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## RECENT ADVANCES IN HIGH POLYMER PHYSICS

A CONFERENCE on "Rheology of Elastomers" was held by the British Society of Rheology during May 29-31 at the British Rubber Producers' Research Association, Welwyn Garden City.

*Equilibrium properties of rubberlike materials.* In an introductory talk, Dr. L. R. G. Treloar (British Rayon Research Association) said that in the main the properties of rubber and of other polymeric materials in the highly elastic or 'rubberlike' state are now well understood. The stress and birefringence of rubber subjected to different types of finite strain at various temperatures are described to a good first approximation by the 'kinetic theory', a relatively simple molecular theory which treats of the changes of configurational entropy and molecular orientation in a deforming network composed of flexible long-chain molecules. Reviewing the shortcomings of the theory (in the Gaussian approximation), Dr. Treloar said that for simple elongations in the range 150-500 per cent, the discrepancies between the theoretical and observed stress-strain relations have so far not received satisfactory 'molecular' explanation.

A crucial test of the applicability of the kinetic theory to polymeric materials is furnished by the prediction that the rigidity modulus should increase linearly with the absolute temperature and with the concentration of junctions in the network. By using gelatin gels specially prepared to give junctions which are substantially unaffected by temperature changes, P. R. Saunders and A. G. Ward (British Gelatine and Glue Research Association) found that the rigidity modulus did increase linearly with temperature in the range 0°-60° C. and at a rate comparable with that required by the theory. Data both from gel rigidities and from dilute solution viscosities at different pH indicated that differences in the rigidities of ordinary gelatin gels must be attributed to differences in concentration and strength of network junctions, rather than to differences in molecular chain 'stiffness'.

Improved techniques for conditioning filaments of natural rubber so as to yield a more accurate attainment of thermodynamic equilibrium (required for comparison with the kinetic theory) were described

by P. Thirion (Institut Français du Caoutchouc). For filaments held at constant extension in the range 0–30 per cent, reversibility of tension–temperature cycles (20°–60° C.) was attained to within 0.05 per cent. A new derivation was given of Gee's formula for determining the coefficients of change of entropy and internal energy with change of extension at constant volume and temperature. From the data, the corresponding coefficients at constant pressure and temperature were determined with accuracies of the order 0.03 gm./cm.<sup>2</sup>/deg. C. and 10 gm./cm.<sup>2</sup>, respectively.

When the individual 'links' of long-chain molecules in a network have anisotropic optical polarizability, the network becomes birefringent when stressed. According to the kinetic theory, which assumes that no crystallization is present, the stress (for simple elongation) should be proportional to the magnitude of birefringence, and the constant of proportionality, or 'stress–optical coefficient', should not depend on the concentration of network junctions. Dr. D. W. Saunders (British Rayon Research Association) presented data obtained at temperatures above the crystal melting points which agreed with both these theoretical predictions in the case of cross-linked natural rubber and gutta percha. For polythene and polymethylene, however, the stress–optical coefficient decreased with increase of junction concentration; this was satisfactorily accounted for by extending the theory to apply to short-chain networks, and the data indicated that these two polymers had comparatively stiff chains. The problem of giving a strict definition of chain stiffness was considered.

The creation and loss of junctions in a network deformed from its unstressed state were considered in a theoretical paper by Dr. J. Scanlan (British Rubber Producers' Research Association). Tobolsky and co-workers have postulated a form of strain–energy function which would be obtained if the actual network behaved as if it were two independent networks, each of which obeyed the kinetic theory. Dr. Scanlan showed that, in the case in which junctions are created but none is lost, this postulate can be justified, but in the case in which one junction is lost for every one created (in the deformed state), the postulated strain–energy function is correct in form but contains coefficients which must be corrected. Two arguments were presented—one based on the network theory of James and Guth, and the other on a corrected form of a theory given by Scott and Stein.

*Elastic recovery, flow and stress relaxation.* A

striking demonstration of high elastic recovery in a liquid was given by Dr. A. S. Lodge (British Rayon Research Association), who poured a liquid (containing about 5 per cent aluminium laurate in paraffin) out of a bottle; on sharply cutting the liquid stream with scissors, the upper part of the stream snapped back into the bottle. Dr. Lodge has applied the network theory of James and Guth and the theory of relaxing networks of Green and Tobolsky to the problem of elastic recovery in solutions of long-chain molecules; for the instantaneous recovery following steady laminar shear flow, the latter theory predicts an unexpected expansion in directions normal to the previous flow lines. The suggestion that this might contribute to the diameter increase commonly observed when polymer solutions and melts are extruded from tubes of circular cross-section gave rise to considerable discussion, and alternative explanations, also in terms of elastic recovery, were mentioned by Dr. P. Clegg (Imperial Chemical Industries, Plastics Division). Dr. Clegg's data for molten polythene showed that at low flow rates the diameter increase did not depend on tube length (in agreement with Dr. Lodge's theory) but did depend on tube length at higher flow rates when the transit time through the tube became comparable with the stress relaxation periods of the melt. In this case, the melt was presumably 'remembering' its convergent flow at the entry to the tube. The main part of Dr. Clegg's paper dealt with still higher flow rates, when marked irregularity occurred in the extruded filament. By observation of the motion of embedded particles and of coloured parts of the polymer, Dr. Clegg established that the cause of the irregularity lay in the conditions of flow in the region of entry to the tube; a motion film was shown which clearly demonstrated very marked disturbances of flow in this region. Independent measurements of melt elastic properties suggested that polymers for which the irregular flow sets in at lower shear stresses (or rates) have longer stress relaxation times.

Unoriented polymers crystallize if left long enough at suitable temperatures; crystallization can be accelerated by stretching processes which cause appreciable molecular orientation. To separate these causes of crystallization as far as possible, Dr. E. L. Foster and H. Heap (Imperial Chemical Industries, Fibres Division) have constructed an apparatus with which a filament can be heated rapidly (in about 1 sec.) and its tension-extension characteristics measured. Data for amorphous polyethylene terephthalate ('Terylene') in the range 90°-120° C. showed

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that at low rates of strain the filament can be extended almost indefinitely with little increase in tension ; at high rates of strain, however, the tension increases catastrophically with marked increase in crystallinity, as indicated by X-ray data.

Many measurements have been made of the relaxation of tension in a polymer strip which is rapidly extended and then maintained at constant extension. Prof. G. Gee, Dr. G. Allen and B. E. Read (University of Manchester) have constructed an apparatus in which the electronic recording of tension enables measurements to be made during the first ten seconds when most of the relaxation occurs, as well as at later times. Data were presented for natural rubber at moderate extensions (up to 50 per cent) and at temperatures in the range 45°-60° C., so that crystallization would be very limited. The data taken at the longer time intervals were used to calculate values for the activation energy and activation flow volume.

Elastic recovery in polythene rods has been investigated by J. J. Benbow (Imperial Chemical Industries, Akers Research Laboratory). A rod was held twisted for a given time, released, and the subsequent untwisting measured as a function of time. Only at very small strains (about 0.1 per cent) did the results agree with a theoretical relation obtained by combining Boltzmann's theory of the 'elastic after-effect' with the empirical result that internal friction in polythene subjected to oscillatory strains is independent of frequency. Polythene appeared less able to 'remember' the duration of the imposed twist as the magnitude of this twist was increased. The temperature was controlled at 30° C. ; the maximum strain imposed was about 100 per cent.

*Miscellaneous properties of polymeric materials.* In the mechanical response of polymeric materials to oscillatory strains of very small amplitude, an increase of temperature can, in a sense, be compensated for by a decrease of frequency. Ferry has given a prescription for the appropriate changes of temperature and frequency scales whereby the data for dynamic modulus and dynamic viscosity for a given polymer can be superposed in master curves over a remarkably wide range. A. R. Payne (Research Association of British Rubber Manufacturers) gave a wealth of data showing the successful application of Ferry's method to various cross-linked and uncross-linked rubbers, for dielectrical as well as for mechanical measurements. In these correlations, there is only one disposable constant, a characteristic temperature the value of which is assigned empirically for each polymer. Mr. Payne also discussed data



already published for a wide variety of polymers with particular reference to the temperature variation of the frequency at which the maximum value of  $\tan \delta$  occurs, where  $\delta$  denotes the dielectric loss angle.

In order to obtain a rational measure of tear resistance of a cross-linked rubber, the growth of tears in rubber has been studied under controlled conditions. The concept and determination of a characteristic tearing energy was discussed by Dr. H. W. Greensmith (British Rubber Producers' Research Association). Measured values of this tearing energy showed much greater variation both with temperature and with rate of tearing for a synthetic rubber (*GR-S*) than for a natural rubber. The difference was attributed to the reinforcing effect of crystallization in the natural rubber. Addition of a filler to the synthetic rubber introduced a new maximum in the tearing energy when expressed as a function of temperature and tear rate.

Exposure of a polymer to radiation from an atomic pile or from a high-energy electron accelerator usually either creates cross-links (network junctions), or breaks chains, but rarely does both together. Mechanical properties of polymers are in the main the same, whether the cross-linking is effected by irradiation or by more conventional chemical means. Dr. A. Charlesby, Miss J. Burrows and T. Bain (Tube Investments Research Laboratories) have measured the modulus, stress-strain curve, elongation at break, and tensile strength for irradiated rubbers reinforced with carbon black, with sulphur, and with other additives. No significant difference was observed as between 'electron' radiation and pile radiation; the changes produced depended only on the total energy absorbed. There was some indication that chemical cross-linking gave a higher tensile strength than irradiative cross-linking. E. Fukada (Imperial College of Science and Technology, London) used  $\gamma$ -radiation to cross-link samples of a commercial polyester resin to which different amounts of styrene had been added. The dynamic modulus and mechanical damping at temperatures in the range  $10^{\circ}$ – $160^{\circ}$  C. at a single frequency of 0.22 cycle/sec. were obtained from observations of the horizontal and vertical deflexions of one end of a rod of the polymer which was rotated about its axis (held horizontally) by means of a rotating chuck at the other end.

The conference was attended by more than one hundred people, including visitors from Japan, Germany, France, and a substantial number from Holland. Discussions were always lively, and one

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was left with an impression of a flourishing field of investigation of considerable fundamental as well as technical interest. Publication of the papers and discussions is in the hands of Pergamon Press.

A. S. LODGE

# THE BRITISH SOCIETY OF RHEOLOGY

Bulletin No. 52

September, 1957

Price to non-members 7s.

## New Members. The following new members are welcomed to the society.

Mr. H. J. Ward, "Rosemary," Woolavington, Bridgwater, Somerset. Interests : High polymers ("plastics") Thixotropic solutions (e.g. viscose).

Dr. W. L. Wilkinson, Department of Chemical Engineering, University College, Singleton Park, Swansea. Interests : High polymers and suspensions. Non-Newtonian fluid mechanics, mixing and heat transfer.

Mr. W. H. Bickle, D.S.I.R., 5 Lower Regent Street, London S.W.1.

Mr. A. W. Morrison, Expandite Ltd., Chase Road, London N.W.10. Interests : Tars and bitumens, Plastics, Road materials.

Mr. J. W. Claassens, Physics Department, N.I.R.D., Shinfield, Berks. Interests : Dairy Products, Measurement of adhesivity, viscosity, elasticity, hardness and other factors pertaining to what is generally termed, consistency.

Mr. W. G. Cobbett, Brit. Gel. & Glue Res. Assoc., 2a Dalmeny Avenue, Holloway, London N.7. Interests : Gelatin.

Mr. G. M. Jenkins, 19 Denison Road, Manchester 14. Interests : Rheology of Thermoplastics (Rheogoniometry).

Mr. J. Chalmers, 497 Queensferry Road, Barnton, Midlothian. Interests : Flour, Bread & Biscuit Doughs, Rotation Viscometry and Thixotrometers, Dough testing equipment, e.g. Brabender & Simons instruments.

Mr. A. Kaye, Brit. Rayon Res. Assoc., Heald Green Laboratories, Wythenshawe, Manchester 22. Interests : Rotation Viscometry.

Dr. D. R. Oliver, Bexford Ltd., Brantham, Manningtree, Essex. Interests : Solutions of polymers, viscoelastic behaviour. Clearly defined stable and unstable suspensions of spherical and irregular particles.

Dr. W. J. Green, Brit. Insulated Callender's Cables Ltd., 38 Wood Lane, London, W.12. Interests : Extrusion of rubbers and plastics.

Dr. R. B. Beevers, Courtaulds Ltd., Research Laboratory, Lower Cookham Road, Maidenhead, Berks. Interests : High polymers. Mechanical behaviour (dynamic modulus, creep extension and creep relaxation, etc.)

