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Future Meetings.

A Symposium on "Rheological Research in the Textile Industry" will be held on Thursday and Friday, 7th and 8th June, 1956 at the British Rayon Research Association Heald Green Laboratories, Wythenshawe, Manchester 22. Intending visitors are asked to inform Dr. A. S. Lodge at the laboratories. Those wishing to contribute a paper should send an abstract to the Secretary, British Society of Rheology, 52 Tavistock Road, Edgware, Middlesex, as early as possible. Programmes are being circulated separately.

"Extrusion and Rolling Processes." This meeting will be held at the University of Sheffield, on September 27th and 28th, and will include a visit to the B.I.S.R.A. laboratories. The Annual General Meeting will also be held during this conference.

"Rheological Control of Industrial Processes." This meeting has been tentatively arranged for December.

Members who would like to give papers at either of these meetings are invited to write to the Hon. Secretary.

News of Members.

Obituary. Mr. Pryce-Jones has died, after a long and severe illness, at the Cardigan Memorial Hospital, Cardigan.

Prof. Dr. Ir A. Van Rossem, Kanaalweg 10, Delft, Netherlands, has now retired. He has kindly consented to continue as an abstractor for our Bulletin.

Sir Geoffrey Taylor, President, 1940-1942, has been elected to the Royal Academy of Science of Sweden.

Mr. S. W. Butterworth has been appointed Chief Chemist of the Central Research laboratories of Joseph Rank Ltd.

New Members.

P. L. Kirby, M.Sc., A.Inst.P., New Research Laboratories, Rowntree & Co. Ltd. Suspensions, Viscometry, Confectionery.

K. K. Schiller, Dr. Phil. A.Inst.P., British Rayon Research Assoc., Heald Green Laboratories, Wythenshawe, Manchester. Textile materials, especially in bulk form, Fundamentals.

D. W. Saunders, B.Sc., A.R.C.S., British Rayon Research Assoc., Heald Green Laboratories, Wythenshawe, Manchester. Polymers and Photoelasticity.

I. Hlynka, B.Sc., M.Sc., Ph.D., F.C.I.C., Grain Research Laboratories, 886 Grain Exchange Buildings, Winnipeg, Canada. Dough, stress and structural relaxation, load extension tests, shear and consistency measurements, mixing behaviour.

G. R. Southern, B.Sc., Grad. Inst. P., c/o 20B Bedford Way, W.C.1. Sound recording media, extension plastometers, rotation viscometry.

Prof. B. Tamamushi, Dr. Sc., 865 Komaba-machi, Meguroku, Tokyo, Japan. Rheology of Colloidal Systems.

Nederlandse Reologische Vereniging.

Dr. A. J. Staverman is the new President following Dr. Saal. The Vice-President, Prof. Burgers is now in America. Dr. P. G. Meerman, Wieënweg 28, Brunssum (L), Netherlands, is the Secretary-Treasurer.

It is hoped to organise a meeting in May to discuss a new proposal for a Rheological Nomenclature. In the recent Netherlands revision of orthography all Rh's have lost the h, so that Rheologisch is now Reologisch.

Abandonment of Master Saybolt Viscometers as Standards.

The National Bureau of Standards announces its intention to abandon after June 30th, 1956, the use of the Master Saybolt Viscometers as standards for the calibration of Saybolt Universal and Saybolt Furol Viscometers which are widely used in the petroleum industry to measure viscosities of lubricating and fuel oils. Published standard conversion tables and factors for the conversion of kinematic viscosities to Saybolt viscosities provide more precise definitions of the Saybolt viscosity scales than do the master instruments.

SUMMARIES OF PAPERS

read at the Symposium on the Rheology of Proteins, held at the Institute of Physics, January 20th, 1956.

Some Rubber-like and Relaxation Properties of Gelatin

By D. W. JOPLING of Research Laboratories, Kodak Ltd., Harrow, Middx.

Gelatin gels containing 90-95 per cent water can only be extended by about 20 per cent before rupture, but if the amount of water in the gelatin is controlled at about 25-30 per cent by weight, by maintaining the gelatin sheet at a high humidity or by immersing it in an alcohol-water mixture with about 85 per cent alcohol, then the gelatin exhibits high elasticity and may be extended by several hundred per cent before rupture. This is especially so if the gelatin is first contracted in boiling methyl alcohol in order to destroy the ordered arrangement caused by anisotropic drying^{1,2}

Gelatin sheets in which the molecules have been crosslinked with formalin may also be treated in this way, and they may then be examined at a temperature sufficiently elevated as to make it likely that normal gelling bonds are absent. When such gelatins are maintained at 60°C. in 85 per cent methyl alcohol, the stress required to cause a given strain decreases rapidly with the time of immersion at first but then remains constant after about 24 hr.

Gelatin in 85 per cent methyl alcohol at 25°C. relaxes so that the stress decreases approximately linearly with the logarithm of the time. At 60°C. the relaxation is Maxwellian: $\log S = A - Bt$ where S =stress, t =time and A and B are constants. At 40°C. the relaxation of stress is at first proportional to $\log t$, but becomes Maxwellian after long times. The time scale examined was from 0.25 to 10,000 minutes. It is suggested that at 25°C. the gelatin has a wide distribution of relaxation times due to a wide distribution of strengths of bonds, ranging from single hydrogen bonds to the covalent bonds formed by the formalin links. At 60°C., at least after the steady state has been reached, the bonds between the gelatin molecules are almost entirely covalent bonds and are of roughly the same strength, while at 40°C. certain of the stronger of the assemblages of low energy bonds still exist; but these relax during the first 1000 minutes to leave the stress being taken by the covalent bonds.

