dependence of mechanical properties and of most relaxation phenomena in the solid state. During the last 20 years we found other preferred conformations of flexible macromolecules besides the fully extended and the randomly coiled state.

One of them is *regular chain folding*, which means that under certain conditions a given chain crystallizes on itself instead of a neighboring chain. Many experiments demonstrated that the length of extended chain segments between folds is regular and temperature dependent, a fact that can be understood by thermodynamics and kinetics. The regularly folded chains have a tendency to form lamellar systems that are stacked up to produce spherulites, microfibrils and other supermolecular elements. Elaborate studies have shown that these morphological units influence mechanical properties of fibers, films and other polymeric samples; the studies have also demonstrated that chain folding can be accompanied by imperfections that correspond to well known dislocations in metallic systems and appear to have similar influence on creep and strength properties of crystalline polymers.

The other new aspect is that, under certain conditions, many polymers prefer *helicoidal* conformations instead of straight, folded and random arrangements. First postulated and established for synthetic polypeptides and proteins in the solid state, helices are important not only in simple chains such as isotactic and syntiotactic polyolefins, polyvinyls and polyacrylics, but also in very dilute solutions. Interesting experimental and theoretical work has been carried out on the establishment of the stability of helicoidal conformations, their transition into the randomly coiled state and quantitative understanding of these phenomena. Hydrogen bonding between subsequent -CO-NH- groups in polypeptide and protein chains was initially considered the main reason for the formation and stability of helices. As more experimental data accumulated it was evident that other factors, such as volume requirement of substituents and dispersion forces, played an important role.

Thus all thermal and mechanical properties of solid (or semisolid) organic polymers are affected not by two but by four types of spatial arrangements of chain segments. They may possess similar potential energies and therefore can be transformed into each other by relatively minor changes in external parameters such as temperature, pressure, strain and plasticizer content.

Dynamics

While, by a series of significant experimental discoveries, the scope of possible chain conformations was widened, there were also successful attempts to give a better dynamic account of the response of randomly coiled macromolecules in solution or in the condensed state to external forces. Refinements of the "classical" theory of rubber elasticity led to inclusion of "nonideal" cases, in which individual chains exert on each other more than negligible intermolecular forces, and in which strains are large enough so the chains show a noticeable orientation and parallelization.

Even more important is a theory that considers a randomly coiled macromolecule as a dynamic system described in terms of normal modes with which it responds to the action of external forces. A polymer molecule in solution is treated as a linear array of Gaussian subunits, each of which acts like an entropy spring damped by the viscosity of the liquid in which the coil is embedded and in which it is carried away by the shearing forces of a laminar flow. The response of the molecule is described by a system of normal-mode frequencies (*Eigenfrequenzen*), the totality of which represents the relaxation spectrum just as the normal modes of a rigid crystal give the frequency spectrum of the lattice. A recent innovation of this treatment, which applies not only to solutions but also to polymer melts, replaces the damping through the solvent by a damping resulting from hindered internal rotation of the chain backbone. Both theories give a fair account of the elastic, viscoelastic and dielectric properties of some polymers in solution and in the melt.

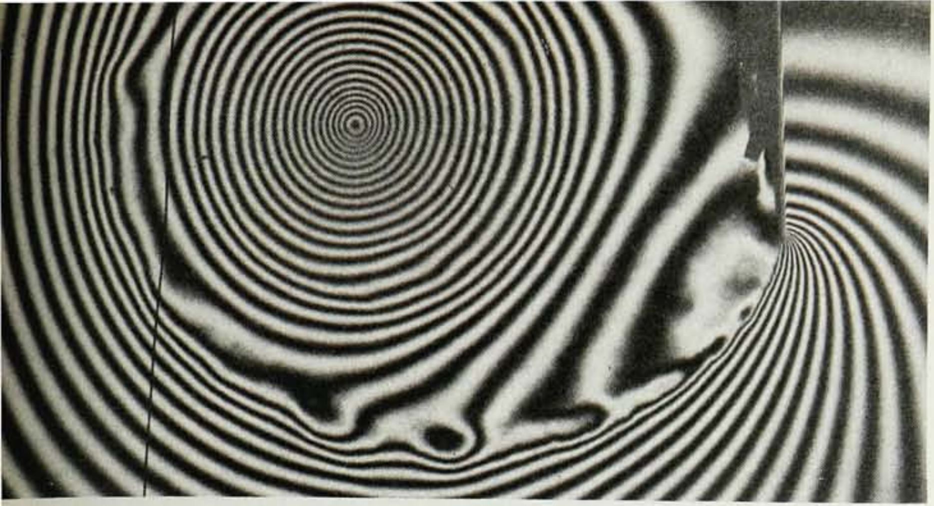
Another interesting problem is posed by a new family of polymers, represented by rigid macromolecules whose chains consist of aromatic rings. These systems cannot be approached by the random-coil model but must be treated more like rigid rods possessing certain elastic characteristics that add up to the mechanical behavior of a macroscopic piece of these materials. There are now many synthetic organic polymers with elastic moduli higher than 10^6 psi and softening points above 1000°C, properties that certainly call for an explanation. □

