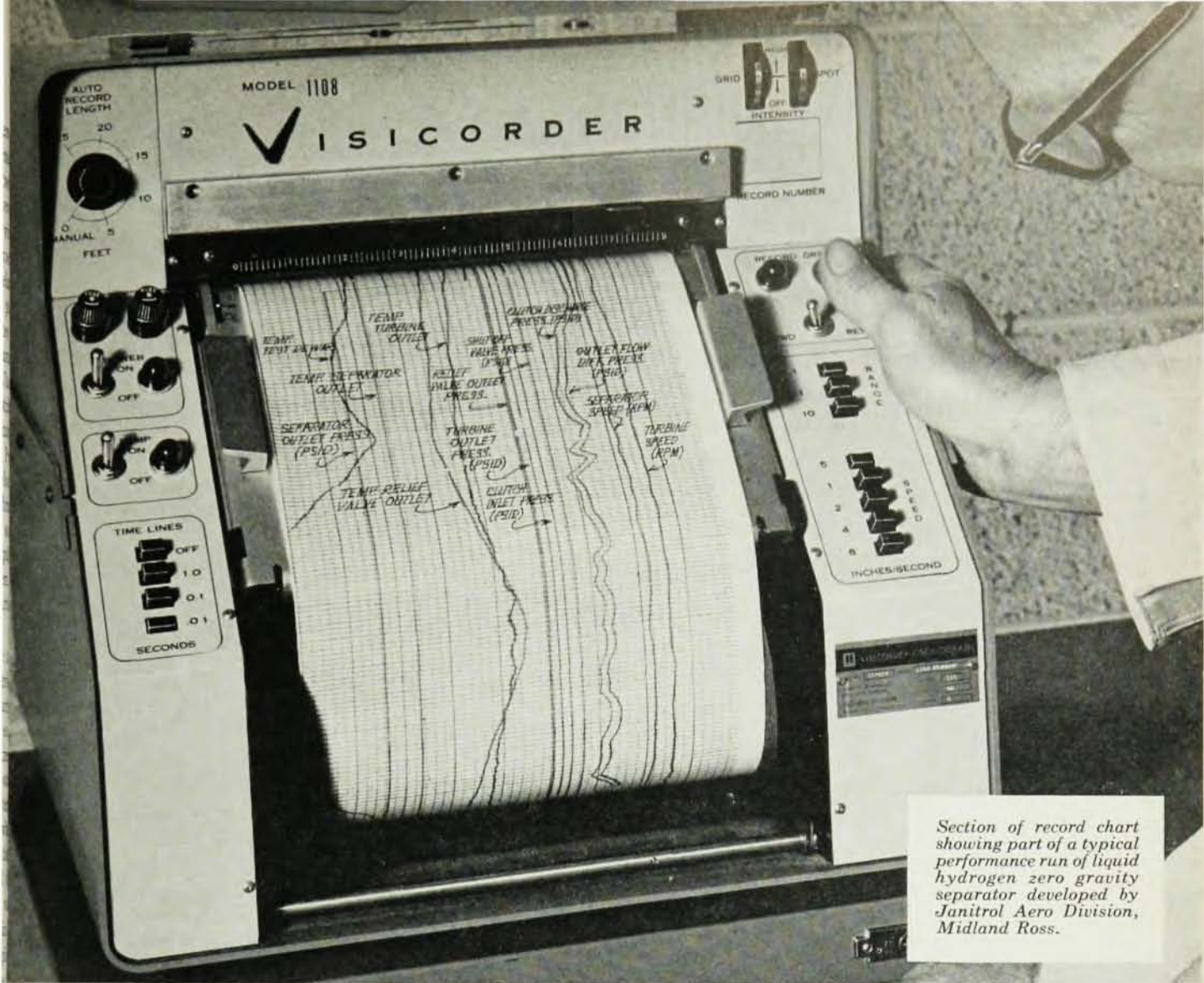


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evaluation of the basic equations. For instance, there is a wealth of experimental information on the density dependence of the viscosity and heat-conduction coefficients; starting with the Boltzmann equation, however, one has not been able to derive corrections to the virial theory by a density expansion of the transport coefficients. An equally serious question concerns the relaxation mechanism to Maxwellian distributions in plasmas. Thus, one does not know the relaxation times in magnetohydrodynamics, in contrast to hydrodynamics. Likewise, there are unstable solutions of the Vlasov equation for spatially homogeneous velocity distributions (unheard of in hydrodynamics), which indicate a more complicated approach to equilibrium. Here Prof. Uhlenbeck speculated on whether turbulence in velocity space may play a role in the transition to equilibrium because of the presence of instabilities. Indeed, some of the questions concerning the approach to equilibrium, he pointed out, had already been of concern to the founding fathers of statistical mechanics, particularly Boltzmann and Gibbs.