If that is the case, then it should be possible to calculate the density of the residual, high-temperature-resistant cross links from the theory of rubberlike elasticity, using the equation:

$$M_c = \frac{\rho R T v^{\frac{1}{3}}}{S} \left(a - \frac{1}{a^2} \right)$$

ρ = density
 T = absolute temp.
 v = volume fraction
 S = stress
 M_c = M.W. between crosslinks
 a = extension ratio

For gelatins containing amounts of formalin varying from 0.5 to 5 mmole. formalin/gm. gelatin, the final level of the stress at 60°C. is approximately proportional to the formalin content, but when the above equation is applied, values of M_c are obtained which are much greater than would be expected, and are in some cases even greater than the average molecular weight of the gelatin. This could be due to :

1. The theory not being applicable in this case owing to some cause such as strong interactions between the chains. This is unlikely, since it has been applied with success to the tanning of collagen^{3, 4, 5}.

2. The effect of the molecular weight of the gelatin; the molecular weight being so low that a large amount of the formalin is used up in linking the molecules together to form a single molecule, in which case there should not be a proportionality between formalin content and stress.

3. A large proportion of the hardener bonds having been destroyed by the time the final level of the stress is reached at 60°C.

This point has not yet been resolved.

The other Summaries will be given in the next Bulletin.

¹ Bradbury and Martin, *Nature*, **168**, 837 (1951).

² Bradbury and Martin, *Proc. Roy. Soc. [A]* **214**, 183 (1952).

³ Wiederhorn and Reardon, *J. Polymer Sci.*, **9**, 315 (1952).

⁴ Wiederhorn, Reardon and Browne, *J. Amer. Leather Chemists Assoc.*, **48**, 7 (1953).

⁵ Schleichter and Lollar, *J. Amer. Leather Chemists Assoc.*, **49**, 414 (1954).

From U.S.S.R. Colloid Journal, 1955, 17 (4), 332-336

Translated and summarized by R. I. Lithgow, M.E.R.L.

Review on the work of the Rheology Section of the Council on the theory of elasticity, of plasticity and theoretical problems of structural mechanics, conducted by the Institute of Mechanics of the U.S.S.R. Academy of Sciences and the Mechanics-Mathematics Faculty of Moscow State University. Meeting 22nd-26th December, 1954.

Sections : Theory of (a) elasticity, (b) plasticity, (c) plates and shells, (d) structural mechanics, (e) soil mechanics and (f) rheology.

(5 sessions with 12 reports reviewing rheological processes in dispersed systems and high-molecular compounds.)

The president, M. P. Volarovich, made observations on the wide use of rheological methods covering structural and mechanical properties of extremely varied dispersed systems in different branches of industry, on the success of Russian studies of rheological principles, on characteristics and processes, involving the elasto-visco-plastic deformation of hard bodies and on easily-deformed dispersed systems such as large visco-plastic deformations during flow, high gradients of speed and presence of thixotropy.

The President emphasised the need for closer connection between mechanics, physics and other branches of science for the successful development of rheology.

The following papers were presented :—

P. A. REBINDER—"Structural-Mechanical properties of dispersed systems and methods of their investigation." Molecular cohesion of particles; two groups, fluid-type and hard-type. 3-dimensional structures; two groups, reversible rupture and non-reversible rupture.

G. V. VINOGRADOV—"Some problems of the rheology of highly-concentrated dispersed systems." Mechanical problems of highly concentrated pastes and pseudo-jellies and comparison with plastic and highly-elastic jellies of high polymers. Mechanism of plastic flow—constant rupturing and restoration of metacrystalline bonds. Quantitative method of study. Peculiarities of viscous properties of highly-concentrated dispersed systems.

G. M. BARTENEVA—"Theory of temperature-time relation of stability of hard bodies" (a) Rupture under uniaxial load (b) loads less than critical (c) critical loading. Formula obtained is generalization of BRUSSE-ZHURKOV formula and is in agreement with experiment.

Yu. S. LAZURKIN—"Some laws of the deformation of polymers in a hard condition." Glass type or crystalline—peculiarities in structure and mechanical properties—main peculiarity. Basic laws and theories of phase transformation.

D. M. TOLSTOI—"Mechanism of gliding of dispersed systems." Coefficient of gliding

B. V. DERYAGIN and S. M. LEVI—"Questions of Rheology in the production of light-sensitive materials." Coating photo-sensitive materials; general case-equation of visco-plastic flow (SHVEDOV). Formula obtained. Einstein's viscosity formula—differential; measurement on viscous solutions of gelatine. Formula for coating has defined limits of application.

N. V. MIKHAILOV—"Investigation and results on flow and stability of structures of dispersed systems." Curve of stress/deformation (constant rate of strain) depends on value of system's reaction period.

A. A. TRAPEZNIKOV—"Rheological Systems." New hypothesis on the complex of parameters. Systems subdivided into hard and fluid plastic—time of reaction.

D. S. VELIKOVSKII—"Thixotropic transformation of consistent greases." Method of measuring structural stability in process of mechanical reaction. (a) normal thixotropy, (b) thixostable, (c) giving different forms of thixotropic fatigue, (d) anomalous thixotropic break-down and (e) dilatant.

M. P. VOLAROVICH and GUTKIN—"Theory of flow of a visco-plastic medium." SHEVDOV-BINGHAM equation is sufficiently accurate. Basic rôle played by viscous properties of system.

G. I. FUKS—"Integral characteristics of resistance to deformation of dispersed systems." Differential methods of studying deformation; fluctuations of pressure on different sectors of flow.

N. V. LAZOVSKAYA—"Rheological properties of peat." Processes of its flow; results of studying external friction and adhesion of peat.

General Discussion.

The importance and industrial significance of the general theoretical work by REBINDER, VOLAVORICH and others. Investigation of nutritive products—instrument to measure rheological properties of dough; difficulties in creating similar fields of stress and deformation and need to study complex stress conditions. Investigations of visco-plastic properties of soap, resin, milk fat, etc. Rheological properties of oils (using rotational instrument). Processes of development of deformation in dispersed systems—constant speed or constant stress.

