

Meetings and Conferences*CONFERENCE ON THE MECHANICAL PROPERTIES OF NON-METALLIC SUBSTANCES*

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A conference on the mechanical properties of non-metallic solids took place in Leningrad from May 19 to May 24, 1958. It was organized by the International Union of Pure and Applied Physics and the Academy of Sciences of the U.S.S.R. The choice of the conference site was determined by the development in that city over the course of many years of the large scientific school in the field of solid-state physics headed by Academician A. F. Ioffe. In view of the very large scale of the physical and technical studies of solids, it was decided to limit the topic of the conference to the non-metallic solids.

The conference was opened with an introductory speech by Academician A. F. Ioffe. He characterized the development of crystal physics over the course of more than half a century, a development in which A. F. Ioffe himself has played a most active leading role. As early as 1903, in his work with Roentgen, A. F. Ioffe showed that there is no elastic after-effect in normal crystals. A normal crystal has a standard electrical conductivity; dielectric anomalies in insulating crystals are explained by thermal dissociation and electrolysis. Ohm's law is obeyed in dielectrics. The action of light or radiation also amounts to dissociation and the motion and accumulation of charges. These studies showed that, in the field of electrical phenomena, the behavior of crystals is subject to thermodynamic laws. In studies beginning in 1918 on the mechanism of plastic deformation of crystals, A. F. Ioffe showed by x-ray structural analysis that the visible bending of a crystal amounts to displacement and rotation of its separate portions, each portion preserving its thermodynamically stable structure.

The problem of fracture of crystals was stated to consist in a large discrepancy between the theoretical and actual strengths. This discrepancy was explained by the influence of defects, and above all, of surface cracks in which excessive strains are localized. It was shown further that large-scale fracture of a crystal has a statistical character. An important stage in the development of solid-state physics has been the study of relaxation processes in amorphous solids (the studies of P. P. Kobeko, A. P. Aleksandrov, M. I. Kornfel'd,

and E. V. Kuvshinskiĭ, who have revealed the physical mechanism of relaxation phenomena in polymers).

After the foundations of the physics of real crystals had been laid, the path was open into the field of crystal defects. The study of these has required a substantial increase in the precision of the methods of study. It was these questions, associated with the defect structure of real crystals, with dislocations, and with the strengths of solids, which were the central theme of this conference. "I hope," said A. F. Ioffe, "that we shall hear and discuss the theory of defects, rather than the defects of the theory." He directed attention to the absence at present of a convincing theory of dislocations, and to the impossibility of confirming whether dislocations constitute the only mechanism of plastic flow. In conclusion, A. F. Ioffe formulated the basic problems of contemporary solid-state physics. He considered the most important of these to be the establishment of a connection between the mechanical properties and the chemical structure of solids. It would be very interesting to combine in one substance the advantages of the different types of bonds, the chemical and intermolecular bonds. A. F. Ioffe expected great advances in the study of surface properties. He indicated that it is hardly proper to draw a sharp boundary between mechanical and the electrical phenomena. Complex investigations of these and other phenomena are especially suitable for application to semiconductors. There is also little basis for the dividing line between inorganic semiconductors and organic polymers. A gradual transition must exist between short-range and long-range order. Finally, an important problem is that of the range of vibrations lying between the ultrasonic and thermal ranges, the study of the spectra of the latter and their anharmonicity, and the absorption and scattering of acoustic waves in all frequency ranges.

The first session was devoted to plastic deformation and fracture of crystals.

S. N. Zhurkov (Physico-Technical Institute, U.S.S.R. Academy of Sciences, Leningrad) gave a paper, "Physical Problems in the Strengths of Solids," in which he noted the very important role

of time and temperature factors in strength phenomena, and presented the results of the study of materials of varying natures: poly- and monocrystalline metals and alloys, ionic compounds, inorganic and organic glasses, and rubber. In all cases, the following expression for the endurance τ (the time between the moment of applying the load and the rupture) appears to be valid:

