

to Reserve

THE BRITISH SOCIETY OF RHEOLOGY



21113

3124-6

3131

→→ 3149

3154

(1954-55)

President:

DR. L. R. G. TRELOAR

Past-Presidents:

SIR GEOFFREY TAYLOR, F.R.S. (1940-42)

SIR CHARLES GOODEVE, F.R.S. (1942-44)

PROFESSOR E. N. DA C. ANDRADE, F.R.S. (1944-47)

PROFESSOR J. B. SPEAKMAN (1947-48)

PROFESSOR N. F. MOTT, F.R.S. (1948-49)

DR. G. W. SCOTT BLAIR (1949-51)

MR. A. G. WARD (1951-53)

Committee:

Honorary Treasurer:

MR. N. WOOKEY,
52, Tavistock Road, Edgware, Middlesex.

Honorary Secretary:

DR. P. FELTHAM
23, Stainburn Drive, Leeds, 17.

Honorary Editor:

MR. A. A. MILNE,
Mechanical Engineering Research Laboratory, D.S.I.R.
Thorntonhall, nr. Glasgow

MR. E. B. ATKINSON,
310, Colchester Road, Ipswich, Suffolk.

MR. L. GRUNBERG,
(Northern Representative)
Mechanical Engineering Research Laboratory, D.S.I.R.

MR. D. W. JOPLING,
Research Laboratories, Kodak Ltd., Harrow, Middlesex.

DR. E. W. J. MARDLES,
Royal Aircraft Establishment.

MR. W. F. O. POLLETT,
Freshwoods, Windsor Road, Gravesend, Kent.

MR. W. A. RICHARDSON,
Shirley Institute, Didsbury, Manchester, 20.

Honorary Auditor:

MR. A. DE WAELE,
Messrs. Gestetner, Ltd.

THE BRITISH SOCIETY OF RHEOLOGY

Bulletin No. 43

April, 1955

Price to non-members, 7s.

COMMENT

The Publications Committee of the Society for Analytical Chemists is showing some concern for the presentation of papers at its meetings and has invited Mr. A. L. Bacharach, as one skilled in the art, to put forward his personal views, and has also put forward its own recommendations to speakers. Both articles (*Analyst*, 79, September, 1954, pp. 529-534) are deserving of the earnest consideration of any of our members who are about to deliver a paper to our society. Only the former essay will be dealt with here.

Mr. Bacharach considers that a research worker reads a paper to a scientific meeting not for the dissemination of information, as this can better be done in print; "not as a way of telling his more immediate colleagues what a clever fellow he has been, for to do this must be either superfluous or immodest"; not even to give advance notice of results to prevent others repeating what has already been done. He claims that the main objective is "consultation with colleagues." The speaker wants to tell what he has done and to present his results and he wants his colleagues to "tell him if, in their opinion, he is about to make an ass of himself in trying to publish his results or his conclusions." He, therefore, has to "interest his colleagues sufficiently to induce them, having heard him and having something to say, to get up and say it."

Mr. Bacharach strongly condemns the solemn reading of a typescript as "insulting to the audience" and "guaranteed to make it impossible to do either of two otherwise perfectly compatible things, to interest an audience and sincerely to ask for its members' honest criticism." He, therefore, suggests that the best method is to "talk about your carefully planned and properly arranged slides without any notes at all," excepting for an *aide mémoire* consisting of a few notes made on small cards numbered as for the slides and containing a reproduction of the slide and a few key words. This enables the author to address the audience instead of the lantern screen—"look at the audience, as many of them in turn as possible but always at some of them."

On the subject of lantern slides he gives some hints that are well worth remembering. No table should ever contain more than 12 rows or ten columns and are better if they only have a quarter or a half of this. Graphs should be "bold, with figures and letters for the co-ordinates clearly indicated, and it is utterly useless to throw on the screen a slide showing several curves running meaningless neck-and-neck races with each other." Always remember the "thumb spot" in the left-hand bottom corner on the front of the slide as there is "only one right way of inserting a slide in the carrier but there are seven wrong ones!"

Finally, but most important of all, timekeeping—remember that the organisers of the meeting have divided your allotted time into time for communication and time for discussion. A minute on the former is a minute off the latter. An author who takes all his discussion time for presentation of the paper is "guilty of an unpardonable act of extreme discourtesy." Nothing "so permanently endears an author to his audience" and "puts his name high among those venerated by the meeting's organisers" as does the man who takes a minute less than the time he is allocated. "Instead of a sigh of

relief from the audience when he sits down, he is likely to elicit a round of cheers " and he will be " the uncrowned king of the evening's proceedings."