Significance of the work of N. V. MIKHAILOV. Objections to division of systems into fluid-plastic and hard-plastic according to the reaction time. Investigation of maxima

on curves of stress-deformation. Use of polarization-optical method of studying flow of high-polymer systems. Need for molecular-colloidal interpretation of processes occurring during flow of colloidal and high-molecular systems. Need to investigate elastic stability properties of dispersed systems for different rates of strain. New instruments for rheological investigations. Insufficiently close co-operation with other sections of the Council, e.g., sections on theory of plasticity, soil mechanics, etc. Need for development of molecular model representations of the mechanical properties of elasto-visco-plastic systems.

Classification suggested for rheological systems. Questions of theoretical rheology. New methods have been developed for approximate solution of flow (cases not permitting linearization of basic equations) and there have been some successes in working out molecular-kinetic theory of rheological processes. Rheological characteristics of easily-deformed materials have been obtained, also rheological parameters of industrially important dispersed systems.

Future Problems.

- (1) Working-out of molecular mechanism of processes of flow of structural dispersed systems, and development of the molecular-kinetic theory of rheological forms.
- (2) Wider use in rheological investigations of contemporary methods of studying the structure of materials (electron microscope, X-ray structural analysis, ultrasonic, etc.).
- (3) Maximum systematic study of full rheological characteristics of dispersed systems and high polymers with a study of the forms of thixotropy for making the rheological classifications of these substances more precise and for the establishment of relations, to which are subject the processes of their deformation and flow.
- (4) Theoretical solutions of industrially important cases of elastic and plastic deformations, and also the flow of visco-plastic media.
- (5) Development of experimental and theoretical investigations of rheological forms under a complex stressed condition.
- (6) Unification and standardization of existing rheological methods and instruments and development of new instruments and methods for rheological investigations.
- (7) Establishment of standard rheological nomenclature.

For the successful development of rheological research in U.S.S.R., the systematic functioning of a constantly active commission, which would co-ordinate research in the field of rheology is necessary in the U.S.S.R. Academy of Sciences.

RHEOLOGY ABSTRACTS

3229. X-ray diffraction studies of crystallization in elastomers.

L. E. ALEXANDER, S. OHLBERG AND G. R. TAYLOR. *J. appl. Phys.*, 1955, **26**, 1068. A.

3230. Stress relaxation in gold wire.

O. L. ANDERSON AND P. ANDREATCH, *J. appl. Phys.*, 1955, **26**, 1518.

Experiments on stress relaxation have been performed on gold wires at 25°, 70°, 100° and 150°C. and the results indicate that the activation energy associated with the relaxation decreases uniformly as the stress increases. S.T.

3231. Retraction of oriented polystyrene monofilaments.

R. D. ANDREWS. *J. appl. Phys.*, 1955, **26**, 1061.

3232. Experimental examination of the statistical theory of rubber elasticity. Low extension studies.

F. P. BALDWIN, J. E. IVORY AND R. L. ANTHONY. *J. appl. Phys.*, 1955, **26**, 750.

An experimental study was made of the behaviour of two rubbers, Butyl (GR-I-18) and Paracril-35, in the low extension region (0 to 15%), at temperatures ranging from -40°C. to 60°C. The results have been compared with the Guth-James theory of rubber elasticity. In general, good agreement with theory was observed. Two effects predicted by the theory have been confirmed, namely, the nonlinear dependence of stress upon temperature at constant extended length, and the shift of the thermoelastic inversion extension to higher values with increasing temperature. Small deviations, which increased with increasing extension and with decreasing temperature, were observed. A.

3233. Calculation of the complex modulus of linear viscoelastic materials from vibrating reed measurements.

D. R. BLAND AND E. H. LEE, *J. appl. Phys.*, 1955, **26**, 1497.

Two methods of determining the variation of real and complex modulus with frequency from vibrating reed test results are detailed. One is based on measurements of the relative amplitude and phase lag of the motion of the free and driven ends of the reed, the other on amplitude resonance measurements only. The analysis is based on a general linear viscoelastic law, and takes into account the influence of the frequency dependent moduli of the material on the frequency and amplitude of the resonance peaks. This influence has not been correctly accounted for in previous analyses which have included the assumption that the material behaves according to a particular, simple viscoelastic law, which will in general not be borne out by the final results. The method is applied to a series of tests. For the material and frequency range used the imaginary part of the complex modulus was small compared with the real part, and the influence mentioned in the foregoing was small. A simpler method of analysis might thus be justified, but in other cases it will be necessary to carry out the complete analysis in order to obtain a satisfactory interpretation of test results. Authors.

3234. Glass transitions in polymer-plasticizer systems.

L. BRIETMAN. *J. appl. Phys.*, 1955, **26**, 1092.

3235. Tensile strength of plastics above the glass temperature.

F. BUECHE. *J. appl. Phys.*, 1955, **26**, 1133.

3236. Viscoelasticity of poly methacrylates.

F. BUECHE. *J. appl. Phys.*, 1955, **26**, 738.

Variation of the viscous and elastic properties is studied as a function of temperature in the range $60 < T < 160^{\circ}\text{C.}$, as a function of molecular weight in the range $5 \times 10^3 < M < 5 \times 10^6$, and as a function of plasticizer concentration over the range 0–100%. A.

3237. Gel formation by main-chain fracture of long-chain polymers.

A. CHARLESBY. *Proc. Roy. Soc. A*, 1955, **231**, 521–34.

It is assumed that the two end-groups produced at a fractured site can attack neighbouring molecules, and link themselves to them. For an initially random distribution gel formation will first occur when one molecule in three is thus fractured. The sol fraction is found to equal $(i/3r)^2$, where r/i is the average number of fractures per molecule; with increasing fracture density the sol therefore tends to zero. Where only a proportion of the fractures result in linking, the sol fraction decreases to a limiting value. To distinguish the process from that usually referred to as crosslinking, the term endlinking is proposed. A.

3238. The measurement of cheese firmness.

C. P. COX, *Dairy Ind.*, 1955, **20**, 1030.

A further statistical study of data of Harper and Baron (Abstr. 1656, 2006) on comparisons of sphere hardness tests with subjective assessment of firmness of cheese by handling.