$$\tau = \tau_0 e^{\frac{u_0 - \gamma \sigma}{kT}},$$

where σ is the tensile stress, and τ_0 , u_0 , and γ are constants characteristic of the material being studied. This formula is valid for time intervals ranging over 8 to 10 orders of magnitude. The fundamental characteristic of the strength for a given σ and T is the endurance τ , rather than the ultimate stress. The concept of ultimate stress in this sense has only a conditional, practical meaning. The molecular mechanism at the basis of the given formula consists in the gradual development in the stressed body of a certain kinetic process. The activation energy of this process decreases with increase in the stress: $u = u_0 - \gamma \sigma$. According to the experimental data obtained, u_0 for pure metals is equal to the bonding energy of the atoms in the crystal lattice. τ_0 is practically identical for all substances, and is of the order of $10^{-12} - 10^{-13}$ sec (of the order of the natural period of vibration of the atoms). The coefficient γ is sensitive to the structural changes which take place on heat-treatment of a metal, on cold work, on introduction of impurities, etc. The measurement of the endurance for a given σ and T , as carried out in one cycle (τ), or in two cycles ($\tau_1 + \tau_2$), shows that $\tau = \tau_1 + \tau_2$. Hence, the changes which have occurred in the material after the time τ_1 persist even after removal of the load. As a result, the material is partially broken down, and has a lowered endurance τ_2 .

A paper of **B. V. Deryagin** and **M. S. Metsik** (Institute of Physical Chemistry, U.S.S.R. Academy of Sciences, Moscow) was devoted to the role of electrical forces in the process of cleaving mica. Mica is an especially suitable object for the study of the forces which hinder the growth of cracks. The very high value of the work of cleavage (of the order of 10^3 erg/cm in vacuo), and its dependence on the rate of the process, the pressure, and the humidity, are necessary consequences, if one considers that the resistance to cleavage depends only on molecular forces. Electrical phenomena are observed in the cleavage of mica, in particular, the emission of high-velocity electrons corresponding to a potential

difference of the order of 10 kv. Study has shown that in the cleavage process, significant forces of electrostatic attraction of opposite charges must be overcome. These charges have a density on the cleavage surfaces of the order of 100 absolute units. The electrification of these surfaces has the character of a mosaic of sign changes, as has been demonstrated by use of an electrometric probe. The mechanism by which this type of electrification is generated is determined by the structure of real crystals of mica containing interplanar layers of water. Increase in the rate of cleavage or in the humidity acts to increase the factors competing with the gaseous discharge by which the surface charges are being neutralized. The charge density was also estimated by observation of the Kerr effect during cleavage in benzene. On the basis of studies of mica and other crystals (quartz, gypsum, tourmaline, etc.), the authors arrive at the conclusion of an essential role of electrical forces in the strengths of brittle crystals.

A paper by **A. V. Stepanov** (Physico-Technical Institute, U.S.S.R. Academy of Sciences, Leningrad) analyzed the data on the characteristic modes of deformation of crystals: slip, twinning, and cleavage. Analysis of these data leads to the conclusion that these processes are two-stage processes. They consist of the stage of the formation of a slip nucleus, a twin nucleus, or a crack, and the stage of their subsequent development. The size of the energy barrier for formation of such a nucleus is of the same order of magnitude as the energy barrier for a phase transition. The central question in the problem of the plasticity and strength of crystals is that of conducting a many-sided study of the formation of these nuclei. A paper by the author and his associates has shown that the elastic limit in slip is equal to the stress at which the slip nuclei begin to grow through the thickness of the crystal. Apparently, the elastic limit for twinning and the ultimate strength for fracture are also the stresses at which the growth of the nuclei of these processes is possible. The stress states in the vicinity of deformation nuclei in silver and thallium halides were studied by optical methods. Data were obtained on the residual stresses in the vicinity of the deformation nuclei.