The remarks of Mr. Bacharach apply with special force to authors delivering papers to our society because we are a small society and, our meeting being informal, there is a greater chance for the author to induce his audience to take part in a really helpful discussion. We do not circulate preprints before our meetings and there is, therefore, less temptation for the author to read his paper *verbatim*, but all the same we do hear an occasional script read in a boring monotone. On the last point of timekeeping, how often has an author, carried away by his own eloquence, not only exceeded the time allocated to him but also to the discussion of his paper as well?

All speakers, experienced or inexperienced, would do well to read this essay in "The Analyst." Maybe not everyone will agree with all Mr. Bacharach's remarks; if not, then it would be interesting to hear their views.

D.W.J.

CORRESPONDENCE

The Editor,
The British Society of Rheology Bulletin,

Dear Sir,

I wonder if other members have recently been troubled, as I have been, by a new and pernicious tendency on the part of referees of scientific articles? I have not found this nuisance with journals devoted to physics so much as in certain applied fields of rheology.

The functions of a referee, which have been admirably formulated by the Institute of Physics, are to ensure that the work is adequate in quality, originality and clarity and is specifically suitable for the proposed journal. If the paper is not rejected, the referee may suggest alterations or corrections if they seem necessary to ensure these requirements.

But it is *not* the function of the referee to re-write the text in his personally preferred style; e.g. to substitute "big" for "large," "which" for "that" or needlessly to alter the order of the words.

I suspect that my English is not so exceptionally bad that I am unusual in having recently had several of my papers mutilated in this way. The substitution of synonyms generally alters, if only slightly, what the author is trying to say and, though extreme brevity is usually essential, referees' attempts to delete every "unnecessary" word can easily change the whole emphasis of an argument. (As an example, I recently had "in the great majority of cases" reduced to "mostly.")

In my recent experience, the worst offenders are among some of the biological journals, but I should be glad to hear from other members who have had the same troubles, so that we may discuss what are the appropriate steps to take to discourage this misuse of the functions of the referee.

G. W. SCOTT BLAIR,
N.I.R.D.,
Shinfield, READING.

Forthcoming Meetings

It is planned to hold a meeting to discuss "Viscoelastic Behaviour" on the 29th and 30th April in the Physics Dept., King's College, Newcastle. Details will be circulated.

The German Rheological Society are to hold a meeting in Frankfurt A/M on the 18th May. The preliminary programme shows that a morning session will be devoted to a discussion on "Flow profiles and/or Relaxation spectra" and the afternoon session to lectures on "Rheological measuring instruments in the construction of chemical apparatus." Enquiries should be addressed to the Secretary, German Rheological Society, Berlin-Dahlem, Unter den Eichen 87.

The Physics of Glass

G. O. JONES

(Queen Mary College)

In the thermodynamic hierarchy, glass is a doubly unstable liquid whose progress towards stability is inhibited because of its high viscosity. It is, first, unstable relative to any ordered crystalline state and will, under certain conditions, crystallize or devitrify. However, in normal use, this does not occur. Of greater physical significance in the study of glass is its instability relative to the state of internal equilibrium which corresponds to ordinary supercooling of a liquid. The temperature at which the viscosity is 10^{13} poise (the transformation temperature T_g) marks a rough boundary above which a glass forming system is merely a supercooled liquid and below which it is a glass. At any temperature below T_g the glass takes a finite time to reach the state of internal equilibrium corresponding to the particular temperature. The progressive approach to this state—often described as stabilisation—is normally shown macroscopically as a contraction. The significance of the figure 10^{13} is only that for most substances it corresponds to a Maxwell relaxation time of the order of the duration of ordinary experimental observations. As the temperature is lowered below T_g the microscopic adjustments necessary for the attainment of the configuration appropriate to the actual temperature take longer and longer times. This has great practical significance in the manufacture of optical glass.

The rheological properties of a glass are of special interest since they can be assumed to imitate—but in slow motion—those of ordinary liquids. The reactions to an applied shear stress consist of a reversible elastic contribution—partly instantaneous and partly delayed or “relaxing”—and an irreversible portion which is Newtonian viscous flow. Under a uniform compressive stress there is of course no viscous flow but again the two reversible reactions appear. The almost exact formal correspondence between the delayed reaction in this case and the process of stabilisation is of special interest.