Author prefers to define firmness, neither in fundamental dimensional terms, nor through subjective assessments, but by a standardized sphere-hardness technique. G.W.S.B.

3239. Equivalent-radius method for determination of Non-Newtonian flow curves from viscometric data.

K. H. CRAM AND J. C. WHITWELL. *J. appl. Phys.*, 1955, **26**, 613.

3240. Viscosity and elasticity of oil surfaces and oil-water interfaces.

D. W. CRIDDLE AND A. L. MEADER, JR. *J. appl. Phys.*, 1955, **26**, 838.

A study of the rheological properties of lubricating oils was made by means of semiquantitative measurements of the viscosity and elasticity of surface and interfacial films. The aged viscous surface and interfacial films studied were found to be non-Newtonian. A.

3241. A rheological equation of state which predicts non-Newtonian viscosity, normal stresses, and dynamic moduli.

T. W. DEWITT. *J. appl. Phys.*, 1955, **26**, 889.

3242. The flow of glass.

R. W. DOUGLAS. *Trans. Brit. Ceram. Soc.*, 1954, **53**, 748.

In a certain range of temperature, silicate glasses exhibit delayed elasticity. The flow curves can be analysed in terms of the usual spring and dashpot elements but it is pointed out that in this same temperature range the physical properties of the glass can be observed to change with time. Such changes can, of course, affect the shape of the flow curves. If the properties change with time, the curves from repeat experiments will be of different shapes, but if the shape is determined entirely by visco-elastic effects repeat experiments should give the same curves. A brief discussion is given of the changes in physical properties of glasses with time, and their underlying causes. This is followed by a description of some experiments on the release of stress in fused silica in which the time variation of properties is separated from the visco-elastic effects. (20 figs.) A.

3243. **Application of the superposition principle and theories of mechanical equation of state, strain, and time hardening to creep of plastics under changing loads.**

W. N. FINDLEY AND G. KHOSLA. *J. appl. Phys.*, 1955, 26, 821.

The superposition principle and the theories of mechanical equation of state, strain and time hardening were applied to the creep under changing loads of four unfilled thermoplastics. The theoretical results predicted by these theories and the experimental results showed good agreement. D.J.K.

3244. **Isothermal viscosity-molecular weight dependence for long polymer chains.**

T. G. FOX AND S. LOSHAEK. *J. appl. Phys.*, 1955, 26, 1080.

3245. **Temperature dependence of viscosity and its relation to vapour pressure for associated liquids.**

L. A. GIRIFALCO. *J. Chem. Phys.*, 1955, 23, 2446.

On the basis of a model for the flow mechanism of associated liquids a theoretical relation between the viscosity and temperature of the type $\log \eta = a/T^2 + \beta/T + \gamma$ where a , β and γ are constants, is obtained; and a similar equation of the form $\log P = -A/T^2 - \frac{B}{T} + C$ is shown to hold for the vapour pressure-temperature relation. S.T.

3246. **Apparatus for making simultaneous stress and birefringence measurements on polymers.**

E. F. GURNEE, L. T. PATTERSON AND R. D. ANDREWS. *J. appl. Phys.*, 1955, 26, 1106.

3247. **The motion of a visco-plastic medium within the narrow space between two rotating cones.**

A. M. GUTKIN, *Kolloidnyi Zh.*, 1955, 17, 421.

Math. treatment for cones differing by small angles only.

G.W.S.B.

3248. **Investigations on the plasticity of ceramic bodies.**

T. HAASE. *Silikat Tech.*, 1954, 5, 429.

Mainly speculative, with no definite results or conclusions. The evaluation of plasticity by Kohl's method (measurement of dry breaking strength) is discussed on the basis of fracture photographs. As tensile stresses are generally inclined 45° to the slip planes, cracks will appear the later the more easily the material can slide and the greater the cohesion (tensile strength) of the particles. Plasticity is stated to be proportional to the tensile strength and inversely proportional to the viscosity. The improvement of plasticity by de-airing is attributed to increased cohesion resulting from the external atmospheric pressure. Another point discussed is the improvement of plasticity by rapid shaping, e.g. shaping by friction pressing, throwing clay into moulds, the process on the potter's wheel, where the material is deformed rapidly, etc. (14 figs.) A.

3249. **The viscosity of liquid helium II.**

W. J. HEIKKILA AND A. C. HOLLIS-HALLETT. *Canad. J. Phys.*, 1955, 33, No. 8, 420-35.

It has been found possible to use the rotating cylinder viscometer to measure the viscosity of liquid helium II between 1.13°K and 2.18°K provided that the fluid velocities do not exceed about 0.08 cm.sec^{-1} . The results, which are calculated directly from experimental observations and do not require any knowledge of the density of the normal component, can be made to fit the Landau and Khalatnikov theory for the temperatures below 1.8°K for which the theory is applicable. The results are somewhat higher than the oscillating disk results above 1.4°K . A.

3250. Interrelation of gaseous viscosity, self-diffusion, and isotopic thermal diffusion.

E. M. HOLLERAN, *J. Chem. Phys.*, 1955, **23**, 847.

The general interrelation of the theoretical first approximations to viscosity, self-diffusion, and thermal diffusion previously derived is modified to conform with a simpler and more accurate approximation for the thermal diffusion ratio due to Kihara. The accuracy and limitations of this interrelation are discussed, with particular regard to the effect of considering higher approximations to the transport properties. With the recently published results for the modified Buckingham potential as a guide, the relation is further simplified, leading in particular to an approximate relation between viscosity and thermal diffusion which is shown to be in good agreement with the experimental data for argon.

Author.