In a paper by **R. I. Garber** and his associates, **I. A. Gindin** and **L. M. Polyakov** (Physico-Chemical Institute, Ukr. S.S.R. Academy of Sciences, Kharkov), an attempt was made to apply the idea of micro-cracks to the description of plastic deformation. In describing the phenomena which

take place in crystals under plastic deformation, one must reject the commonly accepted way of looking at a solid body as a macroscopically continuous medium. A plastically deformed body must be considered as a conglomerate of more or less perfect, ultramicroscopic blocks. The blocks are sintered together in such a way that there are areas of surface not in contact. Plastic deformation of such a conglomerate must be accompanied by the dispersing and the reestablishment and "sintering" of the blocks in their new positions. As a result of this "sintering," the cohesive forces and continuity of the crystal are restored. This leads to the conservation of the original strength of the crystal after the regrouping of the fractures, the rotation of blocks, and the displacement and crushing of the blocks.

Yu. N. Ryabinin (Laboratory of High-Pressure Physics of the U.S.S.R. Academy of Sciences, Moscow) reported the results of measurements of the plasticity under axial tension of cylindrical specimens subjected to high hydrostatic pressure. In the author's opinion, the basic reason for the increase in plasticity in the case studied here is the change in the stress pattern under the influence of the hydrostatic pressure. The data obtained in this paper agree with the well-known results of P. Bridgman. However, for a series of metals (brass, steel-45), a non-linear relation of the limiting plasticity to the pressure was found; this had not been observed previously in Bridgman's experiments.

The results of a study of the resistance of diamond to abrasion were reported by **E. M. Wilkes** and **J. Wilkes** (Clarendon Laboratory, Oxford). The resistance of diamond to abrasion depends on the crystallographic orientation of the face with respect to the direction of abrasion. The authors used the method of micro-abrasion, which had been proposed by Gradzinskiĭ. The hardness appeared to depend sharply on the orientation of the polished face. Thus, cubic faces exhibit only fourfold symmetry of the hardness if they are situated at an angle of 30° from the cubic lattice planes. Measurements in the cubic-dodecahedral zone show that surfaces inclined at 5° from the cubic orientation exhibit marked anisotropy. The rate of abrasion of material from the surface is proportional to the speed of grinding. This result is in agreement with the conception of a mechanical, rather than a chemical, attack on the surface. The authors emphasize that large variations in the observed hardness of diamond are associated with the experimental method. The influence of the nature of the abrasive material on the abrasion of diamond was studied in this paper.

A paper by **G. P. Frederikse**, **R. F. Potter**, and **R. B. Flippen** (National Bureau of Standards, Washington) was devoted to a study of the mechanical properties of indium antimonide. The elastic and plastic properties of InSb were studied by means of a resonator technique at frequencies of 40–50 kcs over a temperature range from 78°K to the melting point. The measured values of the three elastic constants of the cubic lattice of InSb are in agreement with the Born-Smit theory. The Debye temperature was estimated to be 208°K , corresponding to the value $\theta_D = 200^\circ \pm 5^\circ\text{K}$, determined from the heat capacity. Comparison of a series of crystals led to the conclusion that the ratio c_{11}/c_{12} is lowered as the ionic character of the bond is increased; the ionic character for InSb was estimated to be 20%. The mechanical losses in InSb are strongly dependent on the structure. Broad relaxation peaks are observed for longitudinal and torsional vibrations in the range $50^\circ - 350^\circ\text{C}$. Study of hysteresis phenomena and damping of vibrations indicated that the damping is connected with dislocations. The damping is small at 500°C , but rapidly increases just below the melting point at 523°C .

Two theoretical papers were heard at the end of the section devoted to plastic deformation and fracture of crystals.

A. N. Orlov and **Yu. M. Plishkin** (Institute of Metal Physics, U.S.S.R. Academy of Sciences, Sverdlovsk) studied the conditions of equilibrium for a one-dimensional model of a crystal. This model was a chain of atoms for which the interaction energy V_i of neighboring atoms situated at a distance x_i is

$$V_i = -Ax_i^{-\mu} + Bx_i^{-\nu},$$

where A , B , and $\mu < \nu$ are positive constants. The case consisting of a large number of atoms in a slightly-stretched chain is of special interest. It was shown that in this case there is a metastable equilibrium configuration in which the interatomic distance x_i at one site is significantly larger than at other sites (breaking of the chain). The authors considered a three-dimensional crystal as a set of mutually-intersecting families of chains. With some additional simplifying assumptions, they evaluated the critical size $R = R_c$ of a planar crack. For $R > R_c$, the energy of a crystal with a crack is less than the energy of a crystal subjected to a unilateral extension.