Mr. W. Johnson, Engineering Department, The University, Manchester 13. Interests : Forming processes, e.g. extrusion.

Dr. D. Madoc Jones, 36 Cwrtglas, Croesyceiliog, Mons. Interests : High polymers.

Dr. R. C. Faust, 164 Brynhyfryd, Croesyceiliog, Mons. Interests : High polymers with particular reference to textiles.

Dr. J. F. Wallace, Mechanical Eng. Dept., University, Sheffield. Interests : Plastic deformation of ferrous and non ferrous metals.

Mr. M. J. Wolstenholme, The Librarian, The Brown-Firth Research Labs., Princess Street, Sheffield 4. Interests : Iron and steel.

Mr. G. Hulse, 46 Highfield Drive, Uxbridge, Middx. Interests : Thermoplastics, their viscoelastic properties. Extrusion viscometry.

Mr. W. F. Kilby, Brit. Celanese Ltd., Research Laboratories, Potteridge Bury, Nr. Luton, Beds. Interests: Rheology of high polymers.

Dr. W. E. Craker, 64 Mayfield Drive, Loughborough, Leics. Interests: Rotational viscometry. Suspensions of powder in liquids (pastes, colloids).

Dr. D. J. Weeks, 1 Littlecourt, 268 Ballards Lane, Finchley, N.12. Interests: Molten plastics from the viewpoint of behaviour on extrusion.

Mr. A. Please, 3 Randall Close, Langley, Bucks. Interests: Viscoelastic liquids. Solid-liquid system with high solid conc. Rotational viscometry. Fracture.

Mr. B. S. Glyde, Research Division, The Metal Box Company Ltd., Burrfields Road, Portsmouth, Hants. Interests: Thermoplastics, esp. polyolefins. Screw extrusion, calendering, plastimetry. Photoelastic properties.

### **Change of address.**

Dr. Alfred H. Nissan, Department of Chemical Engineering, Rensselaer Polytechnic Institute, Troy, N.Y., U.S.A.

### **Deaths.**

Mr. H. H. Allen.

Dr. P. Grodzinski, member since 1947.

### **Conference on Rheology of Elastomers.**

One of the most successful Society Conferences of recent years was held at Welwyn Garden City at the end of May. The new Conference room of the British Rubber Producers Research Association was kindly put at the Society's disposal for the duration of the Conference. About 130 Scientists attended this meeting and of these, we were glad to welcome 20 Overseas visitors.

The standard of the papers given was high and the discussions showed the very great interest of high elasticity theory to workers in rubber and plastics.

A well-attended dinner was held during the Conference and visits were paid to the I.C.I. Plastics Division and the Akers Research Laboratories.

The Proceedings of the Conference will be published in full by Pergamon Press and a full account will appear in *Nature* (reprints will be sent to Members). Other items concerned with the Conference are appearing in *Research* and *The New Scientist*.

*Further Summaries of papers read at the Conference on the Rheology of Elastomers.*

### **A Note on the Elasticity of Gelatin Gels by**

P. R. SAUNDERS and A. G. WARD (The British Gelatine and Glue Research Association).

The temperature dependence of the rigidity modulus of formaldehyde crosslinked gelatin gels has been studied. The normal gelatin gelling forces were inoperative because the measurements were carried out either at temperatures above the normal gelation region or at lower temperatures in the presence of KSCN, which suppresses ordinary gelation. The rigidity modulus decreased with decrease of temperature in a reversible manner. The temperature coefficient of rigidity between 0°C and 60°C was approximately 0.002 per °C, which is of the same order as that given by the theoretical rubber-like model.

The rigidities of formaldehyde crosslinked gels of fractions of similar Logarithmic Viscosity Number ( $1/c \log. \eta \text{ rel.}$ ), from two gelatins whose normal gel rigidities were quite different, were found to be similar. This shows that the differences in gelatin gel rigidities, which have previously been shown to be independent of the molecular weight of the gelatin, are not related to the intrinsic deformabilities of the gelatin chains. The differences must arise from the number and organisation of the points of linkage in the gelatin gel.

This conclusion was confirmed by measurements of the L.V.N. of the fractions of

the two gelatins as a function of pH. As the pH changes, the charge on the gelatin molecules changes and they stretch out or fold up against a restoring force, due to the elasticity of the molecular chains. The graph of  $L.V.N.$  against combined charge coincided for fractions of the two gelatins, showing that the deformations were the same when the net charges on the molecules were identical. This can only be so when the elastic restoring force per unit deformation is also the same for molecules of the two fractions.

### **A Theory of Elastic Recovery in Concentrated Solutions of Elastomers by**

A. S. LODGE (British Rayon Research Association).

It is assumed that at any given instant long chain molecules dissolved in a low molecular weight solvent may be regarded as forming a Gaussian network in which the junctions, which arise from entanglements and secondary forces, have been formed over a range of different instants in the flow history. The theory of Gaussian networks as given by James and Guth implies that an incompressible rubberlike solid is necessarily isotropic (whether junctions are introduced with the network in one, or more than one, state of deformation) in the sense that the stress tensor in any state  $t$  can be expressed as an isotropic function of a tensor describing the strain  $t \rightarrow t^*$ , where  $t^*$  denotes the unstressed state. In certain idealized conditions, the state  $t^*$  is the state to which a solution would instantaneously recover if the stress were removed at time  $t$ ; the instantaneously recoverable strain tensor has therefore the same principal directions as the stress tensor, but is not completely determined by the stress tensor owing to the dependence on flow history of the elastic modulus. Using the further assumptions and the stress-flow history relations of the theory of Green and Tobolsky, expressions are derived which determine the instantaneously recoverable state and the elastic modulus when the flow history and junction age distribution are known. For steady rectilinear shear flow, the elastic modulus is an increasing function of shear rate which cannot be determined from stress measurements in steady shear flow alone, and the instantaneous recovery can be resolved into (i) a shear opposite in sense but otherwise similar to those involved in the steady shear flow, (ii) a contraction in the direction of the lines of flow, and (iii) an isotropic expansion in directions normal to the lines of flow. This predicted lateral expansion is shown to depend on the introduction of new junctions in an anisotropically-stressed network. Experiments on the permanent set of a cross-linked rubber sheet subjected to pure shear and further cross-linking showed a small but significant expansion in the set state in those dimensions which were unaltered in the pure shear, the magnitude of the observed expansion being about one third of that predicted by the theory. For heterogeneous flow histories, the tensor for the strain  $t \rightarrow t^*$  does not in general satisfy the compatibility conditions, and the stress cannot everywhere become zero instantaneously when external forces are removed; there is reason to expect that when a solution flows out of a capillary tube, the emerging jet will have a larger diameter than that of the tube and will exist for a time in a state of stress of which one component will be a radial tension.

### **The photoelastic Properties of Rubber-like Polymers by**

D. W. SAUNDERS (British Rayon Research Association).

Experimental data are presented to show the relations between the stress-optical coefficient and the degree of cross-linking in simple vulcanizates of natural rubber, gutta-percha, polythene and polymethylene at temperatures above their crystal melting points. The measured elastic moduli of the samples are used to characterise their degree of cross-linking.

It is found that in natural rubber and gutta-percha vulcanizates the stress-optical coefficient is substantially independent of degree of cross-linking over a large range. This is in agreement with the simple kinetic theory of rubber-like elasticity. In polythene and polymethylene, however, the stress-optical coefficient decreases markedly with increasing degree of cross-linking. This departure from simple theory is satisfactorily accounted for by the theory of the photoelastic properties of short chain networks.

By comparing the measured stress-optical coefficients with calculated values for the optical anisotropies of the single monomeric units, information is obtained on the "stiffnesses" of the polymer chains for each of the polymers considered. An attempt is made to give a strict definition of the term "stiffness" as applied to polymer chains and the results are discussed in relation to this definition. The results on polythene and polymethylene are compared with the theories of Kubo and of Sack who have calculated the optical properties of an idealized paraffin chain with hindered rotation about the carbon-carbon bonds.

### List of Publications.

*Further to those volumes given in Bulletin No. 48, September 1956, the following are of rheological interest:—*

Jaeger, J. C.

*Elasticity, Fracture and Flow*, Methuen, 1956.

Grammel, R. (Ed.)

*Deformation and Flow of Solids—I.U.T.A.M. Colloquium, Madrid, 1955*, Springer, 1956.

Eirich F. R. (Ed.)

*Rheology, Theory and Applications, I*, Academic Press, 1956.

Frenkiel, F. N. (Ed.)

*Applied Mathematics and Mechanics.*

Vol. 1. *Gas Dynamics* by K. Oswatitsch, 1956.

Vol. 2. *Jets, Wakes and Cavities* by G. Birkhoff and E. H. Zarantonello, 1956.

Vol. 3. *Mathematical Theory of Compressible Fluid Flow* by R. Von Mises, 1957. Academic Press.

Dryden H. L. and Kármán, Th. v. (Eds.)

*Advances in Applied Mechanics, Vol. IV*, Academic Press, 1956.

Corcoran, W. H., Opfell, J. B. and Sage, B. H.

*Momentum Transfer in Fluids*, Academic Press, 1956.

Pai (Shih—I)

*Viscous Flow Theory I Laminar Flow*, McGraw-Hill, 1956.

American Institute of Physics Handbook.

*Section 3—Rheological material covers gels, tensile strength of liquids, fluid flow through porous materials, viscosity of suspensions, cavitation and diffusion in liquids*, McGraw-Hill, 1957.

The Institute of Physics.

*The Physics of Non-Destructive Testing*, 1957.

The Royal Institute of Chemistry.

*Symposium on Techniques in Polymer Science*, 1956.

*Summary of Papers to be read at the September Conference, Swansea, September 1957*

### Some Rheological Measurements on Pigment/Plasticiser Dispersions by

E. BANTOFT.

The systems studied in this work were dispersions of various pigments in castor oil or tricresyl phosphate prepared by triple-roll milling and ranging in concentration by volume from about 20 to 45%. Their flow properties at low rates of shear were of particular interest in connection with practical problems of storage and handling.

The instruments used were a Cone and Plate viscometer covering the range 0.1 to 200 sec<sup>-1</sup> and a Brookfield viscometer, a rotating spindle viscometer whose range of rates of shear was dependent to some extent on the flow properties of the material being

measured but was around  $0.1$  to  $1 \text{ sec}^{-1}$ . The Cone and Plate viscometer had the advantage that the whole of the paste being measured was subjected to a uniform stress. This feature was of particular value for "plastic" pastes since the possibility of "plug flow" was eliminated. Most of the pastes examined belonged to this general category but showed differences which permitted their classification into fairly well defined types as described below.

Type (1) showed a non-linear relation between shearing stress and rate of shear over the range of shear rates examined (up to  $200 \text{ sec}^{-1}$ ) and its flow properties were not appreciably time dependent over experimental periods up to about an hour. At rates of shear of  $1$  to  $2 \text{ sec}^{-1}$  a fairly sharp bend in the flow curve occurred and at lower rates of shear flow seemed to be of a different type and there may have been some slip between the paste and the containing walls. The upper part of the curve could be reasonably extrapolated to the stress axis to give a "lower yield value." When (shearing stress  $T$ )<sup>1</sup> was plotted against (rate of shear  $D$ )<sup>1</sup> a straight line was obtained in agreement with Casson's equation  $T^{\frac{1}{2}} = A + BD^{\frac{1}{2}}$ , to be discussed at this Symposium, and the value of  $A^2$  agreed well with the lower yield value. Type (2) differed from Type (1) in that the curve relating shearing stress and rate of shear met the stress axis sharply instead of asymptotically and appeared to become linear or very nearly so at higher rates of shear. The flow properties of this type of paste showed only slight time dependence and were fitted reasonably well by Bingham's equation. Type (3) differed from Type (2) in having considerable thixotropy which led to unexpectedly high apparent viscosities at very low rates of shear. The curves relating shearing stress and rate of shear appeared to be quite linear above  $5 \text{ sec}^{-1}$  but Bingham's equation was valid only for the condition of steady shearing.

The static yield values of pastes which had stood for periods ranging from a few seconds to a few hours bore little relationship to the Bingham yield values.

Two methods were used to measure static yield values. In one, using the Brookfield viscometer with a toothed spindle to prevent slip, the shearing stress was increased slowly until rotation started indicating breakdown of structure. The other used the Brookfield "Helipath" device; the viscometer was fitted with a T-shaped wire spindle and moved bodily downwards during the measurement causing the spindle to trace a helical path, constantly cutting through fresh paste. The "Helipath" method was also useful for examining Type (1) pastes, which showed some build-up of structure over several days, but which did not give a sharp breaking point with the ribbed cylinder due to their high viscosities at low rates of shear. In addition to the types of flow described above, a few cases of dilatancy were encountered. Measurements on these pastes were difficult with the Cone and Plate viscometer since the paste was rapidly forced out of the gap, due apparently to a negative Weissenberg effect.