3251. Elastic-plastic instability caused by the size effect and its influence on rubbing wear.

F. V. HUNT, *J. appl. Phys.*, 1955, **26**, 850.

3252. The relaxation of stress in fused silica. I. Experimental.

J. O. ISARD AND R. W. DOUGLAS. *J. Soc. Glass Technol.*, 1955, **39**, 61 T.

It is shown that the relaxation of stress in fused silica can be expressed by the equation $(S/S_0)=f(t)$. If the material is uniform in composition and previous heat treatment, and after a given time-interval the stress at a point has fallen to half its value at that point at the beginning of that time-interval, the stress at any other point will also have halved its value in the same time-interval. For a Maxwellian body $(S/S_0)=\exp. (-Gt/\eta)$, where G =rigidity modulus, η =coefficient of viscosity. Vitreous silica does not behave as a Maxwellian body in this respect for two reasons: (1) if the material is not in configurational equilibrium, η changes with time; (2) even when in configurational equilibrium, the exponential decay of stress is not found, and this is attributed to the effect of "delayed elasticity" or "viscoelasticity."

A.

The relaxation of stress in fused silica. II. Theoretical.

J. O. ISARD AND R. W. DOUGLAS. *J. Soc. Glass Technol.*, 1955, **39**, 83 T-98 T.

It is shown that the experimental relation $(S/S_0)=f(t)$ would be expected, both in Maxwellian body and in a body exhibiting delayed character of an irregularity in the relative arrangement of many vortices. A statistical principle for determining the functional form of P is described, based on the physical meaning of the ergodic hypothesis in statistical mechanics. Finally, $\bar{V}^2$ and $\bar{V}^{*2}$ are discussed hydrodynamically with reference to the known solution of the Navier-Stokes equations for a certain vortex motion.

A

3253. On the viscoelastic properties of polymethyl methacrylate.

S. IWAYANAGI. *J. Sci. Res. Inst. [Tokyo]*, 1955, **49**, 4.

Torsional creep measurements on PMMA (polymethyl methacrylate) were carried out to 140°C. with results supporting the concept of "semipermanent network structure." Relaxation curves obtained with PMMA in the temperature range from -40 to 130°C. fall into low- and high-temperature groups. Supposing the polymer is "thermo-rheologically simple" within each of these ranges of temperature, master relaxation and creep curves are constructed, and the temperature functions $\kappa(T)$'s, and therefrom the activation energies are determined separately. All the viscoelastic data on PMMA, both transient and vibrational as well as dielectric, obtained by various authors up to the present are summarized in a "transition map" and compared with one another.

A.

3254. Dynamical measurements on the viscoelasticity of polymethyl acrylate.

S. IWAYANAGI. *J. Sci. Res. Inst. [Tokyo]*, 1955, **49**, 13-22

The temperature-dependence of complex shear modulus of PMA (polymethyl acrylate) is studied by three measuring methods employing (1) pendulums of frequency 0.5 c/s, (2) a twin transducer (from 100 to 400 c/s) and (3) a tuning fork of natural frequency 1,000 c/s. The activation energy for viscoelastic deformation of PMA is de-

terminated as ~ 75 kcal/mol different from the value of ~ 60 kcal/mol found for dielectric orientation. Contrary to the case of polymethyl methacrylate, the secondary anomalous absorption region cannot be observed separately from the primary. A.

3255. **On the viscoelastic properties of linear amorphous polymers in relation to their molecular structure (polymethyl methacrylate and acrylate).**
S. IWAYANAGI. *J. Sci. Res. Inst. [Tokyo]*, 1955, **49**, 23-34.

The experimental facts, both viscoelastic and dielectric, concerning the existence of a secondary anomalous absorption region beside the primary one in the case of polymethyl methacrylate and the inter-blending of these two regions of the case in polymethyl acrylate, are summarized and reviewed. The nature of secondary anomalous absorption is clarified to some extent in terms of the orientation of polar ester groups of these polymers and of the steric hinderance due to methyl groups of polymethyl methacrylate. A.

3256. **Investigation of the structural-mechanical properties of concentrated aqueous suspensions of cement in the settling process.**

E. E. KALMYKOVA AND N. V. MIKHAILOV. *Colloid Journal (U.S.S.R.)*, 1954, **16** (5), 341.

Studies were made by means of an electronic Selsyn apparatus based on the principle of pure shear in the space between two co-axial cylinders. The elasto-viscoplastic properties of cement pastes and the kinetics of structure formation during setting and hardening can be represented in terms of P_k (limit of flow) and η (maximum plastic viscosity); the plasticity coefficient P_k/η characterizes the plasticity of the cement paste itself. Relations between P_k , η , water/cement ratio and time are established mathematically and discussed. B.S.A.

3257. **Ball test for field control of concrete consistency.**

J. W. KELLY AND M. POLIVKA. *J. Amer. concr. Inst.*, 1955, **26** (9), 881-8.

A simple laboratory and field test for determining the consistency of fresh concrete is described. The method is based on the penetration of a 30 lb. hemispherical weight and is claimed to give better control than the "slump" test. D.J.K.

3258. **Theory of one-dimensional fluid binary mixtures.**

R. KIKUCHI. *J. Chem. Phys.*, 1955, **23**, 2327.

The rigorous solution of a one-dimensional fluid binary mixture with arbitrary interparticle potentials is obtained under the assumption that a particle interacts with its nearest neighbours, and that the system obeys classical statistical mechanics. This rigorous solution provides the interpretation of parameters used in the lattice model of binary mixtures. Author.

3259. **Stress-strain relations in snow under uniaxial compression.**

J. K. LANDAUER. *J. appl. Phys.*, 1955, **26**, 1493.

3260. **The millability tester, an apparatus for studying the milling properties of hard materials.**

H. LEHMANN AND U. HAESE. *Tonindustrie-Zeitung*, 1955, **79**, 91.

The millability of hard materials is measured by the increase in specific surface (cm^2/g) caused by the work applied to the material (mkg/g) by a modified Hardgrove ball mill. Previous German work on millability (of cement) was done by H. G. YEISEL, *Verein Deutscher Zementwerke e.V., Düsseldorf*, 1953, **14**, 31-72. R.H.S.R.