The transition to continuum dynamics was the subject of a talk by H. Grad of New York University. Accepting the Boltzmann equation as the starting point, Prof. Grad discussed the validity of the equations of fluid dynamics and their relationship to kinetic equations. The Hilbert expansion of the distribution function generates sets of differential equations in terms of the usual five fluid-state variables (ρ, u, T), of which the lowest set (f_0) are the inviscid Euler equations. The successive sets form inhomogeneous partial differential equations in the successive expanded fluid variables ($\rho_0, \rho_1, \dots$) which in principle are mathematically more tractable than the functional relationships implicit in the Chapman-Enskog or Burnett equations. The interrelationship between the Hilbert expansion and the Chapman-Enskog theory, the necessity of specifying initial conditions consistent with the approximation inherent in a particular set of equations, and the asymptotic behavior of the solutions were discussed in detail by Prof. Grad.

The concluding talk for the second day of the conference, on transport theory in solids, was given by E. Montroll of the IBM Research Center. The availability of very pure crystals and the tremendous range of frequencies available have allowed very precise measurements in solid-state physics. These fine measurements and the question of what really constitutes scattering, as well as the many problems created by device people, have kept the theorists busy trying to keep up with the abundance of experimental data and techniques. The use of the simple relaxation-time approximation for the right-hand side, and the concern with linear theory most of the time, simplifies the analysis; on the other hand, it is complicated by the use of Fermi statistics. The importance of thin-film phenomena had led to an extensive analysis of transport theory where mean-free-path effects dominate. Another type of transport problem of interest in solid-state physics concerns the dif-



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fusion of various defects such as vacancies, interstitial particles, etc. These are somewhat analogous to the inclusion of recombination and ionization phenomena in gas dynamics. Prof. Montroll concluded his talk by surveying the problem of a free electron gas at low temperatures in a box with periodic scatterers in it to determine the Fermi surfaces.

The last session took place on Saturday morning under the chairmanship of M. Kac of the Rockefeller Institute. Two talks in the special-topics category were given by Prof. Burgers on collisionless magnetohydrodynamic shocks and by R. J. Glauber of Harvard on the time-dependent Ising model (which he defined as an incurable problem or as the "disease of solid state"). The final talk was given by M. Krook of Harvard on astrophysical problems relating to transport theory. Prof. Krook discussed briefly the "Krooked" kinetic equation and suggested ways in which it can be straightened out and, in particular, be fashioned to include the effects arising from velocity persistence during collisions, which are absent in the simple model equation. Proceeding to stellar transport theory, Prof. Krook cited an additional complexity in that the interaction of photons with matter plays a substantial part. Thus, in addition to the kinetic equations for the separate species, one includes a photon transport equation. One also accounts for the rate of the change of the species distribution function by the inclusion of terms on the right-hand side of the respective transport equation due to the interaction of matter with photons. Further complications arise because of the special boundary conditions—thus the absence of solid boundaries in the continuous merger of a star with the interstellar medium, and, more specifically, the fact that the radius of the sun in the microwave domain may be an order of magnitude larger than the optical radius. Further care has to be exercised as there exist domains in which the ratio of the mean free path for the material particles is small compared to a characteristic length (scale height), while the photon mean free path in the same domain is not necessarily small compared to the characteristic length. This necessitates different mathematical procedures for the various domains; thus, for the inner zone in the zero order, one assumes local thermodynamic equilibrium. Currently, Prof. Krook and one of his students are using a perturbation iteration technique to solve these equations by machine calculation in order to obtain the temperature distribution.

This brief summary by necessity only highlights the various subjects discussed. The conference was certainly valuable, as evidenced by the active audience participation in the discussions. This carried over into many discussions during coffee breaks, meals, and in the evenings. J. S. Coleman and L. Slack of the National Academy of Sciences and M. Rogers and S. Jordan of the Air Force Office of Scientific Research were responsible for the efficient planning and arranging of all the various details associated with the conference.