## **A Flow Equation for Pigment-Oil Suspensions of the Printing Ink Type by**

N. CASSON (I.C.I. Ltd. Dyestuffs Division).

From a consideration of the interparticle attractive and repulsive forces operative in non-aqueous media it is concluded that the particles in a suspension of the printing ink type will combine to form clusters or flocules of definite cohesive strength. Since these flocules are subjected to disruptive stresses exerted by the flowing medium, which vary with the rate of shear, their dimensions and hence their contribution to the viscosity of the suspension will also vary with the rate of shear. The method of calculating the viscosity of such a suspension and its variation with rate of shear, is basically similar to that used by Kuhn (Ref. 1). However, there are important differences in detail which lead to a different result. To simplify the problem it is assumed that the flocules are cylindrical rods of high axial ratio  $\gamma$ . By an elementary method the viscosity of a suspension of such rods is calculated. In this calculation the distribution of the rods among the possible orientations is found using an equation due to Mason (Ref. 2). The distribution depends upon the non-uniform angular velocity of the rods, Brownian movement

being neglected. This is considered to be justifiable for suspensions in a medium of high viscosity (20–30 poise at 25°C). The expression obtained is

$$\eta = \eta_0(1-C) + \eta_0 a^{\frac{1}{2}} \mathcal{F} C$$

where  $\eta$  is the viscosity of the suspension,  $\eta_0$  is the viscosity of the suspending medium,  $C$  is the volume fraction of solid in suspension,  $a^{\frac{1}{2}}$  is a constant of value 0.7 approximately,  $\mathcal{F}$  is the axial ratio of the rods.

Each rod experiences a tension the magnitude of which depends upon its orientation and the rate of shear. Consequently a relation between  $\mathcal{F}$  and  $D$  is obtained of the form

$$\mathcal{F} = 3F_A/[48\eta_0 D a^{\frac{1}{2}}]^{\frac{1}{2}}$$

where  $F_A$  is the cohesive force per unit cross sectional area of a rod.

This relation is only valid when  $\mathcal{F}$  is much greater than unity. For lower values of  $\mathcal{F}$  the relation between  $\mathcal{F}$  and  $D$  is not easily calculated. Taking account of the fact that  $\mathcal{F} = \mathcal{F}_0$ , the axial ratio of the primary particles, at some high rate of shear when deflocculation is complete an approximate relation for intermediate values of  $\mathcal{F}$  is proposed which has the form

$$\mathcal{F} = \alpha + \beta/(\eta_0 D)^{\frac{1}{2}}$$

$\alpha$  and  $\beta$  are constants the values of which depend on the degree of flocculation of the suspension, i.e. the complexity of the flocules. Consequently a relation between  $\eta$  and  $D$  is obtained for dilute suspensions. An expression for more concentrated suspensions is derived from this using the method of Brinkman (Ref. 3) and Roscoe (Ref. 4). The result, expressed in the form of an  $F$ - $D$  relation is

$$F^{\frac{1}{2}} = k_0 + k_1 D^{\frac{1}{2}}$$

$$\text{where } k_0 = \frac{a^{\frac{1}{2}}\beta}{a^{\frac{1}{2}}\alpha - 1} \left\{ \left( \frac{1}{1-C} \right)^{a^{1/2}(\alpha-1)/2} - 1 \right\}$$

$$k_1 = \eta_0^{\frac{1}{2}}/(1-C)^{a^{1/2}\alpha-1}$$

Nine pigment/thin lithographic varnish suspensions were measured on the Ferranti Shirley cone and plate viscometer, an instrument in which all the suspension experiences the same rate of shear. In all cases plots of  $F^{\frac{1}{2}}$  against  $D^{\frac{1}{2}}$  were found to be reasonably good straight lines over the range of rates of shear used (20–600 sec<sup>-1</sup>). From the values of  $k_0$  and  $k_1$  values of  $\alpha$  and  $\beta$  were calculated for each suspension. Theoretically values of  $\alpha$  between zero and 5 would be expected for suspensions of spherical particles and between zero and some value greater than 5 for asymmetric particles. Experimentally values between 6 and 14 were obtained which are considered to be of the right order of magnitude. The results indicate that the theory is reasonably well supported by the experimental results.

As a basis for further experimental work the theory predicts the effect of particle size. As this decreases the cohesive strength of the resultant flocules should increase. It follows that a suspension of small particles should be less Newtonian than a suspension of larger particles which are otherwise similar.

From a purely practical point of view the flow equation has proved of value in that it provides a concise method of expressing the flow properties of inks for comparison with their technical behaviour.

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## **The Viscous Flow of Disperse Suspensions in Tubes by**

R. L. WHITMORE (University of Nottingham).

It is well recognised that the viscosity of many suspensions, when measured by their rate of flow down tubes, decreases with decreasing tube diameter. If the suspension possesses a yield value the effect may be explained satisfactorily by the "plug-flow" theory of Scott Blair and his collaborators. However, some suspensions although exhibiting a diminution in measured viscosity with diminishing tube diameter display Newtonian flow characteristics when measured, for example, in a coaxial rotating-cylinder viscometer. Vand considered that a suspension should appear to slip at any solid boundary but measurements in coaxial rotating-cylinder viscometers show the viscosity to be independent of the width of the annulus and do not confirm Vand's conclusion.

The explanation of this phenomenon appears to lie in conditions at the inlet to the measuring tube. Neglecting inertial forces, particles in the suspension attempt to follow particular streamlines converging at the inlet. However some streamlines must pass so close to the wall that a portion of each particle moving along them would have to penetrate the wall in order to keep to the same streamline. These particles are forced inwards until they can just enter the tube so that they travel on faster streamlines located a little further from the wall. The velocity of these particles is, therefore, increased as they enter the tube, causing a reduction in their retention time in the tube and hence in their concentration. The quantitative effect of the migration can be calculated for a suspension of spheres of radius  $r$  if it is assumed that the particles affected by the wall do not displace other particles following streamlines nearer to the centre of the tube. The displaced particles will, on an average, move inwards from distance  $r/2$  to distance  $r$  from the wall. If the magnitude of inward movement is small compared with the tube radius it may be assumed that the velocity of any particle is proportional to its distance from the wall so that the average velocity of displaced particles will be doubled and their average concentration halved. Experimental measurements confirmed that the concentration of a suspension of spheres flowing down a tube was less than that in the feeding vessel and gave a value for the inward movement of the peripheral particles of  $0.66 r$  (compared with  $0.5 r$  given by the elementary theory). Photographically it was possible to show the change in concentration of the initial and final portions of a suspension passing down a tube, as anticipated by the theory.

The magnitude of the inward movement was calculated from published viscosity measurements and found to be approximately  $0.7 r$ . This is in reasonable agreement with the value obtained from concentration measurements.

In a coaxial rotating-cylinder viscometer, movement of particles away from the walls cannot affect the average concentration of suspension in the instrument. Moreover it can be shown that under conditions of uniform shear stress (which apply approximately in rotating-cylinder viscometers) any displacement of particles across the annulus cannot alter the measured viscosity of most disperse suspensions. Thus, in general, no variation of viscosity with annular width can be expected in coaxial rotating-cylinder viscometers.

## **The Apparent Viscosity of Suspensoid Sols by**

T. V. STARKEY.

The theory outlined rests on the single assumption that as a result of the comparatively rapid particle rotation which occurs under typical conditions, minute vortices, centred on the particles, form during shear. The effect of these vortices in modifying the otherwise laminar motion of the suspension fluid appears, as is shown, to form the basis of those phenomena common to suspensoid sols.

The quantitative aspect of the theory, so far as it has been developed, rests on a scalar relationship between viscosity and action, viz. that specific viscosity is the ratio of the total vortex action to the total laminar action for any given change in the configuration of the sol. This relationship is deduced and it is employed in the derivation of a relation between apparent viscosity and concentration.

The apparent viscosity of a sol is the true viscosity of that laminarly flowing fluid for which the same volume emerges from the same tube, under the same pressure difference, at the same temperature and in the same time as for the sol. (The term "laminarly flowing" is used here to imply that the viscous forces are everywhere parallel to the tube axis). On the basis of this definition and on the assumption of the formation of vortices during flow, it is shown that the specific viscosity (sometimes referred to as the relative increase in viscosity) of a sol is the ratio of the total vortex action,  $A_V$  to the total laminar action,  $A_L$ , for any given change in its configuration; that is,

$$\eta_{sp} = A_V/A_L \quad \dots (1)$$

Equation (1) is used as the basis for deriving a relationship between the apparent viscosity,  $\eta_s$ , of a very dilute sol and its volume concentration,  $\phi$ . Assuming that the sol consists of rigid, identical, spherical and non-attracting particles of radius,  $\alpha$ , suspended in a Newtonian fluid of viscosity,  $\eta$ , and maintained at constant temperature, and that its apparent viscosity is measured at a very low Reynolds' number with a capillary of radius,  $R$ , and for which end-effects can be neglected, it is shown that

$$\eta_{sp} = (\eta_s - \eta)/\eta = 1.5\phi(1 - 4\alpha/R) \quad \dots (2)$$

This equation indicates the existence of the so-called "sigma effect."

For suspensions in which the particle diameter is negligible compared with the tube diameter equation (2) reduces to

$$\eta_{sp} = 1.5\phi \quad \dots (3)$$

The value of the numerical constant, here shown to be 1.5, is considered in the light of experiment.

The effects of varying (a) the geometry of the shearing system, (b) the rate of shear employed and (c) the temperature, on the value obtained for  $\eta_s$ , are considered in the light of the theory outlined and are shown in every case to be qualitatively in agreement with the results of experiment. The "viscostatic effect" is deduced as a consequence of the theory.

The effects on  $\eta_s$  of varying (a) the size and shape of the suspended particles, (b) the concentration of the sol and (c) the nature of the solvent, are also considered and the conclusions drawn from the theory are shown to be in every case consistent with experiment. In considering (a), the reason becomes apparent why, for a dilute suspension of spherical particles of given volume concentration, the apparent viscosity is independent of the particle size.

### **Starch-Clay Coating Mixes—The Inter-Relationship of Amylose Content, Total Solids Content and Rheological Properties by**

R. S. LENK.

It was found that the amylose content of converted potato starch is a measure of the degree of conversion. Under-converted starches range from native starch (23.2% amylose) to a starch of amylose content 14½%. Such starches can be used for roll coating mixes which will transfer on to the sheet but the coating will show patterning and open texture. Over-converted starches containing less than about 7% amylose will tend to cause build-up on the applicator roll. The range of good machine operability lies between 7 and 14½% amylose and is characterised by absence of build-up, and even pattern-free and closely-textured coverage.

The viscosity can be controlled by variation of either total solids or amylose content or both. The main rheological requirement for good transfer is pseudo-plasticity, preferably supplemented by thixotropic behaviour. The present investigation has the object of elucidating some of the factors responsible for producing a given mode of rheological behaviour, with the ultimate aim of correlating transfer and basic analytical data.

Conversion brings about a reduction in both quantity and molecular size of the amylose. The interdependence of the amylose content of the starch and the solids content of the mix was established by preparing mixes in which the two variables were mutually balanced so as to give "standard" rheological behaviour. This relationship was found to be linear. Two methods of varying amylose contents were used: (i) blending

of native and amylose-free starch, and (ii) controlling the degree of conversion.

On plotting total solids against % amylose two divergent straight lines were obtained.

Whilst a rheogram was found to give an indication as to *whether* a mix will transfer, it will not tell *how* it will transfer. In order to transfer satisfactorily the amylose must be correct in both quantity *and* micellar size.

As an initial approach to the calculation of relative micellar sizes the following treatment is put forward :

#### *Assumptions.*

(1) At constant temperature and clay content the viscosity of a coating mix depends (a) on the amount of amylose (native  $-A_0$  or converted  $-A_t$ ), and (b) on the mean micellar size ( $N_0$  and  $N_t$  respectively).

(2) From the rheological viewpoint conversion affects amylopectin to a very much lesser absolute degree than amylose.

(3) As a first approximation the viscosity contribution of the amylopectin is negligible compared with that of the amylose.

Let two mixes  $X$  and  $Y$  be rheologically identical at equal solids content; mix  $X$  to contain only native amylose of micellar size  $N_0$ , the actual quantity  $A_0$  depending on the proportion of native to amylose-free starch in the blend; mix  $Y$  to contain converted amylose of micellar size  $N_t$  and quantity  $A_t$  which both depend on the degree of conversion.