3261. **Young's modulus of crystalline, unstretched rubber.**

M. LEITNER. *Trans Faraday Soc.*, 1955, **51**, Pt. 7, 1015.

A specimen of raw, unstretched rubber was allowed to crystallize at 0°C . Measurements of the density and of Young's modulus were taken at intervals while crystallization was in progress. When crystallization had effectively ceased, step-wire melting was achieved by gradual warming and measurements were made on the partially melted speci-

men. Thus, the correlation between the degree of crystallinity of the material and its Young's modulus was established. There appears to be no obvious interpretation of the observed hundred-fold increase in modulus at present. A.

3262. The flow of aluminous refractory products at high temperatures.

Y. LETORT *Trans. Brit. Ceram. Soc.*, 1955, **54**, 1.

Test specimens of 30-mm. side and 50-mm. high, were placed under a load of 12 kg/cm.² in a Meker type apparatus and the deformations at a fixed temperature of 1,350°C. were determined over a period of 2½ hr. It was found that the temperature of firing had a far greater effect on the rate of flow than either chemical composition or apparent porosity. The method of manufacture can also have an important influence, high moulding pressures and high grog contents being conducive to low rates of flow. (10 figs., 13 tables.) A.

3263. A cone-and-plate viscometer.

H. MARKOVITZ, L. J. ELYASH, F. J. PADDEN, JR. AND T. W. DEWITT. *J. Colloid Sci.*, 1955, **10**, No. 2, 165-73.

A weight-driven cone-and-plate viscometer is described. It has a simpler construction and can be used over a wider range than some other instruments of this type. Liquids with viscosities from 1 to 50,000 poises have been investigated, and rates of shear from 0.0002 to 9,000 sec⁻¹ have been achieved with this instrument. With one filling of the viscometer, a 1,000- to 30,000-fold range of rates of shear can usually be covered. With concentrated polymer solutions, it is practically always possible to determine the zero shear viscosity. A.

3264. Low shear capillary viscometer with continuously varying pressure head.

S. H. MARON AND R. J. BELNER. *J. appl. Phys.*, 1955, **26**, 1457.

A capillary viscometer is described for the study of the flow behaviour of non-Newtonian fluids at shear stresses of 0.06-20 dynes/cm². The all-glass instrument consists of two units connected by a ball joint, one unit of which contains the capillary while the second is essentially a manometer. As the test fluid moves through the capillary, the rate of rise of the fluid in the manometer is observed. This measurement of the column height as a function of time allows calculation of both pressure drop and rate of flow. Different combinations of capillary and manometer units can be employed interchangeably to study liquids of widely varying viscosities. Data and methods are presented which show that the instrument can be used to determine the absolute viscosities of Newtonian liquids and the flow curves of non-Newtonian fluids over the indicated shear stress region. Authors.

3265. A New concept of clay plasticity.

C. L. MARSHALL. *Bull. Amer. Ceram. Soc.*, 1955, **34** (2), 54-6.

Clays and standard clay minerals are evaluated for plasticity using the Brabender Plastograph. D.J.K.

3266. A versatile absolute rotating cylinder plastometer.

P. MASON AND L. M. SMITH. *J. sci. Instrum.*, 1955, **32**, No. 7, 275.

The construction and method of use of a rotating cylinder plastometer with a wide annulus are described. Absolute shearing stress-strain-time data can be obtained for liquids with viscosities in the range 10⁴ to 10¹² poises as well as for pastes of a wide range of consistency. Continuous loading can be used to produce shearing stresses in the material ranging from about 50 to 5 × 10⁶ dyn/cm². transient loading with variable duration and frequency can also be applied from about 10⁴ dyn/cm² upwards. A stress range of 20 : 1 can be covered in one test. Examples of application to the study of rubber-bitumen systems and asphalts are given. A.

3267. Diffusion controlled stress relaxation.

R. H. McMICKLE AND E. T. KUBU. *J. appl. Phys.*, 1955, **26**, 832.

3268. Contribution to the study of transport phenomena in gases at high densities.

A. MICHELS, J. A. M. COX, A. BOTZEN AND A. S. FRIEDMAN. *J. appl. Phys.*, 1955, **26**, 843.

The results of recent measurements of the viscosity and thermal conductivity of argon have shown the importance of studying these transport phenomena over a large density range in different regions of the reduced temperature. A.

3269. Theory of viscoelasticity of amorphous polymers.

O. NAKADA. *J. Phys. Soc. Japan*, 1955, **10**, No. 9, 804.

A statistical mechanical theory of the inter-chain relaxation in amorphous polymers is presented. The generalized diffusion equation of configurational changes of a chain imbedded in polymer environment is solved for a dynamical case under suitable potentials assumed. The derived spectrum of relaxation times just coincides with the experimental formula of the wedge-type spectrum found by Tobolsky for polyisobutylene, manifesting a characteristic slope of $-1/2$ in the log-log plot of the relaxation spectrum. A.

3270. On the application of the kinetic theory of liquids of Born and Green to the problem of the calculation of the volume viscosity.

R. E. NETTLETON. *J. Chem. Phys.*, 1955, **23**, 1560.

A formula for the bulk viscosity of a gas is quoted and the method by which this is obtained is explained very briefly. S.T.

3271. The effect of interfacial stabilizing films on the elastic and viscous properties of emulsions.

J. G. OLROYD. *Proc. Royal Society, A*, 1955, **232**, 567

The investigation in a previous paper (Oldroyd, 1953) of the elastic and viscous properties of a dilute emulsion of one incompressible viscous liquid in another, when subjected to small variable rates of strain, is extended to include the possibility of an interfacial film being present everywhere between the two components, which resists deformation as a result of internal friction or of elasticity. When the film is purely viscous its presence has no effect on the *type* of elastico-viscous behaviour of the emulsion, although the values of the viscosity, relaxation time and retardation time of the system are altered. When the film is ideally elastic, the viscosity in slow steady flow is the same as that of a suspension of solid particles, and two relaxation times and two retardation times are required to describe the elastico-viscous behaviour of the emulsion completely. When the interfacial film shows more complicated elastic and viscous properties combined, these can be described by means of two operators (expressible in terms of d/dt) taking the place of elastic moduli. A viscosity operator describing the macroscopic elastic and viscous properties of the emulsion is calculated in terms of the elasticity operators of the film in the general case. Author.