A paper by **T. A. Kontorova** (Institute of Semiconductors, U.S.S.R. Academy of Sciences) was concerned with the calculation of the influence of the anharmonicity of lattice vibrations on the proc-

ess of plastic deformation. Ya. A. Frenkel' and T. A. Kontorova had previously proposed a microscopic theory of the process of plastic deformation of crystals for a very simple model. This model was a one-dimensional chain of atoms joined together by elastic forces and interacting with a periodic field in the medium. It was shown that, along with the ordinary small oscillations in such a chain, a collective motion of the chain between nodes is possible. This leads to a displacement of the entire chain at distances which are multiples of the lattice constant. In the development of this theory, a calculation was made of the influence of anharmonicity in the interaction forces between the particles in the chain on the process of collective displacement. An analysis of the initial assumptions of the theory was made, taking anharmonicity into account. It showed that the propagation of a displacement along the chain is possible only when the interaction of the particles in the chain with the medium is weaker than their interactions with each other.

The next session was devoted to the experimental study of dislocations.

Great interest and much discussion were elicited by a report by J. Gilman and V. G. Johnson (General Electric Laboratories, Schenectady), "The Motion of Dislocations in Crystals of Lithium Fluoride." The motion of the dislocation lines was observed by the method of selective etching as a measure of the displacement of the dislocations. If the time of application of the load is known, then the average velocity of movement of the dislocations may be calculated. The influence of various factors (the type of dislocation, the plane of slip, the stress, the temperature, impurities, and radiation damage) on the velocity of movement of the dislocations was studied. As the experiments showed, the velocity of movement of a dislocation decreases very sharply as the stress is lowered toward a definite critical value; below this value, movement of the dislocations does not occur. The relation of the velocity to the stress was followed over a wide range. This began at a velocity of movement of the dislocation of several atomic distances per second, and extended to 3×10^{12} atomic distances per second (a value close to the velocity of sound). It was possible to establish a relation between the critical shear stress and the multiplication of dislocations, and also to observe the interaction between dislocations which takes place in deformation hardening.

S. A. Amelinckx (Laboratorium voor Kristalkunde, Rijksuniversiteit, Ghent, Belgium) reported

on the results of his studies of alkali halide crystals. In this work, use was made of the method of detection of dislocations in transparent crystals by microscopic observation of visible particles which precipitate along the dislocation lines (the method of "decoration"). Such experiments were conducted in varying ways in the study of dislocations in the alkali halides. The different experimental techniques were examined, and the results found by the various methods were compared. The observations obtained by the decoration method were interpreted on the basis of the modern theory of dislocations.

M. V. Klassen-Neklyudova, V. A. Indenbom, A. A. Urusovskaya, and G. E. Tomilovskii (Institute of Crystallography, Academy of Sciences of the U.S.S.R., Moscow) compared the results of optical studies of crystals with the distributions of etch figures. Crystals of $\text{Al}_2\text{O}_3\text{-LiF}$ were studied by polarized light and by the method of selective etching. The optical measurements were compared with the density of etch figures on the slip lines. Also, the decrease in stress as a function of the distance from the slip line was studied. These data gave evidence of satisfactory agreement between theory and experiment. Some slip lines correspond to the very simple model of a horizontal series of edge dislocations. Study of the stresses and lattice rotations associated with "irrational twins" and the distribution of etch figures shows that this phenomenon may not be considered the counterpart of translational slip, nor can it be reduced to the formation of faulting bands or deformation bands. Movement and multiplication of dislocations were observed. It was shown that screw dislocations have higher mobility than edge dislocations. In the slip lines produced by a concentrated stress, the dislocations are grouped in transverse rows, depending on the distance from the point of application of the stress. This effect is explained by the interaction of dislocations in the parallel slip lines. The possibility of optical study of individual dislocations was discussed.