Then  $AN$ , which is a bulk entity referring to amylose, is constant, or

$$A_0/N_0 = A_t/N_t = Q, \text{ the "amylose conversion coefficient"}$$

The respective amylose contents  $A_0$  and  $A_t$  of a mix at any desired solids content and at "standard" rheological behaviour (which is defined) can be read off from a graph by means of horizontal tie lines.

It is interesting to note that in such  $X$  and  $Y$  pairs of mixes as have been used for hand coating paper experimentally, the wax-pick and wet-rub resistance were equal. It was in order to equal the wax-pick and wet-rub resistance of a mix of  $A_0 = 10.4\%$  that the idea of converting starch to its rheological analogue of  $A_t = 13.8\%$  first arose.

There are three regions of  $Q$  values which give the following coating results :

- $Q < 0.4$  : tendency towards dilatancy, inoperable on a coating machine, poor wax-pick and wet-rub resistance, high solids content.
- $Q = 0.4$  to  $0.85$  : mix pseudo-plastic and thixotropic; range of machine operability with pattern-free coverage. Good wax-pick and wet-rub resistance.
- $Q > 0.85$  : mix pseudo-plastic and thixotropic; will transfer but cause heavy patterning. Excellent wax-pick and wet-rub resistance, low solids content.

Within the wide middle range there is still much scope for variation of (a) solids content, and (b) wax-pick and wet-rub resistance and for tailoring the mix to specific requirements since (a) and (b) represent opposing tendencies.

It is likely that these principles apply equally to other starches and diverse conversion techniques, but the straight lines of the graph may have different slopes and intercepts, leading to different sets of numerical values for  $Q$ .

The variation of rheological properties with amylose contents at constant solids contents was investigated. The families of rheograms obtained for each solids level are fundamental to the conclusions drawn and will be shown in graphs when the paper is given.

#### **Rheology of Molten Chocolate by**

E. H. STAINER (British Food Manufacturing Industries Research Association).

In the melted state chocolate is a polydisperse system of cocoa and sugar particles in liquid cocoa butter. The measurement of the viscosity of melted chocolate is important in process control, in research into the effects of varying ingredients and, thirdly, in providing a standard for the assessment of quality. The anomalous flow properties of chocolate have been known for many years. Both Bingham body behaviour (Ref. 1, 2)

and continuous curvature (Ref. 3, 4, 5) in the flow diagram have been reported and opinions differ considerably on the magnitude of the yield value. Both rheopectic and thixotropic behaviour have been claimed (Ref. 4).

In 1955 the International Office of Cocoa and Chocolate instigated a study of the flow properties of three samples of couverture. Results were obtained from seven laboratories in different countries using five different types of rotational viscometer (Bayer, Drage, Emila, Ferranti Portable and Rotovisko). The results which showed fairly good agreement, exhibited marked curvature in the stress-rate of shear diagrams below about  $15 \text{ sec}^{-1}$ , but tended increasingly to become linear at higher rates of shear. The yield stresses appeared to lie below  $100 \text{ dynes/sq. cm.}$  Treatment of the curves as being of Bingham type above  $15 \text{ sec}^{-1}$  led to reasonable agreement on plastic viscosities though not on the apparent yield values as obtained by extrapolation of the linear part of the curve.

The usefulness of the Bingham hypothesis at higher rates of shear was shown in a comparison of measurements with rotational and capillary viscometers carried out at the B.F.M.I.R.A. laboratories on 8 samples of chocolate. By applying a small constant correction for slippage at the wall the plastic viscosities and apparent yield values determined with the two types of instrument could be brought into agreement.

A rough correlation was established between plastic viscosity and MacMichael viscometer reading (used extensively in U.S.A. as a standard for chocolate). The latter reading is arbitrary and the existence of any correlation is dependent on the absence of crossing over in the flow curves.

Temperature, fat and lecithin contents are the most important of the controllable factors which influence the viscosity of chocolate. In the melted state linearity between  $\log \eta$  and  $1/T$  ( $\eta$  = apparent viscosity,  $T$  = absolute temperature) is found to hold up to  $60^\circ\text{C}$  or  $70^\circ\text{C}$ , the viscosity decreasing by approximately 2 or 3% per  $1^\circ\text{C}$  rise (Ref. 6). Changes in the fat content over the range 32 to 40% can reduce the viscosity by a factor of about ten. A relation between plastic viscosity and volume of solids after centrifuging which has been found to hold for a number of samples of chocolate and other materials is (Ref. 7)

$$\eta_p/\eta_0 = [1 - C/(1 - v)]^{-k}$$

where  $\eta_p$  = plastic viscosity of suspension,  $\eta_0$  = viscosity of liquid phase,  $C$  = % solids in suspension (by volume),  $v$  = % voids in packed solids (by volume).

Lecithin reduces the viscosity of molten chocolate by adsorption on the surface of the sugar particles and consequent liberation of cocoa butter. About 0.3% commercial lecithin is equivalent in viscosity reducing power to an extra 4 or 5% of cocoa butter. Experiments by some Russian observers on the thixotropic effects of chocolate (Ref. 9) have shown that an addition of about 0.2% lecithin prevents the plastic viscosity from rising on standing. With only 0.1% lecithin present a considerable increase in plasticity was observed and this was attributed to an increase in the number (and surface area) of the sugar particles brought about by the lecithin.

The problem of correlating viscosity measurements with the consistency of chocolate at the enrobing or moulding stage in manufacture is especially difficult owing to the continued crystallisation of cocoa butter which is taking place. The stresses and rates of shear to which chocolate is subjected in these final stages are likely to be under  $250 \text{ dynes/sq. cm.}$  and  $10 \text{ sec}^{-1}$  and further study of the rheological behaviour under these conditions is required.

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## Some Observations on Dilatancy and Thixotropy by

A. JOBLING and J. E. ROBERTS.

A new and very general technique for testing the mechanical properties of materials has recently been suggested by Weissenberg (*Bull. Brit. Soc. Rheology*, 1955, No. 43, p. 6). Instead of being deformed by the movement of rigid grips or boundary members, the specimen under test is spread in a thin film on a substrate which is itself deformable. The substrate can then be caused to undergo any one of a wide range of movements, the components of which in the plane of the interface are transmitted to at least the bottom layer of the sample provided that the two materials adhere adequately. The method has three major advantages:—

(i) it enables mechanical tests to be made simply with any general homogeneous strain and many types of heterogeneous strain;

(ii) it affords improved control over the behaviour of the material in the plane of the film as evidenced by the remarkable regularity of the patterns of "flow lines" produced if a straining action applied in this way is continued either in time or space to the point where failure occurs. In isotropic materials, the directions of this pattern can be related to the strain geometry;

(iii) it extends the range of materials that can be tested in any given deformation so that, for example, actions involving tensile stresses can now be applied to materials of little cohesion such as pastes or powders. As a result, striking similarities in the behaviour of materials of widely-differing physical and chemical properties are now revealed (e.g. the generality of "fatigue" failure).

The technique has been found to be particularly useful for the study of dilatancy. The term is used here to describe not merely an increased resistance to shear with increasing rate of shear but in the original literal sense of an increase of apparent volume on shearing. In a paste, this increase in the apparent volume of the solid phase is well-known to result in a drying-out and dulling of the free surface at a sufficiently high rate of strain. The material in this state is brittle and easily ruptured by a further increment of strain. A material which is dilatant in one type of mechanical action seems to be dilatant in all provided that both strain and rate of strain are sufficiently large. In some dilatant systems, the brittle state relaxes spontaneously to a fluid or soft state if the material is left undisturbed and in other dilatant systems this relaxation can be brought about by the application of a small-amplitude oscillatory shear of the right amplitude and frequency. Conversely, by the application of a mechanical vibration of this type, a dilatant material can be kept fluid throughout some shearing action under which it would normally dry out on the surface, become brittle, and crack. This may have some application in any industrial process in which a dilatant system has to be spread or pumped. An analogous process is the vibration of a powder (e.g. by tapping the container) to bring it into a closer-packed (non-dilatant) state. Mechanical relaxation can now be studied more exactly since by the thin-film technique the effect can be produced in well-defined shearing movements whose type, amplitude, and frequency can be controlled.

The whole phenomenon of dilatancy appears to be more complex and more widespread than is generally believed and none of the present theories is adequate. The thin-film technique shows up clearly very slight traces of dilatancy so that a change of surface texture on shearing has even been observed in many systems which are normally classified as thixotropic. A surface roughening in shear is well-known for many metals and though the detailed mechanism may well be different, it is interesting to note that relaxation (softening) of a number of work-hardened metals and alloys by the application of small-amplitude mechanical vibrations has recently been claimed (N. H. Polakowski and A. Palchoudhuri, *Proc. A.S.T.M.*, 1954, 54, p. 701).

Other experiments by the new technique indicate that dilatancy is observed in some materials over a wide concentration range and may also be accompanied by marked changes in electrical properties (e.g. a 150-fold *drop* in the d.c. resistance of a graphite/oil paste in simple extension for a 70% stretch, which indicates a marked increase in electrical strength although the graphite particles are moving apart).

## The Bursting Strength of Porous Bodies Injected with Bentonite Suspensions by G. K. JONES.

Practical means of decreasing the permeability of porous sands and sandstone are becoming increasingly important in civil engineering practice. Ideally, it is desired to reduce the permeability of the porous body to zero by the injection of a disperse system which sets to a gel, preventing passage of fluids below a critical pressure referred to as the "breakthrough pressure,"  $P$ , after which the body becomes permeable once more.

Experiments have been carried out by injecting beds of close-packed glass spheres with bentonite suspensions of known rheological characteristics. The hydraulic pressure required to create breakthrough was observed and related to the average pore diameter of the bed and to the hydraulic permeability of the bed before bentonite injection. By using air and water as the bursting media it was possible to show that the breakthrough pressure  $P$  was independent of the nature of the bursting fluid, but was proportional to the shear strength of the bentonite suspension at the time of carrying out the bursting test, a result which can be expected by considering the simple analogue of a capillary radius  $r$ , length  $l$  filled with a Bingham body of shear strength  $S$  and subjected to a hydrostatic pressure at one end, where  $P = 2lS/r$ .

Presumably breakthrough in a bed of closely packed spheres takes place along a path where  $l'/r'$  is at a minimum, where  $l'$  is the tortuous length of the breakthrough channel through the bed and  $r'$  is the average pore radius along this path. The work of Schlichter was used in an attempt to relate  $l'$  and  $r'$  to  $P$  for dispersions of known  $S$ . Good agreement with theory was obtained providing that precautions were taken to prevent bursting along the set of pores lying between the bed and the vessel walls, where the pore size is larger than in the main body of the bed. Under these conditions failure occurs when  $P = 16.9 l'S/d$ , where  $d$  is the diameter of the close packed spheres.

Another approach is to relate the breakthrough pressure  $P$  to the hydraulic permeability  $p$  of the bed. It is deduced that  $P$  is proportional to  $(v/p)^{1/2}$  where  $v$  is the bed porosity. Fair agreement with experiment was obtained.

Finally, the extent of penetration of a Bingham body into a porous mass was deduced for a given injection pressure  $P^*$ , by using the Buckingham-Reiner equation. The proportionality between  $\tau_B$  the Bingham yield stress and the linear extent of penetration through a horizontal bed deduced from the Buckingham-Reiner equation was demonstrated experimentally for constant  $P^*$ .

## Behaviour of Suspended Spheres in Laminar Shear by

S. G. MASON, W. BARTOK and M. A. NAWAB (Pulp and Paper Research Institute of Canada and Department of Chemistry, McGill University).

Particles suspended in a liquid subjected to a velocity gradient undergo rotational and translation movements. At low velocity gradients fluid spheres rotate at the same angular velocity as rigid spheres, but as the velocity gradient is increased fluid particles are distorted into ellipsoids and the rotation is modified.

The translational movement of equal-sized spheres causes the particles to come into collision with one another and form collision doublets. The rate of formation, the lives, persistence times, and rotational velocities of the transitory doublets of rigid spheres have been found to be in excellent agreement with values calculated on the basis of rectilinear approach of two spheres until they collide. The spheres approach one another very closely but do not come into true physical contact. When the two interacting spheres are of different diameters, the interactions are much more complicated.

Comparable behaviour is shown by collision doublets of fluid spheres, but in this case the two particles can, under certain conditions, coalesce to form a single sphere.

The significance of these phenomena is described with particular reference to the formation of aggregates and the viscosity behaviour in dilute suspensions.