By varying the temperature the relative importance of the separate reactions to applied stress may be varied and they can be studied individually by simple methods. At temperatures well above T_g only the viscous flow is normally of importance. Near T_g the three types of reactions are of about equal magnitude in the time-scale of ordinary observations, and this gives rise to the possibility of observing frozen-in stresses between adjacent layers when glass in which a temperature gradient exists is cooled through the neighbourhood of T_g . The removal of these stresses (often known as “strain”) is the main function of annealing processes in commercial glass-ware.

At sufficiently low temperatures the instantaneous elastic strain preponderates over the other reactions to applied stress and glass (though still thermodynamically an unstable liquid) becomes in its mechanical properties the model of a brittle solid.

Paper read 28th January, 1955.

The Thermodynamics of the Stabilization of Glasses

R. O. DAVIES

(Queen Mary College)

Although a glass is not in thermodynamic equilibrium it is possible to give a thermodynamic discussion of stabilization. In order to do this one must assume that the instantaneous state is fixed not merely by the pressure and temperature (say) but by one or more internal ordering parameters as well. The principle involved is not new but has

been used in chemical thermodynamics since the time of Gibbs. (In chemistry the internal parameters are "degrees of reaction," describing the progress of chemical changes which can take place in the system.) With glasses the simplest procedure is that of Tool who introduced and used a "fictive temperature" ($\bar{T}$) which gives a measure of the internal state of the glass. When $\bar{T}$ is equal to the real temperature (T) the glass is in thermodynamic equilibrium and has its equilibrium structure; if not, the structure is that of a glass which would be in equilibrium at a temperature higher or lower than T (according as $\bar{T} > T$ or $\bar{T} < T$).

Tool's idea can be fitted into a rigorous thermodynamic formalism which—with appropriate extensions—should be applicable to any isotropic process in glasses. The main results for a single ordering parameter are: (a) a set of thermodynamic relations connecting the properties of a glass with those of the corresponding equilibrium liquid, (b) a means of predicting the kinetic behaviour under various experimental conditions (e.g. isothermal-isobaric, adiabatic-isobaric, etc.) in terms of that under any one of the conditions.

Experimentally it is found that in no case which can be checked are the predictions under (a) exactly fulfilled. Those of (b) have never been tested. The reason for the failure of (a) is that one ordering parameter is not enough. This fact is conspicuous in the special case of borosilicate glass (Douglas). The remedy is to introduce more parameters and the limiting case is that of an infinity of parameters and a continuous distribution of relaxation times. Thus the thermodynamic theory goes over to a treatment of the general isotropic response of a linear body, of a type familiar to rheologists. The thermodynamic approach is, however, more flexible and attractive than the purely mechanical treatment.

It is clearly desirable to extend the thermodynamic treatment so as to deal with shearing motion as well. Here a curious situation appears. We should like to be able to exhibit delayed elasticity and flow as a special case of stabilization. It is possible to deal with delayed elasticity provided we exclude permanent deformation and admit a tensorial degree of order instead of a scalar quantity. Alternatively, it is possible to derive the Stokes-Navier equations for the case where there is no delayed elasticity—only permanent deformation. But the central problem of combining both reversible and irreversible fluidity within a single thermodynamic framework seems to be more difficult.

Paper read 28th January, 1955.

Determination of Relaxation-time Spectra from mechanical measurements on solids

H. KOLSKY AND F. C. ROESLER

(Imperial Chemical Industries Ltd., Butterwick Research Laboratories, Welwyn, Herts).

The mechanical properties of most solids are found to depend on the rate at which forces are applied to them and this is found to apply particularly to high polymers. When the amplitude of the deformation is sufficiently small these materials generally behave in a "linear" manner, i.e. at any one mechanical frequency the amplitude of deformation is found to be proportional to the applied stress whilst the energy loss due to internal friction is proportional to the square of this amplitude. Thus at any one frequency two independent quantities define the mechanical behaviour of the solid; for small amplitudes of vibration these are usually given as the elastic modulus and the damping loss of the material. By analogy with the electrical case these two quantities are often combined to give a complex elastic modulus, the real part of which corresponds to the elastic behaviour whilst the imaginary part corresponds to the dissipative behaviour. It may be shown from the theory of such linear systems that if the value of either of these quantities is known at all frequencies it is possible to determine the value of the other at all frequencies,

but the use of mathematical techniques for doing this from a numerical set of data has not hitherto met with much success, although many attempts have been made.¹