Some results of observations of plastic deformation in rock salt were reported by M. P. Shaskolskaya and Sun Jui-Fang (Institute of Steel, Moscow). They used the phenomenon of birefringence, together with interference and electron-microscopic studies of the surface relief. In the initial stage, as the experiments showed, plastic deformation takes place by means of slip. The slip plane or the set of closely spaced slip planes corresponds to the band of birefringence. It was found that the lines of emergence of the slip plane

on the opposite surfaces of the crystal were not the same in magnitude. This is evidence of the presence of locked dislocations in the crystal. It may be assumed that these locked dislocations are the cause of the residual stresses which give rise to the bands of birefringence. The appearance of slip lines on crystals of silver chloride was studied, along with the study of birefringence and the detection of structural defects by the methods of selective etching and decoration. It was shown that the wavy slip lines in the final stage are also rectilinear.

A. A. Chernov (Institute of Crystallography, Moscow) indicated the possibility of deriving a kinetic equation for steps on the surface of a crystal. By making use of the distribution function of the step heights, he obtained a kinetic equation describing the coalescence and breakdown of steps in the processes of growth and solution of the crystal. The problem of the variation in time of the coalescence of steps was studied.

Much interest was shown in a film demonstration of the formation of dislocation centers for growth and evaporation of a crystal. The film was made by **G. G. Lemleĭn** and **E. D. Dukova** (Institute of Crystallography, Moscow). The process of formation of a screw dislocation and the appearance of a growth spiral on the surface of the crystal were shown. The centers of spiral growth are formed during the overgrowth of the re-entrant angles of dendritic crystals. Spiral-layered growth and spiral-layered evaporation were demonstrated, as well as the transformation of a growth spiral into an evaporation spiral.

V. N. Rozhanskiĭ, **Yu. V. Goryunov**, **E. D. Shchukin**, and **P. V. Pertsov** (Moscow University and the Institute of Physical Chemistry, U.S.S.R. Academy of Sciences) noted that the decrease in surface tension due to adsorption of surface-active substances has a substantial influence on the emergence of dislocations at the surface of the crystal, and on the formation and development of cracks. One of the manifestations of this effect involves the appearance of brittleness due to the action of melted metallic coatings.

Three papers were devoted to mechanical twinning.

R. I. Garber (Physico-Technical Institute, Ukr. S.S.R. Academy of Sciences, Khar'kov) gave a paper "Mechanical Properties of Single Twinning Bands." The relation of the thickness of the twinning bands to the stress was studied, the stress being applied stepwise or increased continuously. With continuous application of the load, the observed rates of change in the thickness of the

bands could be either diminishing, accelerated, or steady, depending on the rate of application of the stress. With stepwise increase of the load, the length, thickness, and width of the elastic twins increase over the course of the period of time of each addition to the load. The mechanical properties of the twinning bands do not depend on the direction of the twinning process. If a new band is formed at a site where a previous band had vanished, it shows the same mechanical properties as the previous band had shown at the same stage of deformation.

E. V. Tsinzerling (Institute of Crystallography, U.S.S.R. Academy of Sciences, Moscow) reported a very interesting "memory" phenomenon of the quartz lattice. This phenomenon was observed in quartz after annealing of a crystal which had been twinned by torsional deformation. The more difficultly the crystal had twinned, the more easily it returned to its initial state. Such a return to an original orientation takes place only in quartz which contains impurities.

A paper of **M. A. Chernysheva** (Institute of Crystallography, U.S.S.R. Academy of Sciences, Moscow) was concerned with the peculiarities of the deformation of polysynthetic twins, namely, crystals of Rochelle salt. Over the temperature range from -18° to $+24^{\circ}$ C, Rochelle salt is transformed from a rhombic to a monoclinic phase, and becomes a polysynthetic twin. According to optical data, the twin components have the form of thin layers having uneven thicknesses. Distortions of the twinning pattern under the influences of mechanical or electric fields make it possible to judge the nature of the crystal defects. The temperature dependence of the rotation angle of the optical indicatrix, which is proportional to the twinning angle, was studied. This made it possible to determine the thermodynamic potential of Rochelle salt in the temperature range between the Curie points.