3272. Flow of peat-water mixes through tubes.

I. I. ORLOV, *Kolloidnĭ Zh.*, 1955, **17**, 434.

A study of the change-over from streamline to turbulent flow. Critical Reynolds number is calculated from yield-value and plastic viscosity. G.W.S.B.

3273. Creep of refractory materials.

J. H. PARTRIDGE. *Trans. Brit. Ceram. Soc.*, 1954, **53**, 731.

Most refractory materials consist of crystals set in a glassy matrix and the rate of creep of specimens subjected to low tensile stresses of 500 to 1,000 g/cm.² at temperatures in the region of 1,350°C. has been used to study the characteristics of this inter-crystalline glassy cement. It is shown that the flow of fired specimens of china and ball clays appears to be an exponential function of temperature and is governed by the viscosity of the glassy matrix. (6 figs., 5 tables.) A.

3274. The viscosity of linear and branched-chain polymers.

A. PETERLIN. *Z. Naturforsch.*, 1955, **10a**, No. 5, 412-19.

The modified Flory equation can represent the whole course of the viscosity curve for straight and branched-chain polymers. The linear polymers have a curve of viscosity v . degree of polymerization with a steadily decreasing slope, whereas branched polymers show a steady rise, if the monomer and low molecular weight parts are neglected. A.

3275. Intrinsic viscosity of polymethylmethacrylate.

A. PETERLIN. *J. Chem. Phys.*, 1955, **23**, 750.

In this letter the intrinsic viscosity of polymethylmethacrylate solutions is considered on the light of a proposed model of the molecule, and the dependence of the viscosity in the molecular weight is discussed. S.T.

3276. Preliminary results in measuring dynamic compressibilities.

W. PHILLIPLOFF AND J. BRODNYAM. *J. appl. Phys.*, 1955, **26**, 846

To supplement dynamic measurements in shear and bending, the vibration tester of the Franklin Institute was used to measure the bulk compressibility of plastics. Polyethylene and plasticized polyvinyl chloride were investigated. The values of the compressibility were comparable to the static values as far as they are known. A noticeable phase shift between pressure changes and volume changes could not be detected with certainty so that the bulk modulus B in dynes/cm.² is not a complex quantity. Especially for the polyethylene, a temperature range from -25 to $+95^{\circ}\text{C}$. and a frequency range from 0.0003 to 5 cps. was used. The isothermals obtained could be shifted together using the method of reduced variables of Ferry. From the frequency shifts A_r , an activation energy of 60 kcal/mole was obtained. Authors.

3277. On the stability of the spherical shape of a vapour cavity in a liquid.

M. S. PLESSET AND T. P. MITCHELL. *Q. appl. Maths.*, 1956, **13**, 419.

3278. Rheological behaviour of continuously sheared polyethylene.

W. F. O. POLLETT. *Brit. J. appl. Phys.*, 1955, **6**, 199.

A commercial grade of polyethylene was tested between its melting point and 190°C . at constant shear rates from 0.1 to 9.8 sec^{-1} . A disk-and-cone rheometer was used, and an improved technique introduced to provide a complete picture of the pressure distribution in the flowing melt by measuring each normal and tangential stress component individually. Changes of great complexity occurred with increasing shear, and varied with temperature and rate of shear, but simple relations could be established between the stress components and the measured strain recovery, which were in reasonable agreement with Weissenberg's theory. The observed behaviour is attributed to successive structural changes in the polymer, and an attempt is made to define equivalent structural states produced at different rates of shear A.

3279. Theory of Non-Newtonian flow. I. Solid plastic system.

T. REE AND H. EYRING. *J. appl. Phys.*, 1955, **26**, 793.

3280. Theory of Non-Newtonian flow, II. Solution system of high polymers.

T. REE AND H. EYRING. *J. appl. Phys.*, 1955, **26**, 800.

3281. On methods of plotting and interpretation of thermo-mechanical curves.

E. I. REGIRER AND M. S. KALANTAROVA, *Kolloidnyi Zh.*, 1955, **17**, 439.

3282. Non-Newtonian viscosity of solutions of ellipsoidal particles.

H. A. SCHERAGA. *J. chem. Phys.*, 1955, **23**, 1526.

A satisfactory theoretical interpretation of the non-Newtonian viscosity of solutions of ellipsoidal particles has been given by Kuhn and Kuhn, and also, by Saito, who made use of Peterlin's distribution function for the orientation of particle axes in the streaming

liquid and calculated the energy dissipation due to both the hydrodynamic orientation and the Brownian motion. Also, a theory for the non-Newtonian viscosity of solutions of rod-like particles has been developed by Kirkwood. These theories involve extensive computations which have been carried out here with the aid of a computing machine by expressing Saito's results in terms of Legendre coefficients previously evaluated in the related problem of double refraction of flow. As a result, data are available for the dependence of the viscosity factor ν on axial ratio and on the parameter a , where $a = G/\theta$, G being the velocity gradient in sec^{-1} and θ being the rotary diffusion constant in sec^{-1} . With these data it will be possible to determine the rotary diffusion constants of ellipsoidal particles from the non-Newtonian viscosity of their solutions, and also to correct viscosity measurements to zero velocity gradient in order to obtain the intrinsic viscosity. A.

3283. **Thixotropy and its significance for road and hydraulic engineering.**

F. SCHUTZ. *Tekn. Tidskr.*, 1955, **85** (21), 491.

After a description of the phenomenon of thixotropy, the author explains how the thixotropy of certain materials, particularly clay soils, may be an important factor in the planning of roads for heavy traffic. D.J.K.