## Density Separation in Gaseous Fluidised Beds by

T. C. DANIELS.

When air is blown vertically up through a column of powder there are at least three possible final states of the column of powder depending on the upward velocity of the air. Firstly, for low air velocities the air will flow through the passages between the particles of powder causing no disturbance to the individual particles of the bed; this is a packed bed acting as a filter. Secondly, if the air velocity is increased the bed will visibly expand and the individual particles will be supported on the upward stream of air, the fall in air pressure across the bed being equal to the weight of the powder per unit cross-section in the bed. The bed is said to be fluidised in this state and possesses apparent fluid properties such as density and viscosity. Thirdly, if the air velocity is further increased the expansion of the fluidised bed increases until the powder is transported by the air.

When a bed becomes fluidised with an upward stream of air the surface of the bed "boils," and provided that the air velocity is not too high there will be no carry-over of the powder from the column. These beds have apparent densities which can be found experimentally from the pressure drop of the rising air flow

$$\Delta P = \rho_f H$$

or calculated from

$$\Delta P = W/A\rho_p \cdot (\rho_p - \rho_a)$$

as  $\rho_a$  for air and gases is low in comparison with  $\rho_p$  for the powders

$$\Delta P = W/A$$

$P$  can also be expressed in terms of bed height and voidage fraction  $\epsilon$

$$\Delta P = H\{1 - \epsilon\}(\rho_p - \rho_a)$$

These fluidised beds, owing to their apparent densities, are capable of behaving like liquids, i.e. certain substances can float, others will sink to the bottom of the bed, depending on the density difference between the substances and the apparent density of the fluidised bed. This is the key to the designing of dry separators, e.g. the coal industry would welcome a dry separator for separating the coal dust from the stone dust.

The investigation so far has been conducted along the following lines. In the first stages it became immediately obvious that the finer particle size powders were much more fluid than the coarser particle powders, even of the same substance. A fine-powder fluidised bed is less viscous than a coarse one. Therefore the value of this apparent viscosity is dependent on the particle size of the substance and also on the apparent density of the substance.

The falling-sphere method of measuring viscosity is being used. Metal spheres varying in density and diameter are allowed to fall through the fluidised beds. The rate of fall once the terminal velocity of the sphere has been established is experimentally determined. The bed consists of a 2-in. diameter column, on the outside of which are two detecting coils at different levels of the column which emit a signal as the metal sphere falls through them. Therefore the time taken to fall from one coil to the other is recorded and hence the rate of fall is evaluated.

A plot of the rate of fall against diameter squared is linear over the range of sizes investigated and can be represented by the equation

$$V = md^2 + V_0$$

The slope of the line is dependent on the density of the spheres. If  $m_1, \rho_1$  are the slope and density for one metal and  $m_2, \rho_2$  for another it is found experimentally that

$$m_1/m_2 = \{(\rho_1 - \rho_f)/(\rho_2 - \rho_f)\}^n$$

where  $\rho_f$  = density of fluidised bed calculated from the air pressure drop across the bed.

A modification of the familiar Stokes Law for the terminal velocity of the falling sphere is now proposed.

Stokes Law for terminal velocity

$$V = \frac{gd^2}{18} \frac{(\rho - \rho_f)}{\mu}$$

*Proposed modification.*

$$V - V_0 = \frac{gd^2}{18} \frac{(\rho - \rho_f)^n}{\mu'}$$

$$\mu' = \frac{g}{18} \left[ \frac{d^2}{V - V_0 / (\rho - \rho_f)^n} \right]$$

It has been established experimentally for different fluidised beds that

$$\frac{d^2}{V - V_0 / (\rho - \rho_f)^n}$$

is a constant for that bed for a suitable choice of the constant “ $r$ ,” and although  $\mu'$  has not the usual units of viscosity owing to the index “ $n$ ,” nevertheless it is a value closely allied to viscosity.

Values of  $\mu'$  the apparent viscosity have been found for different beds, and Reynolds Numbers for the falling spheres were subsequently calculated and found to be well below one which is the upper limit for applying the Stokes Law.

The investigation so far suggests that the index “ $n$ ” is independent of density of the fluidised bed and varies with the particle size of fluidised powder. Whereas the apparent viscosity is dependent on both particle size and particle density. Work is being continued on establishing how “ $n$ ” varies with particle size using the same material, and also whether “ $n$ ” is a constant for the same particle size but different materials.

*Notation.*

|                        |                                                             |
|------------------------|-------------------------------------------------------------|
| $\Delta P$             | = Air Pressure drop across height $H$ of the fluidised bed. |
| $H$                    | = Height of fluidised bed.                                  |
| $\rho_f$               | = Apparent density of fluidised bed.                        |
| $\rho_p$               | = Density of the fluidised powder.                          |
| $\rho_a$               | = Density of air or gas causing fluidisation.               |
| $W$                    | = Weight of powder in the fluidised bed.                    |
| $A$                    | = Cross-sectional Area of fluidised bed.                    |
| $\epsilon$             | = Voidage fraction.                                         |
| $V, V_0$               | = Terminal velocities of metal spheres.                     |
| $\rho, \rho_1, \rho_2$ | = Densities of metal spheres.                               |
| $d$                    | = Diameter of metal spheres.                                |
| $g$                    | = Gravity.                                                  |
| $m_1, m_2$             | = Slopes of linear graphs.                                  |
| $\mu'$                 | = Apparent viscosity of fluidised bed.                      |

## Rheological Measurements on Lutings by

W. A. DUKES.

Lutings are soft plastic and adhesive compositions, used for sealing and waterproofing screw-threads. A typical formulation (B.P.756,548), designated R.D.1284, is a dispersion of a synthetic wax in polyisobutene of low molecular weight. A critical comparison is made of different ways of measuring both the yield value and apparent viscosity of lutings, which approximate to Bingham materials at low rates of shear. Various theories concerning the use of the parallel plate plastometer are compared in the light of results obtained with lutings. Peek's theory (*J. Rheology*, 1932, 3, 345) gives the best approximation to the yield value, as a precise extrapolation to zero rate of shear is possible.

Yield values of lutings have also been determined with edge-on plate penetrometers and with sinker gauges, both of which methods are less precise than the parallel plate plastometer, although they are simpler to perform. Houwink's lower yield value (Elasticity, Plasticity and Structure of Matter, Cambridge, 1937, p. 14) may be estimated

with a torsional viscometer capable of use at very low rates of shear; this quantity approximates to the results obtained by the other three methods. The parallel plate plastometer is unsuitable for measuring the apparent viscosity of lutings at low shear rates: the methods of Peek and of Dienes and Klemm (*J. Appl. Phys.*, 1946, 17, 458) give inconsistent results. In contrast, torsional viscometers are suitable, and the divided cylinder plastometer of Ward and Freeman (*J. Sci. Instr.*, 1948, 25, 387) is suggested for future work.

*Second Indian Congress on Theoretical and Applied Mechanics, National Physical Laboratory, New Delhi, October 1956. President—Dr. K. S. Krishnan.*

*The following papers of rheological interest were included:—*

**The Flow of Gas-Saturated Fluids in the Hydraulic System Reservoir-Well** by  
V. A. ARKHANGUELSKY, U.S.S.R.

The two-phase flow may be computed by means of numerical integration of the differential flow equation, considering the real properties of fluids and the empirical relationships for the energy losses and for the density of the mixture.

The unsteady flow in a stratum is computed by the method of succession of steady states.

The graphoanalytical method is used for computation of flow in the hydraulic system reservoir-well. The curves are plotted, which represents the relationship between the rate of liquid discharge in the stratum and the bottom hole pressure and between the liquid production of the well and the bottom hole pressure. In this case the surface pressure data and the gas-liquid ratio are used as parameters. The reservoir pressure data and the productivity index corresponding to the cessation of flowing and the duration of the flowing period are determined by means of these graphs.

**Vibration Damping Characteristics and Anelastic Behaviour of Low Carbon Steel** by

G. P. CHATTERJEE, Calcutta.

The specific damping capacity of a material which is defined as the energy dissipated per unit volume of the material per unit stress in one stress-cycle is an extremely structure sensitive property. The anelastic behaviour of low carbon steel specimens as revealed by its non-linear stress-strain diagram appears to be directly associated with its damping capacity. Studies on changes of damping capacity as function of the mechanical or thermal history of a material appear to be a very sensitive and powerful tool of research for the metallurgist and the engineer.

**On the Steady Laminar Flow of a Viscous Liquid Through an Elastic Tube with Constant Temperature Gradient** by

M. N. L. NARASIMHAN, Kharagpur.

The flow of blood through arteries which are flexible tubes at a constant temperature gradient is a typical problem. It is found that the temperature gradient effect tends to increase the radius of the elastic tube with distance along the axis. This effect is found to be similar to that of cross-viscosity, or the normal stress effect exerted on the tube wall during the flow of highly viscous liquids like blood, paint, etc., which are known as non-Newtonian liquids. Some numerical examples are worked out for olive oil, lubricating oil, water and turpentine.

**The Effects of Cross-Viscosity on the Performance of a Slider Bearing without Side-leakage** by

S. RAMACHANDRA, Kharagpur.

The existence of stresses in directions across the velocity gradient in Non-Newtonian liquids has been shown by Braun and Reiner. This property is applied to the case of a slider bearing without side-leakage. The equations for pressure, load capacity and coefficient of friction are developed. It is found that the load bearing capacity of the slider is greater than that with Newtonian liquids having the same viscosity.

# RHEOLOGY ABSTRACTS

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**3544. On the calculation of the critical shearing stress of dispersed systems in experiments with a cone plastometer.**

N. N. AGRANAT and M. P. VOLAROVICH, *Koll. Zh.* 1957, 19 (1) 3.

**The theory of the method for determining the critical shearing stress for dispersed systems with a cone penetrometer.**

N. N. AGRANAT and M. F. SHIROKOV, *Koll. Zh.*, 1957, 19, (1) 9.

Authors discuss modifications of Rebinder's method for calculating yield-values from cone plastometer penetrations and derive a method which gives good agreement with yield-values obtained from other types of experiment. G.W.S.B.

**3545. Methods of testing the mechanical strength of glass.**

G. M. BARTENIEV and A. I. IVANOVA, *Steklo i Keram*, 1956, 13, 12; *Verres and Réfract*, 1956, 10, 382.

Examination of bending strength under centre load. Bending strength increases with decreasing thickness of sample, because cutting strain existing on cross section starts off rupture in these places, and liability to breakage therefore increases with cross-sectional area. A.

**3546. Experiments on Controlled Fractures.**

J. J. BENBOW and F. C. ROESLER, *Proc. Phys. Soc. B.*, 1957, 70, Pt. 2, 201.

A new type of fracture experiment is described. The specimen is a flat strip, which is split lengthwise by gradually propagating a crack down the middle. The crack is made stable in direction by holding the specimen in a state of lengthwise compression. The energy balance of the system can be established by simple beam theory. Measurements made on plastics, with specimens of varying size, show that the crack propagation is governed by a constant specific fracture energy, which is invariant with respect to scale transformations of the stresses. For a sample of polymethylmethacrylate the specific fracture energy was  $4.9 \times 10^5$  dyn cm<sup>-1</sup>. For a sample of polystyrene it was  $25 \times 10^5$  dyn cm<sup>-1</sup> for slow cracks, but dropped to  $3 \times 10^5$  dyn cm<sup>-1</sup> for fast-running cracks. A.

**3547. Constant Stress Creep Apparatus.**

R. C. BOETTNER and W. D. ROBERTSON, *Rev. sci. Instrum.*, 1956, 27, 1039.

A simple creep apparatus for approximating a constant stress in tensile specimens of large cross-sections, where large applied loads are required, is described. The apparatus consists of a lever with a large built-in mechanical advantage, together with means for removal of incremental weights from the applied load. A.

**3548. On the Question of the Rayleigh-Beilby Film on Glass.**

E. BRÜCHE and H. POPPA, *Z. angew. Phys.*, 1956, 8, No. 10, 486.

The authors prove the existence of a surface film (the "Beilby film") a few millimicrons thick, which is formed under stress and which retains fluidity for a time of order  $10^{-4}$  sec. The film is likely to have different properties from the bulk glass. A semi-quantitative theory of the mechanism of polishing is given. A.

**3549. Viscosity of Polymers in concentrated Solutions.**

F. BUECHE, *J. chem. Phys.*, 1956, 25, 599.

Previous theories predict  $\eta \propto M^{2.5}$  for large molecular weights ( $M$ ), whereas  $\eta \propto M^{3.4}$  is found experimentally. The discrepancy is due to the neglect of a circulation effect within each molecule; when this is included in the theory it gives  $\eta \propto M^{3.5}$ . A.

**3550. Dynamic Determination of Viscosity.**

A. CARRELLI and A. DE VITO, *Nuovo Cimento (Ser. 10)*, 1956, 4, 1009.

A method is described for measurement of the coefficient of internal friction in fluids, in such conditions that the velocity of the various layers and the velocity gradient are not constant in time. The experimental results show that the fluids having a complex molecular structure exhibit in such dynamical conditions of measurement values of the coefficient of internal friction which differ from the ones obtained in the conditions in which the velocities and the velocity gradient are constant. A.