Local deformation phenomena were discussed in the papers of **E. M. Elistratov**, **D. M. Vasil'ev**, and **Yu. K. Auleitner**.

The paper of **E. M. Elistratov** (Institute of Semiconductors, U.S.S.R. Academy of Sciences, Leningrad) was concerned with deformation phenomena occurring during the decomposition of supersaturated solutions. Data obtained from x-ray studies were given. In solid solutions (Be-Cu, Ag-Al, Zn-Al, Te-Ni-Al), regions of anomalous scattering surrounding the reciprocal lattice points of the solid solution were found. These were shown to be basically due to imperfections appearing in the matrix itself, produced

by the stresses caused by the nuclei of the precipitating phase. At an early stage in the decomposition of the solid solution (Be-Cu, Ag-Al, Zn-Al), cylindrical scattering regions appeared (the so-called two-dimensional diffraction effect). These had previously been considered to be the effect of planar Guinier-Preston zones, but were actually due to scattering from flat regions of strongly decreased electron density ("submicro-cracks"). These submicro-cracks are deformation disturbances in the matrix. The interpretation of the two-dimensional diffraction effects as being the effects of the form of the submicro-cracks was well corroborated by the observation of these effects in the decomposition of a solid solution of copper in germanium having a very small content of copper ($\sim 10^{-4}$ atom %).

D. M. Vasil'ev (Polytechnic Institute, Leningrad) read a paper, "On Micro-Stresses Appearing in Polycrystals on Plastic Deformation."

In this paper, a hypothesis advanced by the author concerning the appearance of orientated micro-stresses during plastic deformation was discussed. This assumption permits a graphic explanation of the shifts in x-ray diffraction lines which are observed after homogeneous plastic deformation. The conclusion was drawn that disoriented micro-stresses (in the ordinary sense of the term), in general, do not arise during deformation. Oriented micro-stresses, one may assume, arise because of the existence of "strong" and "weak" regions in the plastically deformed specimen.

Yu. K. Auleitner (Warsaw) spoke on "The Determination of the Orientation of Mosaic Blocks by the Use of a Fine-Focus x-ray Tube." The method was based on the photographic recording of Bragg reflections, with synchronization of the motion with the oscillations of the crystal. In this way, it was possible to determine the disorientation of mosaic blocks for angles not less than 30° . The x-ray source was a fine-focus tube built by the author, having a focal spot of $20 - 30 \mu$.

S. A. Amelinckx (Ghent) reported on a study of the radiation hardening of sodium chloride crystals. The surface hardening of an NaCl crystal on irradiation with x-rays (Cu radiation at 40 kv) was studied in relation to the distance between the tube and the crystal and the time of irradiation. The measured hardening corresponds to the amount of absorbed x-rays in the different absorption bands. It was found that an irradiated surface is etched more intensively than a non-irradiated one. The experimental results may be explained by the assumption that the aggregation of point defects may lead to a hardening effect.

The following session of the conference was devoted to the hardness of amorphous solids.

A paper of **M. I. Bessonov, S. K. Zakharov, G. A. Lebedev, and E. V. Kuvshinskii** (Institute of High-Molecular-Weight Compounds, U.S.S.R. Academy of Sciences, Leningrad) gave results of a study of the mechanical fracture of solid polymeric materials. Mechanical fracture is a local process consisting in the appearance, growth, and fusion of separate cracks in the stressed medium under deformation. The authors studied the fracture of polymethylmethacrylate (Plexiglas). Shortly after application of the stress, numerous transverse cracks appear on the surface of the sample. These cracks widen, maintaining their semicircular form. When the dimensions of the cracks become comparable to the distances between them, a stage of concordant growth begins. Fracture takes place by the unrestrained growth of one of cracks resulting from fusion of the crack in question with secondary cracks. It is interesting that in a moderately loaded specimen, cracks may arise and spread through almost the entire cross-section of the specimen without bringing about fracture. A direct connection was established between the fracture of the material and the accumulation of creep deformation.