Another type of measurement which gives results mathematically related to the mechanical response to oscillatory applied forces is the relaxation of stress and strain in specimens which have been deformed. Thus if a specimen is deformed a fixed amount and held in its deformed condition the stress is found to relax slowly with time, alternatively if after the specimen has been deformed the applied stress is removed, the strain decreases with time. The numerical transformation necessary to compare results of this type with those obtained from cyclical deformations is once again a matter of some considerable difficulty. Finally, in attempting to correlate the mechanical behaviour of materials with the microscopic processes which cause them, it is desirable to obtain what is termed a *relaxation-time spectrum* of the material. This treatment postulates that the mechanical behaviour of the solid corresponds to the summation of an infinite number of relaxing elements each with its own *time of relaxation* and the spectrum describes the relative *strength* of these elements. Thus peaks in the relaxation-time spectrum would correspond to the presence of a large number of mechanisms which have characteristic times of values around the peak, and in many cases, especially with metals, it has been possible to correlate these peaks with specific processes taking place in the material.² Here again, however, the conversion of experimental results into relaxation-time spectra has not been hitherto accomplished by any systematic mathematical treatment.

Recently in this laboratory a number of methods have been developed³ for the determination of relaxation-time spectra from experimental data and for the conversion of results of one type of measurement into another. The basis of this method is the Fourier analysis of the experimental curve on a logarithmic plot into its separate components. Each component is then multiplied by an appropriate *eigenvalue* and a new curve is thus synthesised. These methods have been tried on a number of published experimental results, and have proved to be extremely effective in dealing with these problems. They have also been applied with some success to the experimental results for organic glasses obtained in these laboratories⁴. The computational labour involved in these analyses is considerable, but is still negligibly small compared with the time which must be spent in making such dynamic measurements, and the methods developed should prove to be of considerable help to many workers in the field of visco-elasticity. The method has the advantage that it does not involve any numerical differentiation and that the experimental accuracy necessary to obtain any degree of resolution can be ascertained. Furthermore, it can be shown that this method can give the highest accuracy that is theoretically possible. Recently⁵ a numerical iteration method which avoids the necessity for an explicit Fourier analysis has also been developed and whilst this is not of such wide application as the other approach in the cases where it may be used it is generally more convenient and may be shown to be equivalent to the more detailed method which employs Fourier analysis.

References

1. Leaderman, H., (1954), *J. Appl. Phys.*, **25**, 294.
Gross, B., (1953), "Mathematical Structure of the Theories of Viscoelasticity," (Hermann : Paris).
2. Kolsky, H., (1953), "Stress Waves in Solids," (Clarendon Press : Oxford).
3. Roesler, F. C. and Pearson, J. R. A., (1954), *Proc. Phys. Soc. B*, **67**, 338.
Roesler, F. C., (1955), *Proc. Phys. Soc. B* (In Press).
4. Benbow, J. J., (1954), *Proc. Phys. Soc. B*, **67**, 120.
5. Roesler, F. C. and Twyman, W. A., (1955), *Proc. Phys. Soc. B* (In Press).

To be read at Conference on "Viscoelastic Behaviour" at King's College, Newcastle,
29th and 30th April, 1955.

Recent Advances in the Goniometry of Flow

K. WEISSENBERG

(Ernest Oppenheimer Laboratory, Dept. of Colloid Science, Cambridge).

There has been an extension of the theory and experimental technique of the goniometry of flow, i.e. of the calculation and measurement of the distributions of forces and displacements in a flowing material round the full solid angle of directions. The extension, which has been greatly helped by the co-operation of Mr. A. J. Gaskin from the C.S.I.R.O. (Australia), has made it possible to study states of flow not only for the two dimensional case of simple laminar shearing movements, but also for other shearing movements, including the three dimensional case of pure (irrotational) shear.

The experimental technique uses deformable boundary members as containers for the material under test. Both the container and the material are deformed during the testing. For experiments of a qualitative nature it often suffices to spread the material in a thin layer on a plane sheet of rubber, whilst for quantitative experiments it is preferable to contain the material between two such sheets, or within a rubber tube, and measure the displacements and forces across three mutually perpendicular planes. The above technique has many applications, a few of which will be discussed below.

1. Materials which have a dilatent consistency are difficult to test in instruments of the conventional type because under shearing actions such materials tend to creep out of a gap with rigid boundary members, and change from continuous flow at low rates of shear to a jerky break-up under high rates of shear. With the new technique it is possible to test dilatent materials in a qualitative and quantitative manner over the whole range of continuous flow and break-up. (Demonstrations).