**3551. Activation Energy of the Eyring Theory of Liquid Viscosity and Diffusion.**

F. C. COLLINS, *J. chem. Phys.*, 1957, 26, 398.

The determination of the activation energy of the Eyring viscosity and diffusion theory from the isobaric temperature coefficient of the transport property is shown to be inconsistent with the assumed mechanism of the process. An alternative form of the Eyring theory makes use of an activation energy determined from the constant volume temperature coefficient of the transport property. Here the calculated viscosities and their isobaric temperature coefficients turn out to be in moderately satisfactory agreement with experiment in the case of several simple liquids. A.

**3552. The Effects of Grain Boundaries on the Plastic Deformation of Zinc Crystals.**

G. B. CRAIG and B. CHALMERS, *Canad. J. Phys.*, 1957, 35, 38.

The tensile plastic deformation of single-crystal and tricrystal specimens of zinc was investigated by analysis of the external change in shape of the specimens, and of the changes in X-ray diffraction patterns. It was demonstrated that the single crystals deformed by slip on the basal plane, but pyramidal as well as basal slip occurred in specimens containing grain boundaries. A.

**3553. Anisotropy of Elastic Properties of Single Crystals of Gallium.**

M. ERNY, R. CABARAT, A. DEFRAIN and I. EPELBOIN, *C.R. Acad. Sci. (Paris)*, 1956, 242, 2698.

A dynamic method is used to determine Young's modulus of cylindrical specimens of Ga single crystals having different orientations. The elastic constants in the relationship between the modulus and the orientation are derived. The modulus is of the order of 10,000 kg/mm<sup>2</sup> and shows little variation with temperature between 18°C and the melting point (29.75°C). A.

**3554. On the Destabilizing of Cream in a Field of Uniform Shear.**

V. FAVSTOVA and I. VLADOVETS, *Molochn. Prom.*, 1956, 17, 29.

Suitably treated cream was churned into butter in a concentric cylinder viscometer fitted with a device for measuring power output. End effects were eliminated by a mercury layer. Process of formation of butter granules was followed microscopically and by analysis of filtered samples. Time required to produce butter ( $t$ ) was inversely proportional to rate of shear. As fat content of cream was increased,  $t$  decreased fairly steadily. The optimum temperature range (minimum  $t$ ) was 20–25°C. G.W.S.B.

**3555. On the Mechanism of High-Temperature Creep in Metals with Special Reference to Polycrystalline Lead.**

P. FELTHAM, *Proc. Phys. Soc. B*, 1956, 69, 1173.

On the basis of Mott's suggestion that intracrystalline deformation in creep takes place by fine slip, and that the activation energy is that for the motion of screw dislocations impeded by jogs, expressions for the high-temperature transient and equilibrium creep rates are obtained in terms of the applied stress, the temperature, the grain size and the

characteristics of the intragranular substructure. The equations give a good interpretation of the known creep behaviour of a number of metals as reported in the literature. The synthesis is based primarily on lead as, in conjunction with the present experiments, the available literature provides a fairly comprehensive account of the creep of both single crystals and polycrystals of this metal. A.

**3556. Preliminary Measurements on the Viscoelastic Properties of Animal Tissues at Audio-Frequencies.**

E. R. FITZGERALD, E. ACKERMAN and J. W. FITZGERALD, *J. Acoust. Soc. Amer.*, 1957, 29, 61.

In this preliminary investigation the electromagnetic transducer method of Fitzgerald and Ferry is used to obtain the complex shear compliance and shear modulus of muscle tissue taken from a freshly killed cow at room temperatures and in a frequency range from 25 to 2500 c/s. Both the level and the shape of the compliance—frequency curves are found to depend on the elapsed time after slaughtering. While there are some difficulties due to the rapid changes in viscoelastic properties with time, the results indicate that the method can be successfully applied to determine the viscoelastic properties of animal tissues. A.

**3557. Wave Motions on a Free Oil Surface.**

J. R. D. FRANCIS, *Phil. Mag. (Eighth Ser.)*, 1956, 1, 685.

It is found that when air is blown over an oil surface in a wind tunnel there is a certain critical windspeed at which tiny ripples occur on the surface which rapidly grow and accelerate downwind. Experiments on a number of viscous liquids show that viscosity has a large effect upon ripple height and speed though not upon the critical windspeed. The results are in accord with the Kelvin-Helmholz instability of surface waves. A.

**3558. Summarized Proceedings of a Conference on the Structures of Semi-Crystalline and Non-Crystalline Materials—London, Nov. 1955.**

R. E. FRANKLIN and R. L. GORDON, *Brit. J. appl. Phys.*, 1956, 7, No. 11, 385.

A conference held by the X-ray Analysis Group of The Institute of Physics. The three sessions dealt respectively with coals, cokes and carbons; with glasses, liquids and disordered structures; and with non-biological fibres. A.

**3559. Studies in the Field of the Physical Chemistry of Agar (1) on the Method for Determining the Intrinsic Viscosity of Agar.**

S. A. GLIKMAN and I. G. SHUBTSOVA, *Koll. Zh.*, 1957, 19, (2), 172.

Curves plotting reduced viscosity *vs* concentration show a sharp minimum at low concns. in the presence of  $\text{CaCl}_2$ . A true  $\eta$  can be obtained for solutions containing 0.05–0.25 g. equiv./l. KCl. Testing temperatures must be above a critical value, marked by a break in the  $\eta$ /temp. curve. G.W.S.B.

**3560. Testing Indentation and Abrasive Hardness of Hard Materials.**

P. GRODZINSKI, *Ind. Diamond Rev.*, 1957, 17, 29.

Survey of abrasion testing chiefly covering use of gem polishing and engraving methods in hardness testing. Grinding on plane disks covered in respect of flat grinding equipment, means of adjusting face to be ground, measurement of torque and power consumption, measurement of optical and thermal phenomena, and suggested standardization of disk abrasion tests. In second part, micro-abrasion testing with double conical surface, as in Grodzinski micro-abrasion tester, fully described, together with use of hand piece with flexible shaft for producing micro-abrasion marks for practical wear measurements. Survey completed with study of drum abrasion tester. A.

**3561. Testing Indentation and Abrasive Hardness of Hard Materials.**

P. GRODZINSKI, *Ind. Diamond Rev.*, 1957, 17, 70.

This part deals with the micro-abrasion method of testing, covering the measurement of micro-abrasion marks, the investigation of surfaces damaged by abrasion marks, the effects of neutron bombardment, tests on diamonds from various mines, the dependence of micro-abrasion resistance upon azimuth, and tests with an oriented diamond cube. A.

**3562. On Types of Structure-Formation in Clay Suspensions.**

M. M. GURVICH, *Koll. Zh.*, 1956, 18, (6), 666.

Drilling muds are of two types, one of which is thixotropic whereas the other is not, and may even toughen on stirring. These types of behaviour are related to theories of clay structure propounded by Rebinder and Serb-Serbina. G.W.S.B.

**3563. Equilibrium of a Visco-Plastic Dispersed System on a Rotating Disk.**

A. M. GUTKIN, *Koll. Zh.*, 1957, 19, (1), 31.

Formula is derived relating yield-value of plastic materials to limiting radius and layer thickness on a disk rotating at a given angular velocity. G.W.S.B.

**3564. Yield Effect in Nickel Single Crystals.**

P. HAASEN and A. KELLY, *Acta Metallurgica*, 1957, 5, 192.

Various investigators have reported the existence of a small but measurable yield point in the stress-strain curves of single crystals of metals re-strained after prior deformation and ageing. The authors found this effect in single crystals of nickel and aluminium deformed at 20°, 78° and 90°K. (−253°, −195° and −183°C.) and at room temperature. It is pointed out that the phenomenon appears to be general in single crystals of pure face-centred-cubic metals deformed at low temperatures. Possible explanations are discussed. A.

**3565. Viscoelastic Theory of Branched and Cross-Linked Polymers.**

J. S. HAM, *J. chem. Phys.*, 1957, 26, 625.

A model of polymer chain motions is developed which in the limit of long, flexible chains can readily be applied to branched chain and cross-linked systems. The equation governing the motion of a chain takes the form of a differential equation rather than the form of the large set of difference equations that occur in most other treatments. The present model gives essentially the same distribution of relaxation times for linear polymers as previous treatments, and it also gives the same dependence of viscosity upon branching as the theories based on the effective radius of randomly coiled chains. The theory also yields the distribution of relaxation times for branched chain polymers, permitting the calculation of the energy stored in steady state shear. A.

**3566. The Elastic Constants of Anisotropic Materials. II.**

R. F. S. HEARMON, *Advances in Phys.*, 1956, 5, 323.

A review of theoretical and experimental work published between 1945 and 1955 with about 400 references. A.

**3567. Low Temperature Release of Stored Energy in Cold Worked Copper.**

J. W. HENDERSON and J. S. KOEHLER, *Phys. Rev.*, 1956, 104, 626.

Pure polycrystalline copper and alpha-brass specimens were deformed in compression at temperatures near −185°C. The release of stored energy was observed during subsequent warm-ups to room temperature and above. The annealing spectrum of pure copper shows prominent peaks at −25°C and −90°C, and smaller resolvable peaks at lower temperatures. The total energy release was about 0.17 cal/g for a specimen strained to 0.65. In contrast to pure copper, the spectrum for brass shows only one

clearly resolvable peak at  $-10^{\circ}\text{C}$  and extends to higher temperatures. The energy release was almost three times that of pure copper for comparable strains. A tentative theory of the multiple peaks in the rate of energy release below  $-70^{\circ}\text{C}$  is given. This theory supposes that the moving imperfections in this temperature range are divacancies and that the energy of motion of a divacancy is different depending on its orientation in the internal stress field. A.

**3568. Dynamic Elastic Moduli of Iron, Aluminum, and Fused Quartz.**

D. S. HUGHES and C. MAURETTE, *J. appl. Phys.*, 1956, 27, 1184.

The dynamic elastic constants of Armco iron, pure aluminium, and fused quartz have been measured with a supersonic pulse technique as functions of pressure and temperature over the range 1 to 9000 bars and  $25^{\circ}\text{C}$  to  $300^{\circ}\text{C}$  ( $200^{\circ}\text{C}$  for quartz). Within the experimental accuracy the dynamic elastic moduli of these materials can be represented by linear functions of pressure and temperature. The isothermal bulk moduli of other observers have been used to compute the equivalent adiabatic moduli by use of the thermodynamic relations. Comparison shows that at high pressures the dynamic moduli agree with the adiabatic moduli within the experimental accuracy for iron and aluminium. At low pressure the dynamic modulus of Armco iron is less than the adiabatic. The deviation is small but is about four times the estimated probable error. A.

**3569. Measurement of High Viscosities by Shearing between Parallel Plates.**

F. E. HUMPHREYS and N. STONE, *J. sci. Instrum.*, 1957, 34, 26.

Viscosities in the range  $10^4$ – $10^7$  poises have been measured by shearing thin films between two parallel stainless steel plates. In this way frictional heat is rapidly dissipated, temperature being registered by a thermistor. A.

**3570. The Nature of the Distortions on the Gliding Planes of Metals.**

V. S. IVANOVA, *Dokl. Akad. Nauk SSSR*, 1954, 94, No. 2, 217.

The author considers results of his experimental investigations of the plastic distortion of iron and steel. It is concluded that plastic extension progresses discontinuously and that the onset of the movement on gliding planes is associated with a "critical" strain of the grain. Relations between plastic distortion and work hardening are discussed in some length. A.

**3571. Specific Nature of the Deformation behaviour of Gelatin Jellies.**

L. V. IVANOVA-CHUMAKOVA, P. A. REBINDER and G. I. KRUS, *Koll. Zh.*, 1956, 8, (6), 682.

Jellies are subjected to simple shear between parallel plates under constant stress, and viscosities, shear-moduli and relaxation times are determined for concentrations of 5, 7.5 and 15% gelatin. The results are said to be similar to those previously obtained for polyisobutylene. G.W.S.B.

**3572. Methods of Determining the Relationship between the Propagation Velocities of the Plastic and the Elastic Deformation.**

D. A. KAL'NER, *Zavodsk Lab*, 1956, 22, 1086.

Experimental basis for and method of computing velocity of propagation of plastic deformation in metals from known propagation velocity of elastic deformation, which is equal to velocity of sound in material. A.