S. N. Zhurkov, V. A. Marikhin, and A. I. Slutsker (Physico-Technical Institute, U.S.S.R. Academy of Sciences, Leningrad) studied the submicroscopic porosity of deformed polymers. To explain the nature of the clouding which takes place in the deformation of polymer specimens, light scattering, small-angle x-ray scattering, and density changes were studied in polymethylmethacrylate and nitrocellulose. The relation of the light-scattering coefficient to the wavelength, the scattering indicatrix, and the degree of polarization were studied. These all showed that scattering takes place according to the theory of Mie, and is caused by the presence of submicroscopic voids with dimensions of the order of hundreds of Angström units. The same results were obtained from the study of the scattering of x-rays with $\lambda = 1.54 \text{ \AA}$, and from the density changes ($\Delta\rho/\rho \sim 10^{-3} - 10^{-2}$) measured by flotation and by hydrostatic weighing. It is possible that the formation of such voids is the initial stage in the process of fracture of the polymer.

A paper of **G. M. Bartenev** (Institute of Glass, Moscow) was concerned with the influence of the dimensions of the specimen on the strength of glasses. An anisotropic effect was found. In particular, the strength of a glass fiber does not depend on its cross section, but depends on the length and the degree of extension of the fiber. These

data do not agree with the statistical theory of strength, and may be explained by the orientation of long chains formed of silicon and oxygen atoms. The strength of flat glass specimens also depends anisotropically on the dimensions, in that the thickness of the plate has a different effect on the strength from that of the other dimensions. The strength-thickness relation is associated with the differing surface conditions in thin and thick glass specimens. This difference in the conditions is apparently due to the time-dependent thermoelastic stresses which arise in the process of preparation of the glass. These stresses bring about the formation of micro-cracks during vitrification. The dependence of the strength on the other dimensions may be explained by the statistical theory.

A paper by **Hsiao** (University of Minnesota, Institute of Technology, Minneapolis, Minn.) was concerned with molecular orientation and strength of polystyrene. An attempt at interpretation of the experimental data on the basis of a simple model was described. The author assumed that the structure of the polymer may be considered as an aggregation of linear molecular elements which are responsible for the strength of the material. The strength depends on the degree of orientation of these elements, and may be calculated from the orientation azimuths. The author presented data on the unilateral stretching of polystyrene as evidence, in his opinion, of the agreement of the theory with experiment. Those who entered into the discussion did not agree with Dr. Hsiao, and stated that the elementary model which he had considered cannot characterize the strength of polymers.

In a paper by **G. A. Lebedev** and **E. V. Kuvshinskiĭ** (Institute of High-Molecular-Weight Compounds, U.S.S.R. Academy of Sciences, Leningrad), "Stress-Relaxation in High-Elastic Deformation of Amorphous Materials of the Polymethylmethacrylate Type in the Solid State," it was shown that the time for stress-relaxation in rubber-like elasticity increases sharply with decreasing temperature. In the temperature range near the glass-transition point, deformations of appreciable size may appear in a short time only under the action of large stresses. Studies of the conditions for the phenomenon of necking and an analysis of the relaxation times in different regions of the stretching curve were carried out. These showed that the phenomenon differs from the plasticity of metals. When an amorphous polymer is stretched, the ordinary process of stress-relaxation of the high-elastic deformation takes place, and may be described by the equation of Maxwell.

Three papers devoted to the incompletely-crystalline state were presented in the last session.

The paper of **A. S. Akhmatov** and **L. V. Koshlakova** (Institute of Machine and Instrument Building, Moscow), "A Study of the Elastic Properties of Two-Dimensional Molecular Crystals of Fatty Acids Formed on the Surface of a Crystal," discussed the question of the physical nature of the mechanical resistance produced by the adsorption forces at the surface of a metal covered by a layer serving as a lubricant. The authors developed and applied a "multilayer" method which made it possible to carry out very accurate measurements. It was shown that the fatty acids which occur in bulk in an oily or greasy state acquire true elasticity of shape in the boundary layer. The elastic constants of the boundary layers fall off as the thickness of the layer increases; this indicates the inhomogeneity of the boundary-layer phase along the normal to the surface. It was also shown that, when the length of the carbon chain is increased, the shear modulus decreases, while Young's modulus increases. The authors interpreted the data which they had obtained on the basis of the molecular structures. They showed that the tangential resistance to slip is proportional to the square of the number of interacting groups (CH_3 or CH_2), while the normal resistance to extension or compression is proportional to the cube of this number. When the carbon chain is deformed, the compensation of the dipole moments of the C-H bonds is disturbed, with the result of a dipole moment which is a function of the degree of deformation.

