and precision optical glasses, crystalline materials, and artificial diamonds and borides has influenced optics in many ways.

The challenge of "seeing in the dark" has led to the development of image intensifiers of a wide variety that are now finally achieving the goal dreamed of by astronomers, of yielding a net information gain over the photographic emulsion. Both static and scanning devices are now leaving the laboratory arena and appearing on telescopes!

The developments of color films of high speed and outstanding color portrayal and the Polaroid process rank with the zoom lens as living evidence of the everyday influence of optics. In the scientific and technical fields we have had the development of a whole spectrum of films and processing including grainless holographic emulsions, fast emulsions for astronomy, extreme-ultraviolet-sensitive emulsion, bimat films for lunar photography and a host of other items.

Now the entire electromagnetic spectrum, from short x rays to the radiowave region, has been opened up for the geophysicist and astronomer. The stimulus for infrared sensors and systems applications over the past 20 years has given the scientist and industrial engineer many detectors, which cover spectral ranges from the visible out to the millimeter wave region, and many cryogenic and amplifier devices.

Optics industry

The growth of the optics industry under the influence of 20 years of discovery and exploitation of the emerging technology deserves notice. The initiative for advances in optics has been largely from industry rather than the university laboratory, but we hope that a partnership is now growing.

The technology for making high-acuity optical systems for astronomy, reconnaissance and space exploration has progressed because of a large change in the state of the art of optical fabrication and testing. Astronomy is currently benefiting, from both the new level of optical technology and the national support of science, through a major round of new telescope construction, including at least seven telescopes in the 3.5–6-meter aperture class.

The importance of aspherics in precision optics was recognized many years ago, but it has been slow to develop as a "standard" item in optical systems. Development of new techniques for producing aspheric surfaces is a current activity of industry along with novel methods for correcting small residual errors in optical surfaces, such as selective deposition methods and ionic polishing. Optical instrumentation in the chemical engineering and pharmaceutical fields for on-stream process monitoring is also of growing importance. □

TWENTY YEARS OF PHYSICS

HIGH-POLYMER PHYSICS

By HERMAN F. MARK

STUDY OF ORGANIC polymers in the solid state began in the early 1920's with x-ray investigation of natural representatives such as cellulosic fibers, starch, silk, wool, rubber and certain resins; the general, qualitative result was that all these materials, despite their chemical dissimilarity, produce x-ray diffraction patterns indicating a certain degree of molecular regularity. Together with the concept of substantially linear chain-like macromolecules, these findings led to the conclusion that, in the polymeric solid state, there are volume elements or domains with essentially parallel chains. They have a three-dimensional geometrical regularity that resembles the structure of a crystal. Other volume elements, however, are occupied by other portions of the same chains; here individual segments are irregularly arranged so that these domains possess the structural characteristics of a liquid or a glass.

Formation of chains

During the next 20 years several synthetic polymers—polyethers, polyesters, polyamides and polyvinyls—gave corresponding experimental results and confirmed the concept that linear macromolecules exist essentially in *two* characteristic *conformations*: substantially *extended* chains in crystalline domains and *randomly coiled* chains in amorphous areas. *Thermally* the transition from extended to random represents melting; the opposite transition is crystallization. *Mechanically* the transition from extended to random means contraction; the opposite represents extension.

This concept permitted a general, qualitative interpretation of the phenomena of rubber elasticity, the stress–strain curve of fibers and their behavior on cold drawing. It failed, however, in a more precise and detailed description of the temperature

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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.