TWENTY YEARS OF PHYSICS

FLUID DYNAMICS

By RAYMOND J. EMRICH and FRANÇOIS N. FRENKIEL

In 1948 vehicles were already moving faster than sound without being shot out of gun barrels. The "sonic barrier" was being penetrated. Soon rocket-propelled vehicles were to become intercontinental and were even likely to go into orbit. There was an urgent need to understand the fearful damage caused by blast waves from nuclear explosions and to determine whether they could be used for constructive purposes. The processes in the atmosphere that produce weather could already be modeled with high-speed computing techniques.



VORTEX BEHIND A TRANSVERSE WALL is recorded by interferogram. Understanding turbulence remains one of the great challenges to fluid dynamicists.

lence phenomena through studies in fluid dynamics.

The needs of aeronautical and naval technology, which have profited to a great extent in the past from advances in fundamental fluid dynamics, are still far from being fulfilled. Problems remain in both incompressible and compressible fluid dynamics. The study of flow near a boundary, such as a flat plate, has led to many important contributions, including a much better understanding of the problems of hydrodynamic instability and of the inception of a turbulent flow. Now under way are extensive studies of boundary-layer phenomena, of the microstructure of such layers and of the acoustic noise that boundary layers radiate.

In addition to nuclear explosives and electronic digital computers, other important devices for studying fluid dynamics had emerged during the preceding war years, including the supersonic, blow-down wind tunnel and the shock tube. Fluid dynamic processes taking place in minutes in a blowdown tunnel, and in milliseconds and microseconds in a shock tube, could now be studied.

Temperature, turbulence

With increased speed flows as rockets became more effective, it soon became evident that extremely high temperatures were involved. With shock tubes having chemical explosives to drive the shocks, and later with electrically driven shocks, gases at temperatures of tens of thousands of degrees were produced and studied. Air, which consists mainly of molecular nitrogen and oxygen at familiar temperatures, becomes a complex mixture of atoms, ions, electrons and oxides of nitrogen as it is compressed by shock waves as strong as those preceding a hypersonic vehicle reëntering the earth's atmosphere. Means of shielding the reëntering vehicle from the extreme heat long enough for it to slow down were devised. The gas is so hot that it transmits appreciable amounts of internal energy to its surroundings by optical and infrared radiation. Interesting processes combining atomic excitation, chemical reaction and radiation emission and absorption are being studied, and fluid dynamicists find themselves working in the laboratory on processes formerly thought to exist only in stellar atmospheres.

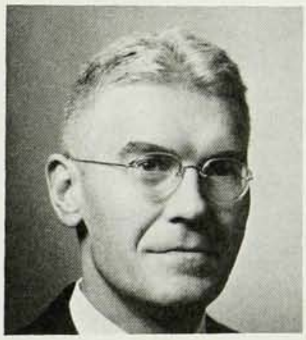
During the past few decades the basic laws of the statistical theory of turbulence have been studied both theoretically and experimentally. Some idealized models of turbulence have been developed for homogeneous and isotropic turbulence. The transport of kinetic energy from larger-size eddies to smaller-scale fluctuations has been formulated as a theory based on the fundamental equations of fluid dynamics and a variety of assumptions. Whether such assumptions are correct is still in question, and, notwithstanding many important advances, the study of turbulence remains one of the great challenges in fluid dynamics. Difficulties encountered in the study of atmospheric and oceanographic turbulence, as well as in plasma turbulence, and the importance of turbulent diffusion in air-pollution studies have, however, provided an increased incentive to find a satisfactory understanding of turbulence phenomena through studies in fluid dynamics.

Shock and detonation waves

Although no "sonic barrier" appeared to prevent the acceleration of a vehicle to supersonic speeds, a "sonic-boom" problem has arisen to challenge the fluid dynamicist. The study of a shock wave as a mathematical discontinuity and of the interaction between shock waves had to be followed by a more realistic approach dealing with the physical structure of shock waves and the transition through a shock wave on a molecular scale.

There have been surprising developments in combustion and flames. Detonation waves apparently are always intimately connected with a series of local instabilities on the chemical-reaction front and a turbulent structure of the burned gases behind.