3284. **Surface tension and viscosity of liquids.**

J. H. SIMONS AND W. H. WILSON, *J. Chem. Phys.*, 1955, **23**, 163.

Empirical relationships have been found between the energy of vaporisation, the surface energy, the energy of activation of viscosity and the boiling temperature, for liquids of (a) the inert gas type, (b) the normal fluorocarbon type, and (c) the normal hydrocarbon type. S.T.

3285. **Effect of molecular weight distribution on the creep behaviour of cellulose acetate.**

D. L. SWANSON AND J. W. WILLIAMS. *J. appl. Phys.*, 1955, **26**, 810.

3286. **The motion of a viscous fluid conducting heat.**

J. L. SYNGE. *Q. appl. Maths.*, 1955, **13**, 271.

Attention is drawn to the comparatively simple equations governing the behaviour of a viscous compressible fluid which conducts heat. The author uses entropy and specific volume as thermodynamic variables. R.R.

3287. **The rheology of Portland cement pastes.**

H. G. TATTERSALL. *Brit. J. appl. Physics*, 1955, **6** (5), 165-7.

Experiments with a rotation viscometer on the structural breakdown of Portland cement/water pastes are described. Hysteresis curves are shown and an empirical equation $T = T_E + (T_O - T_E) \exp(-Bt)$ for the decay of torque T with time t at constant rate of shear is given. This equation is also derived theoretically. D.J.K.

3288. **Birefringence and crystallization in elastomers.**

G. R. TAYLOR AND S. R. DARIN. *J. appl. Phys.*, 1955, **26**, 1075.

3289. **The bar viscometer.**

D. TOLLENAAR AND M. C. BISSCHOP. *J. Colloid Sci.*, 1955, **10**, 151.

An instrument in which an accurately machined and polished bar falls through a ring, with the material under test in the annular gap, is suitable for viscosity measurements at shear stresses of 10^4 to 10^6 dyne/cm². The temperature rise can be arranged to be much smaller than in a rotating cylinder viscometer at the same shear stress by using narrower gaps (down to 0.030 mm.) J.G.O.

3290. On analogues for the deformation-properties of fluid-and solid-plastic systems and on two kinds of plastic deformation and plastic viscosity of colloidal systems.

A. A. TRAPEZNIKOV AND T. A. SHALOPALKINA. *Kolloidnyi Zh.* 1955, 17, 471 (letter).

Authors discuss stress-strain curves for 2% solns. of Al.naphthenate. These consist of a series of regions—a linear region, followed by a hardening, passing a maximum stress through a softening, followed again by a state of steady flow. Final deformation reaches 40,000%.
G.W.S.B.

3291. Hypo-elasticity.

C. TRUESDELL. *J. Rational Mechanics and Analysis*, 1955, 4, 83

A new theory of the large deformation of materials which are perfectly elastic in small strain. It has an important bearing on the mathematical theory of plasticity.

R.R.

3292. Vibroscope measurements of the elastic moduli of nylon 66 and dacron filaments of various draw ratios.

J. H. WAKELIN, E. T. L. VOONG, D. J. MONTGOMERY AND J. H. DUSENBURY. *J. appl. Phys.*, 1955, 26, 786.

3293. Viscosimetric investigation into the influence of pH and ionic strength on molecular shape of a structural muscle protein.

A. WASSERMANN. *Rec. trav. chim.*, 1955, 74, 976.

Viscosities of aqueous solutions of actomyosin at various pH values and ionic strengths were determined. The differences in intrinsic viscosities between solutions at high and low electrolyte content are explained by changes in the average distance between the ends of the chain molecules.
P.G.M.

3294. Short-time stress relaxation behavior of plastics.

M. T. WATSON, W. D. KENNEDY AND G. M. ARMSTRONG. *J. appl. Phys.*, 1955, 26, 701.

An apparatus for measuring stress relaxation of plastics at constant strain in the time range of 0.01 to 2.5 sec after load application is described. Brittle plastics sustain only low strains without fracture at the speed of the apparatus and undergo little relaxation of stress; ductile plastics sustain higher strains and undergo considerable relaxation of stress. Increasing the strain, temperature, or plasticizer content generally increases the relaxation rate. By application of one form of the Eyring absolute rate theory, an average free energy of activation for the relaxation process can be calculated. The value thus calculated for polymethyl methacrylate is in the range reported in the literature for other polymers.
A.

3295. Streaming birefringence as a hydrodynamic research tool—Applied to a rotating cylinder apparatus above the transition velocity.

H. WAYLAND. *J. appl. Phys.*, 1955, 26, 1197.

3296. The sedimentation of suspensions of spheres.

R. L. WHITMORE. *Brit. J. appl. Phys.*, 1955, 6, 239.

The derived value of Einstein's viscosity constant appears to vary with the size range, possibly exceeding 3.4 for equi-sized spheres. When spheres of the same density as the sedimentary fluid were added to the suspension, a slight decrease in settling rate was produced at total volume concentrations not exceeding about 10%. Above this figure, appreciable increases in settling rate were found and were attributed to hydrodynamic attractive-forces between the spheres leading to the development of vertical streams in the suspension.
A.

3297. The temperature dependence of relaxation mechanisms in amorphous polymers and other glass-forming liquids.

M. L. WILLIAMS, R. F. LANDEL AND J. D. FERRY. *J. Amer. Chem. Soc.*, 1955, **77**, 3701.

The ratio a_T of all mechanical and electrical relaxation times at temperature T to their values at a reference temperature T_s can be expressed, after suitable choice of T_s , by the equation $\log a_T = -8.86 (T - T_s) / (101.6 + T - T_s)$. Over a T range of $T_s \pm 50$ deg., this applies to a wide variety of polymers, polymer solutions, organic glass-forming liquids and inorganic glasses. As chosen, T_s lies about 50 deg. above the glass transition temperature T_g . If, alternatively, the reference temperature is chosen as T_g , then $\log a_T \simeq -17.44(T - T_g) / (51.6 + T - T_g)$. A.

3298. Extension of the Hertz theory of impact to the viscoelastic case.

YOH-HAN PAO. *J. appl. Phys.*, 1955, **26**, 1083.