**3573. On the Question of the Mechanism of the Hardening of Thermosetting Plastics (Compound Powders).**

I. F. KANAVETS, L. G. BATALOVA and A. G. ROMASHOVA, *Koll. Zh.*, 1957, 19, (2), 204.

"An investigation was made into the hardening process and certain mechanical properties of thermoreactive\* plastics by measuring changes in the shearing stress with

the aid of a plastometer designed by one of the authors. Press powders were made of phenol-cresol-xylenol-formaldehyde resins, of melamine-formaldehyde resins and of aminoplast. The effect on the properties of the press powders was studied of the degree of condensation of the resin, of the low molecular ingredients, both reactive and non-reactive towards the resin, and of the method and conditions of preparing the powders. It was found that duration of the state of viscous flow of the powders is determined not by physical factors but by the rate of the chemical reaction transforming the low molecular resin fraction (and the products capable of reacting) to higher molecular compounds. The rate of hardening of the press powders was found to depend not only upon the degree of condensation of the resins, but also upon their structure. The rate increases with increasing viscosity of resins prepared with crystalline phenol. Press powders prepared with cresol and xylenol resins, because of the different low molecular compound content in the resins and their loose structure, may show a slower hardening rate, despite the increase of viscosity of such resins."

\*Thermosetting.

(Authors' abstract).

### 3574. **The Mechanism of Work Softening in Aluminium.**

A. KELLY, *Phil. Mag. (Eighth Ser.)*, 1956, **1**, 835.

The appearance of slip lines on polished surfaces of aluminium crystals has been studied under the optical microscope as a function of plastic extension at 90°K and at room temperature. A.

### 3575. **Effect of Fatigue Stresses on the Recovery Properties of Metals.**

A. J. KENNEDY, *Nature*, 1956, **178**, 810.

The rate of recovery from the work hardening brought about by creep is accelerated in lead by the application of a low-level 300 c/s fatigue stress. Prolonged application of the stress brings about a rehardening which, it is suggested, is associated with the development of fatigue in the metal. A.

### 3576. **A New Theory of Fatigue.**

A. A. KHEIRALLA, *Naturwissenschaften*, 1956, **43**, 321.

It is assumed that the effect of each cycle of applied stress is to translate the stress state of each element of the material in an arbitrary direction in the space of principal stresses. Failure is taken to occur when the stress state reaches the critical surface, which is cylindrical if failure is independent of hydrostatic stress. The computation of failure is thus identical with the problem of random walk within a circle in stress space. An alternative approach is to view the problem somewhat similarly, but to treat the steps according to diffusion theory. Formulae are given for each of these cases. A.

### 3577. **The Propagation of Stress Pulses in Viscoelastic Solids.**

H. KOLSKY, *Phil. Mag. (Eighth Ser.)*, 1956, **1**, 693.

The propagation of short mechanical pulses along rods of three polymers, polythene, polystyrene and polymethylmethacrylate, has been investigated experimentally. The pulses were produced by the detonation of small quantities of explosive at one end of a rod and a condenser microphone was employed to record the displacement of the opposite end. Some experiments on pulses through blocks of plastic are also described. A.

### 3578. **Thixotropic Structure Formation and Elastico-Viscoplastic Properties of Suspensions of "Askangel."**

E. I. KOBACHIDZE and M. E. SHISHNIASHVILI, *Koll. Zh.*, 1957, **19**, (1), 59.

Loading and recovery curves are given for a bentonite treated with I.N. NaOH. Thixotropy and syneresis are studied. G.W.S.B.

**3579. Investigation of the Viscosity of Dilute Solutions of Polyacrylonitrile. (Pan).**

V. E. KOTINA and V. S. KLIMENKOV, *Koll. Zh.*, 1956, **18**, (6), 703.

The concentration dependence of viscosity of dilute solutions of PAN in dimethyl formamide varies with the method of polymerization, hence intrinsic viscosities do not give reliable values for molecular weights. The molecular chains have considerable rigidity. G.W.S.B.

**3580. A Theory of Elastic After-Effect.**

J. KUBÁT, *Ark. Fys.*, 1956, **11**, 189.

Relaxation and primary creep are discussed in a model consisting of  $n$  independent systems in which an irreversible spontaneous change can take place. The consequences of correlation between some of the systems are investigated. A.

**3581. Study of Stresses in Crystals of Silver Chloride during Elasto-Plastic Bending.**

B. A. KUZNETSOV, *Zh. tekhn. Fiz.*, 1956, **26**, No. 7, 1611.

The bending stress distribution was studied in smooth and notched coarse-grained specimens: outer portions of smooth specimens showed a smaller resistance to plastic deformation than the interior (probably because the hardening due to the bending of glide packets was less at the edge). Presence of notches highly increased the flow limit of the crystal on bending. A.

**3582. On the Effect of Surface-Active substances on the specific Viscosity of Solutions of Gelatin.**

S. M. LEVI, *Koll. Zh.*, 1957, **19**, (1), 78.

When surface-active substances are added to gelatin solutions, the former are sorbed by the gelatin, causing changes in the shape of its molecules. These changes increase the viscosity of the solution. An equation has been given for the change in the specific viscosity of the gelatin solution as a function of the quantity of surface-active substance sorbed by the gelatin. The equation has been confirmed experimentally.

Author's Abstract.

**3583. Transport Properties of a Dense Fluid of Hard Spheres.**

H. C. LONGUET-HIGGINS and J. A. POPE, *J. chem. Phys.*, 1956, **25**, 884.

From the two assumptions, that the pair distribution function of relative position is independent of the rate of strain or the temperature gradient and that the velocity distribution is locally Maxwellian, expressions are derived for the shear viscosity  $\eta$ , the bulk viscosity and the thermal conductivity  $\lambda$  of a hard-sphere fluid at high densities. A.

**3584. The Internal Friction of Metals.**

G. LÖSCHNER, *Technik*, 1956, **11**, 289.

The internal friction is represented as a result of the relation between elongation and stress, both of which depend to some extent on time (anelasticity). Another factor is dynamic hysteresis, which is a special case of relaxation, deformation being determined not only by the instantaneous external forces but also by the variation of the forces. The causes of internal friction are internal structural rearrangements, including thermo-elastic effects, and the transmission of vibration from grain to grain in the case of polycrystalline metals. Other causes are an interaction between the conductivity electrons and the elastic lattice vibrations. In ferro-magnetic materials there are magneto-elastic effects producing magneto-strictive non-elastic elongation, which causes mechanical vibrations to be damped. The stress-induced ordering of atoms in the metal lattice is different from the equilibrium distribution and the tendency of the metal to re-establish the equilibrium condition by means of irreversible processes causes internal friction. The grain-boundary viscosity has anelastic effects, also dislocation and plastic flow due to cold working and phase transformation in conjunction with a dimensional change. A.

**3585. Internal Friction and Fatigue in Metals at Large Strain Amplitudes.**  
W. P. MASON, *J. Acoust. Soc. Amer.*, 1956, **28**, 1207.

A barium titanate transducer coupled to an exponential horn can produce large strains in metals. Measurements of the impressed voltage and a voltage from a pick-up electrode on the titanate make it possible to calibrate the device so that the internal friction, change in elastic constant, and the strain in the sample are all determined. The shape of the internal friction curve allows one to evaluate the dislocation distribution with results in accord with etch-pit methods. A.

**3586. The Cold Work Introduced during the Fatigue of Copper.**

R. D. McCAMMON and H. M. ROSENBERG, *Phil. Mag. (Eighth Ser.)*, 1956, **1**, 964.

Specimens of polycrystalline high-conductivity Cu were annealed at 600°C for 3 hours in argon and furnace-cooled, after which they were deformed in fatigue or tension by a Goodman's vibration generator, operated by a.c. to make the fatigue measurements and by d.c. for direct tension. These experiments show that an appreciable amount of work hardening anneals out at a comparatively low temperature, far lower than the annealing temperature of the work hardening introduced by unidirectional strain. The work hardening produced by fatigue, therefore, is different from that produced by tensile strain. A.

**3587. Viscosity and Density of the Liquid System TNT—Picric Acid and Four Related Pure Materials.**

D. W. MOORE, L. A. BURKARDT and W. S. McEWAN, *J. chem. Phys.*, 1956, **25**, 1235.

The viscosity and density were investigated over a range of temperature which included both normal and supercooled liquids. The temperature-dependence of viscosity was found to be best represented by a continuous exponential function of the type  $\eta = A \exp(B/T + C/T^2)$ , which yielded a good fit to the data even well into the supercooled region. The results are interpreted as arising from an inverse temperature dependence of the flow activation energy,  $\Delta E_{\text{vis}}$ . It is suggested that  $\Delta E_{\text{vis}}$  may drop to zero at sufficiently high temperature and pressure. A.

**3588. The Working of Butter** (in 4 parts).

H. MULDER, F. C. A. DEN BRAVER and T. G. WELLE, *Netherlands Milk Dairy J.*, 1956, **10**, 200, 206, 214, 230.

This is an attempt to base a theory of butter-working on Smoluchowski's equation, relating number of collisions of dispersed droplets (water) in continuous medium (fat) in laminar flow, to size and number of particles and velocity gradient. Ideal conditions are so far from holding that the treatment is only semi-quantitative. Moisture content is not simply related to number and size of droplets nor do all collisions result in fusion. Most of the flow of butter in mixing machines is "plug" and care must be taken to ensure adequate shearing. Specific applications are quoted for churns, with and without rollers, for continuous process mixers and for printing machines. G.W.S.B.

**3589. Wear: A Physical-Chemical Problem.**

H. NOWOTNY, *Oest Ing.-Arch* 1956, **10**, 232; *Appl Mech Rev*, 1957, **10**, 64.

Two characteristic aspects of wear (dry friction and cavitation) considered from point of view of more detailed mechanisms. Role of local energy concentrations and their significance for chemical reactions discussed. High local energy densities lead to breakup of grains, loosening of structure and production of highly activated and reactive areas. A.

**3590. On a Classification of Non-Homogeneous Elasto-Plastic Bodies.**

W. OLSZAK, *Bull. Acad. Polon. Sci.*, 1956, **4**, 29.

Subdivisions of the class of nonhomogeneous elastoplastic bodies in which the stress is not appreciably dependent on the rate of shear are enumerated. The general types of stress-strain law, for loading and for unloading, are discussed briefly. A.

**3591. On the Fundamentals of the Theory of Elasticity of Physically Non-Linear Non-Homogeneous Bodies.**

W. OLSZAK and M. ZYCZKOWSKI, *Bull. Acad. Polon. Sci.*, 1956, 4, 63.

General stress-strain relations and equations of motion are considered for elastic bodies with variable moduli depending explicitly on the space coordinates as well as on the strains. The possibility of classifying such bodies is discussed. A study of the torsion of a circular cylindrical bar is used to illustrate the theory. A.

**3592. Dependence of Intrinsic Viscosity of Dilute Solutions of Macromolecules on Velocity Gradient.**

Y.-H. PAO, *J. chem. Phys.*, 1956, 25, 1294.

For the general case for free-draining random coils, where the perturbations resulting from all the components of the velocity gradient tensor are considered, there is a dependence of steady-state shear viscosity on velocity gradient. Where all the relaxation times have nearly the same value the rotation and distortion of the coils compensate for each other and the intrinsic viscosity is independent of velocity gradient. A.

**3593. Dynamometer for Tensile Testing of High Polymers.**

A. R. PAYNE and J. F. SMITH, *J. sci. Instrum.*, 1956, 33, 432.

This dynamometer measures force by the deformation of a proof ring. Load range and sensitivity can be changed instantaneously by adjusting an attenuator in the electronic circuit; this obviates the necessity for stopping the test and changing the pendulum weight of the conventional test machine, and also gives a much greater range of loads. Preliminary tests show that the instrument gives more reproducible results in tensile tests on rubber than do pendulum machines. A.

**3594. Delayed Fracture of Sintered Alumina.**

S. PEARSON, *Proc. Phys. Soc. B*, 1956, 69, 1293.

The strength of sintered alumina, when tested in the normal atmosphere, is shown to depend on the time for which the stress is applied. When stressed in bending under constant load, the average time to fracture increases from 1 sec. to  $10^6$  sec when the stress is reduced by about 22%. This delayed fracture can be largely eliminated by heat treating and testing in a vacuum. The vacuum heat treatment does not change the strength of the material permanently since the delayed fracture effect reappears when the material is again exposed to the atmosphere. It is concluded that the effect is due to attack of the stressed material by constituents of the atmosphere. A.

**3895. Study of Deformations of a Plate of an Elastic Suspension.**

J. E. PLAINEVAUX, *Nuovo Cimento (Ser. 10)*, 1956, 4, 922.

A general method is derived for calculating the plane deformations of a single plate of an elastic suspension. The method can be used for determining the vertical contraction of a plate for which the tangents to the extremities of the neutral axis are not parallel and for studying the deformation when the plate is stiffened centrally, or when the suspension is no longer symmetrical or symmetrically loaded. A.