M. V. Vol'kenstein (Institute of High-Molecular-Weight Compounds, U.S.S.R. Academy of Sciences, Leningrad) read a paper on the subject, "The Amorphous and Crystalline States of Polymers." The great tendency of polymers to form glasses is the result of the relatively small mobility of the macromolecules. A qualitative theory of vitrification may be based on the study of a kinetic system having one relaxation time. The theory leads to the relation

$$\left(\frac{d\tau}{dT}\right)_{T=T_g} = \left(\frac{dT}{dt}\right)^{-1},$$

where τ is the relaxation time and T_g is the glass-transition temperature. The theory gives a complete qualitative description of all the observable facts concerning vitrification. Incompletely-crystalline polymers must be considered as single-phase systems, as highly defective polycrystals. The defects, or amorphous regions, result from kinetic and steric hindrances to crystallization. The equilibrium state of a monodisperse, regular polymer should correspond to complete crystallinity. The kinetic defects decrease on

heating or swelling, as shown by the methods of x-ray diffraction and infra-red spectroscopy. When an amorphous polymer is stretched, a cooperative process occurs in each chain. This consists in the transition of the coiled rotational isomers into the extended ones, as may be shown directly by polarized infra-red spectroscopy. The author expressed his conviction of the necessity of a re-examination of the modern network theory of high elasticity, taking into account the bundle structure of amorphous polymers (based on the conceptions of V. A. Kargin, A. I. Kitaigorodskii, and G. L. Slonimskii) and the cooperative character of the stretching process.

G. L. Slonimskii and A. I. Kitaigorodskii entered into the discussion, indicating the necessity of a change in the concept of "phase," as applied to crystalline polymers. G. L. Slonimskii presented a conception which had been developed by V. A. Kargin and himself, according to which the equilibrium state of a polymer corresponds to incomplete crystallization.

A paper of A. I. Kitaigorodskii (Institute of Element-Organic Compounds, U.S.S.R. Academy of Sciences, Moscow) studied certain problems in the physics of organic crystals. The free energy of an organic crystal is determined by the density of packing and the symmetry of the molecule in the crystal. When the temperature is lowered, a significant decrease takes place in the distances between atoms which are not in contact with each other. The author connects this phenomenon with the decrease in the role of the entropy component of the free energy. In a number of cases, phase transitions are observed upon heating of crystals; the author designates these as tran-

itions into the "gaso-crystalline" state. In this process, the long-range order in the distribution of the centers of gravity of the molecules is preserved, but order in their orientations is not preserved. The transition from the crystalline to the gaso-crystalline state is similar to melting.

The behavior of mixtures of optical antipodes of gaso-crystalline substances is of considerable interest. Their phase diagram has the form of a horizontal straight line. This may be explained by the maintenance of identical dimensions of the unit cell at all concentrations. A continuous transition takes place in these solutions from non-centrosymmetric to centrosymmetric crystals. In concluding, the author mentioned the anisotropic electrical conductivity of organic crystals and its dependence on the nature of the packing of the molecules. In the discussion, it was noted that the concept of a gaso-crystalline phase completely coincides with the concept of orientational melting which had been developed at one time by Ya. I. Frenkel'.

In his concluding remarks, A. F. Ioffe noted the scientific value of the series of presented papers and of the discussion, and expressed his conviction that the discussion at the conference had significantly clarified the problem of dislocations.

In the name of the foreign participants in the conference, Dr. Gilman expressed his thanks to the Organizing Committee, and noted the success of the conference as a step in the direction of establishing close international cooperation among scientists.

Translated by M. V. King