Flow of ionized gases and the observation and study of luminous fronts



Raymond J. Emrich is chairman of the physics department at Lehigh University, a post he has held since 1958. He is currently visiting the Ernst Mach Institute in Freiburg, Germany. In 1946 he received his PhD from Princeton and joined the faculty at Lehigh. He specializes in shock-tube research.

François N. Frenkiel, consultant at the Applied Mathematics Laboratory of the Naval Ship Research and Development Center, is editor of *Physics of Fluids*. He received his physics PhD from Lille in 1946. He was at Cornell, the Naval Ordnance Laboratory and Johns Hopkins before joining the center in 1960.

accompanying the production of shock waves has become another area of interest in fluid dynamics. Sharp luminous lines have been observed in what appears to be the collision of interstellar clouds, and the violent turbulent motion involving shock waves is thought to be at its origin. These magnetofluid-dynamic shock waves are but one example of a large area of phenomena combining magnetic forces with flowing and conducting media. The influence of a magnetic field on wave propagation, boundary-layer flow, shock-tube flows and other fluid flows has become the subject of extensive studies.

Statistics

Several big steps forward have been made in the statistical-mechanical formulation of fluid-dynamics equations and other transport equations. One of these is the development of the correlation-function method, in which the assumptions are more clearly seen than by previous techniques using the Boltzmann equation. Interest in rarefied-gas flow has been increasing continuously. A whole range of conditions, from continuum at one extreme to free-molecule (collisionless) flow at the other and embracing a large number of problems in the region between those two extremes, now occupies a number of fluid dynamicists.

Geophysical fluid dynamics

Interaction between classical fluid dynamics and high-speed computing methods has been particularly important to meteorology and oceanography. Most of the problems in meteorology involve laws of fluid dynamics; however, meteorological applications require extremely long computations. Thus meteorology is a somewhat special discipline based in part on known physical laws and in large part on insight gained from long experience. Many complex flow problems can now be treated with fast computers. There is, too, an increasing interaction between fluid dynamicists and meteorologists. Fluid instabilities, convection phenomena and problems involving rotating fluids were the subject of a variety of studies related to the field of geophysical fluid dynamics.

Superfluids

20 years ago the theoretical description of liquid helium by Lev Landau was suspect. It has described the properties of the strange fluid below 4.2°K so successfully that it now forms one very satisfactory approach. The superfluid properties of no viscosity and no thermal resistance then known have been augmented by the discovery of quantized vortices. A bucket of superfluid cannot have a range of values of angular momentum. Discrete vortices are detected by their effect on the motion of tiny bubbles surrounding electrons moving in an electric field. An alternative theory starting from Bose statistics furnishes a description of the properties of a superfluid condensate. The amalgamation of the two approaches is a recent exciting development.

Outlook

Since fluids, including plasmas, essentially constitute the entire content of the universe, with solids but a trace impurity, it might appear that for all but a few exceptions natural phenomena would be within the domain of the physics of fluids. Of course only a fraction of the activity in physics is organized under this topical heading, and this probably represents our inability to handle the complexities of large and complicated motions. Laws governing subnuclear, nuclear and atomic "particles" are believed to provide for the behavior of collections of "particles." However, the ensemble of particles that constitutes a fluid produces many phenomena that are not always expected from these laws.

Will the evident and recurrent processes going on about us all the time be understood better by frontal attacks from macroscopic fluid dynamics? We wonder if high-speed computer studies of nonlinear problems in the next 20 years will bring us to an understanding of the big unanswered problems in our surroundings. It is possible that emphasis on understanding small phenomena may decrease and that more attention to organized systems will constitute our new era of progress. In any case it is interesting to raise the question. □

TWENTY YEARS OF PHYSICS

PLASMAS

By MELVIN B. GOTTLIEB

TWENTY YEARS AGO the study of plasmas occupied a relatively minor role in physics: The wide variety of plasma phenomena remained unexplored. The field had its origin early in this century in the study of the gas discharge, a relatively dense, slightly ionized plasma regime where the dominant effects are ionization, excitation, recombination and other atomic collision processes. Irving Langmuir initiated modern plasma physics through his discovery of plasma electrostatic oscillations and his realization that this was an aspect of collective particle motion. It is these collective motions which, generating and interacting with electric and magnetic fields, are responsible for the wealth of physical phenomena that take place in a plasma and make it so different from ordinary fluids.

Astrophysical and geophysical studies also played an important early role. Edward Appleton, in his ionospheric studies, correctly described (in the thirties) the propagation of elec-