**3596. Creep of Alpha Uranium during Irradiation with Neutrons.**

A. C. ROBERTS and A. H. COTTRELL, *Phil. Mag. (Eighth Ser.)*, 1956, 1, 711.

During neutron irradiation at  $100^\circ\text{C}$  alpha-uranium creeps slowly under external stresses of order of one-hundredth of the normal yield stress of the metal at that temperature. This effect is predicted as a consequence of the phenomenon of "radiation-growth" which occurs in uranium, and is then confirmed by creep experiments on helical springs of natural uranium in a flux of  $1.3 \times 10^{12}$  thermal neutrons per  $\text{cm}^2$  per sec. In addition to this steady-state creep, transient effects occur at the start of irradiation and when the neutron flux is removed. A.

**3597. On the Theory of the Low-Temperature Internal Friction Peak Observed in Metals.**

A. SEEGER, *Phil. Mag. (Eighth Ser.)*, 1956, **1**, 651.

Recent data on polycrystalline copper suggest that the low-temperature internal friction mechanism in metals is determined by intrinsic properties of dislocations. This is contrary to an explanation according to which the activation energy of the process should depend on the impurity content of the material and the separation between dislocation nodes. A mechanism proposed elsewhere seems to account for all the major features of the experimental results. The relaxation phenomenon is thought to be due to dislocations which are confined by the Peierls stress to certain crystallographic directions. Under the combined action of thermal fluctuations and the applied stress they may form pairs of kinks. Internal friction peaks are observed if the frequency of the applied alternating shear stress is equal to the frequency of the formation of these kink pairs. The Peierls stresses deduced from the experimental results are rather large, being of the order of one thousandth of the shear modulus.

A.

**3598. The Effect of an Active Filler and of the solvent on the Structural-Mechanical Properties of Bitumen.**

S. YA. SHALYT, N. V. MIKHAĬLOV and P. A. REBINDER, *Koll. Zh.*, 1957, **19**, (2), 244.

Effects of widely differing amounts of  $\text{Ca(OH)}_2$  on data from an "electronic electroviscometer." A well-defined region of (volume) concentration of  $\text{Ca(OH)}_2$  was found, corresponding to a three-dimensional structure in the material. Above this concn., limiting max. viscosity (L.M.V.) and viscosity-temperature coefficient (V.T.C.) increase sharply. The plasticizing effect of "green oil" was also studied. This disintegrates the three-dimensional network and causes the L.M.V. and V.T.C. to fall sharply. By balancing the concentrations of filler and plasticizer, L.M.V. could be maximized and V.T.C. minimized.

G.W.S.B.

**3599. Viscoelastic Properties of Polymeric Substances.**

K. SHIBATA, *Sci. Rep. Yokohama Nat. Univ. L*, No. 4, 1955, 19.

Creep in torsion and bending of polymethyl methacrylate is found to be linear when plotted against time (range  $10^4$  min) on a logarithmic scale. The results are compared with the theories of Tobolsky and Eyring (1943) and Gross (1947). Dynamic measurements of Young's modulus at 500 and 1000 c/s in the temperature range 20–120°C are reported and Gross's theory is used to correlate the transient and steady state results.

A.

**3600. Absorption of Ultrasonic Vibrations as a Characteristic of the Elastic Properties of Rubber.**

L. A. SHINYANSKIĬ and V. N. SOLON'KO, *Zh. tekhn. Fiz.*, 1956, **26**, 2302.

The absorption coefficient at 2.5 Mc/s of three rubbers of different degrees of vulcanization is plotted against relative extension. The resulting curves are discussed in terms of the kinetic theory of rubber elasticity and the crystallinity of the rubbers.

A.

**3601. The Impact Testing of Hard Metals.**

W. SPAETH, *Ind. Diamond Rev*, 1957, **17**, 65.

Since the usefulness of hard metals depends to a great extent on their ability to resist dynamic loads, particularly of a shock type, the impact testing of such metals is of some considerable importance. A new impact tester of the Izod type is described and test results are summarized on four qualities of hard metals.

A.

**3602. Tabor Abrasion Testing Machine.**

TABER INSTR CORP. *Machinery* (London), 1956, **89**, 1412.

Type 174 abrasion testing machine (with wheel truing unit) for metals, rubber, plastics, porcelain, etc. Material to be tested is attached to disk-shaped holder, mounted on vertical spindle. Two abrasive wheels, Calibrase medium grade and Calibrade hard

abrasive, contact testpiece, and form pattern by abrading action. Tungsten carbide wheels for testing resilient materials; other wheel grades for various materials. Both wheels, when loaded, are mounted on spindle of truing attachment and diamond traversed across faces by screw-operated slide.

**3603. The Drag on a Circular Cylinder placed in a Stream of Viscous Liquid midway between Two Parallel Planes.**

Y. TAKAISI, *J. Phys. Soc. Japan*, 1956, **11**, 1092.

The problem is treated by a method based upon Stokes' equations of motion using image methods which are developed by Faxén in the case of the sphere problem. A.

**3604. On the Thixotropic Properties of some Printing Inks.**

A. A. TRAPEZNIKOV and T. G. SHALOPALKINA, *Koll. Zh.*, 1957, **19**, (2), 232.

Two printing inks were intensively studied in a concentric cylinder viscometer. During shear, pressure first increases sharply then falls. At high shear-rates, the stress-levels fall as the number of shears increases but recovers on resting. Thixotropy is claimed to be of two kinds: structural, marking a breakdown in continuous network; and viscous, representing destruction and re-building of individual aggregates.

G.W.S.B.

**3605. Creep Properties from Short Time Tests.**

E. E. UNDERWOOD (Battelle Memorial Inst.) *Materials & Methods*, 1957, **45**, 127.

Results are given of research at the Institute in correlating hot hardness and strength properties. A.

**3606. Anomalies in the Temperature Dependence of the Viscosity of Supercooled Liquids.**

S. S. URAZOVSKIĬ and P. A. CHERNYAVSKIĬ, *Dokl. Akad. Nauk SSSR*, 1956, **111**, 640.

Nine different liquids are investigated above and below their melting points. The logarithm of viscosity is plotted against the reciprocal absolute temperature. It is claimed that these graphs consist of rectilinear segments having different slopes. In this paper only one of these graphs is actually shown; it refers to menthol and shows two kinks. Generally the points of discontinuous slope are identified with the melting point of the liquid or transition points in the solid phase. A.

**3607. The Relative Significance of Hardness Tests.**

V. V. VARNELLO, *Izmer Techn*, 1956, 34; *Inhaltsverzeichnisse sowjet Fachzeits*, 1956, 5, 1690.

Hardness tests only of relative significance because expressed in terms of size of indentation which is function of experimental conditions. "Hardness" not physical characteristic of material. True absolute significance of hardness awaits development of precise relation between it and mechanical constants of material. A.

**3608. A Study of Plastic Dispersed Systems under Uniform Stress Conditions.**

G. V. VINOGRADOV, V. G. LEBEDEV and V. A. PROTOD'YNAKOV, *Koll. Zh.*, 1956, **18**, (6), 633.

In the shearing of greases and oils between concentric cylinders, there is a danger of slippage on the smooth surfaces of the cylinders. The effects of roughening the cylinder surfaces are discussed. G.W.S.B.

**3609. Relaxation Theory of Vitrification. I. Solution and Investigation of the Fundamental Equation.**

M. V. VOL'KENSHTEĬN and O. B. PTITSYN, *Zh. tekh. Fiz.*, 1956, **16**, 2204.

A kinetic theory of vitrification is advanced, based on the description of structural relaxation in the system by a first-order chemical reaction equation. A solution of this equation is obtained and investigated. An expression for the temperature of vitrification

softening,  $T_y$ , as a function of the rate of cooling or heating and of the molecular parameters of the system, is given. It is shown that in vitrification liquid freezes in a structure corresponding to equilibrium at a temperature somewhat above  $T_y$ , and that in cooling and subsequent heating there should be a structural hysteresis, even when the rates of these processes are identical. A.

### 3610. **Anisotropic Relaxation Peak in the Internal Friction of Crystalline Quartz.**

J. H. WASILIK, *Phys. Rev.*, 1957, **105**, 1174.

An anisotropic relaxation peak has been observed in the internal friction of crystalline quartz. The height of the loss peak increases by a factor of 2.1 between a sample stressed in the  $Y$  direction and one stressed in a direction  $-18.5^\circ$  from the  $Y$  axis. A.

### 3611. **Compressional Creep on Tin Single Crystals.**

J. WEERTMAN, *J. appl. Phys.*, 1957, **28**, 196.

Compressional creep tests were run on single crystals oriented so that the direction of compression was along the  $c$  axis. Two activation energies of creep were found: approximately 24500 cal/mole above  $120^\circ\text{C}$  and 12000 cal/mole below this temperature. A.

### 3612. **Microhardness Testing at High Temperatures.**

J. H. WESTBROOK (Gen Electric Co.), *ASTM Bull*, 1957, (221), 16.

Abstr of paper to ASTM Mtg June 17-21, 1957.

The construction, operation and characteristics are described of a hot hardness tester of modified Bergh design with a temp range of 20 to  $1,500^\circ\text{C}$  and a load range of 20 to 900 g. Testing problems are discussed, particularly with reference to hard and brittle materials. Typical results are shown and examples of the application of these tests described. A.

### 3613. **The Fundamental Slip Process in the Torsion of a Crystal having a Single Active Slip Plane.**

A. D. WHAPHAM and H. WILMAN, *Proc. Roy. Soc. A*, 1956, **237**, 513.

The process of deformation of a single crystal by torsion is elucidated in the general case where the slip plane is inclined to the torsion axis. It is shown to consist primarily, in zinc crystals about 0.8 cm in diameter, of a new type of slip which will be called "flexural" rotational slip. In this slip process the slip lamellae are rotated relative to adjacent lamellae, about the common normal at any point of the interface, but with simultaneous development of pronounced saddle-like flexure. This flexure results in a variation in the amount of relative rotation of neighbouring lamellae over their interface, and also causes a cylindrical crystal to develop a rounded-triangular cross-section. Optical examination shows S-shaped (0001) slip bands about 0.05 to 0.1 mm wide. Electron diffraction shows that at the saddle-shaped (0001) cleavage face the lattice is mainly practically undistorted (apart from the macroscopic flexure) to a depth of 200  $A$  or more, thus the slip lamellae are at least 200  $A$  thick. An expression defining the shape the slip lamellae must take up is deduced assuming that the elastic deformation is negligible. A.

### 3614. **Temperature Dependence of the Viscosity of Liquid Argon.**

N. F. ZHDANOVA, *Zh. eksper. teor. Fiz.*, 1956, **31**, 724.

Viscosity of liquid argon is measured as a function of the temperature at constant density; at any given density, measurements start with the temperature of the vapour-liquid equilibrium and are extended upward near to room temperature. Densities are varied between 1.37 and  $0.70\text{ g/cm}^3$ . Results are shown in graphs; it would appear that the reciprocal viscosity is nearly a linear function of the temperature. At the higher densities the familiar exponential formula is nevertheless in agreement with measurements. At a density of 1.02 the coefficient of viscosity is virtually independent of the

temperature; it decreases or increases with increasing temperature if the density is higher or lower, respectively. At constant temperature viscosity increases markedly with increasing density but the rate of increase is different for different isothermals; in the density-viscosity diagram all isothermals intersect in a single point corresponding to approximately double the critical density. A.

**3615. Concerning the Mechanism of Plasticization of High Polymers: the Structure of Jellies. 8. The Influence of the Nature of the Plasticizer on the Kinetics of Swelling and on the Viscosity of Dilute Solutions of Divinyl-Styrol Rubbers.**

P. I. ZUBOV and M. P. ZVEREV, *Koll. Zh.*, 1956, **18**, (6), 679.

Swelling data using various plasticizers are compared with viscosities of dilute solutions and it is concluded that the plasticizing process is connected with weakening of interaction between molecular chains and their elongation. The latter is greater, the less the polarity of the plasticizer. An earlier hypothesis that swelling depends on a relaxation mechanism, is confirmed. G.W.S.B.

**3616. The Structure of Gels (9) Influence of the Nature of the Plasticizer on the Physico-Mechanical Properties of Divinyl Styrene Rubber.**

M. P. ZVEREV and P. I. ZUBOV, *Koll. Zh.* 1957, **19**, (2), 201.

Due to the greater weakening of intra- and intermolecular forces by non-polar, than by polar plasticizers, the former give higher glass-temperatures, tensile strengths and elongations than do the former, for incomplete vulcanizates. G.W.S.B.