2. Elastic and viscoelastic materials subjected to shearing actions exhibit in general a stress-strain relation of great complexity. Some part of the complexity is due to the colloidal-chemical structure of the materials whilst another part is due to the geometry of the method of testing. The conventional technique of testing produced motions of "simple" laminar shear, and in these the geometry is very complicated because there is a shear dependent angular deviation between the main axes of the stresses, the strains, and their various derivatives in time. The new method of testing resolves this complexity as it produces motions of pure irrotational shear in which the main axes of all the stresses and strains and time derivatives remain always parallel to one another. (Demonstrations). The resolution of the geometric complexities has received a new impetus through the study of some unusual phenomena flow which had previously been known to occur only in isolated cases, when tube formation was observed by rolling red hot cylinders of metal (Mannesmann Process), or a particular kind of natural clay (Williamson). The tube formation by rolling of a cylinder has now been established as a phenomenon of great generality, which may be regarded as counterpart to the well-known normal pressure phenomenon occurring in elastic and viscoelastic solids and liquids (such as the climbing up of a material on a rotating stirring rod). The theory calculated the pressure distributions in both types of phenomena from the same general principles. It predicted for the climbing effects an accumulation of compressional pressure toward the points on the axis of the stirring rod, this compression becoming stronger with the amount of elastically recoverable strain. For the tube rolling effects on the other hand it predicted an accumulation of tensional pressure towards the points on the axis of the rolled cylinder, if the material is plastic with no or little elastic recovery, the tension becoming weaker for materials exhibiting more elastic recovery, and vanishing altogether, or even being reversed into compression if the elastic recovery exceeds a certain amount. The theory had already been confirmed for the phenomena occurring in viscoelastic liquids by the quantitative experiments of J. E. Roberts. Subsequently Mr. Egan and A. Jobling investigated plastic materials of greatly varied structures and consistencies, and confirmed in a qualitative manner the predictions in respect to the tube rolling phenomenon. (Demonstrations).

To be read at the Conference on "Viscoelastic Behaviour" at King's College, Newcastle, 29th to 30th April, 1955.

The Flow Properties of a Polymer/Coal Tar Pitch System

L. J. WOOD AND G. PHILLIPS

(The Coal Tar Research Association, Gomersal, nr. Leeds)

The viscoelastic properties of a vertical retort coal tar pitch/tar oil/polymethylmethacrylate system have been studied using a rotating conical cylindrical viscometer. In the absence of the polymer the pitch/oil mixtures are of high viscosity, but essentially Newtonian in behaviour. Addition of the polymer results in an elastic fore-effect on deformation and an approximately equal retarded recovery on release of the stress. About 20 units of shear are needed for the full development of the elastic effect.

Experiments have been carried out to study the effect of varying stress, temperature, polymer concentration and pitch/oil ratio on the flow behaviour, which has been characterised by a measurement of the rate of shear after development of the elastic effect, extent of recovery, and the retardation time, defined as the time taken for 0.632 of the total recovery. The viscosities of mixtures of pitch and oil of the same ratio of concentrations, but containing no polymer have also been measured. From the results viscosities, specific viscosities, and moduli, defined as the viscosity divided by the retardation time, have been calculated. The investigation has covered a stress range of $1-6 \times 10^4$ dynes per cm^2 and a viscosity range of 10^3 to 10^7 poises.

Both the specific viscosity and the elastic recovery are practically independent of temperature, but markedly dependent on stress. The equilibrium rate of shear and the stress are related by a power law; the apparent viscosity increases as the stress is raised. The elastic recovery bears a similar relationship to the stress as that found by Saal and Labout (*J. Phys. Chem.*, 1940, **44**, 149) for bitumens of elastic sol type. It can be expressed as:

$$\frac{1}{e} = \frac{1}{e_m} + \frac{b}{S}$$

where e is the elastic recovery, S the stress, and b the gradient of the reciprocal recovery/reciprocal stress plot. Its intercept on the recovery axis, $1/e_m$, suggests a limiting value, e_m , for the recovery at infinite stress. With increasing polymer concentration from 0 to 2% the value of e_m increases steadily and that of b decreases slightly. Results to date suggest, however, that above about this concentration e_m and b remain practically constant. Temperature has little effect on either of these parameters.

The retardation time decreases somewhat with increasing stress, but its variation with temperature seems to be closely linked with the large change in viscosity. The value of the modulus thus increases with increasing stress, but is independent of temperature within the experimental error.

These relationships are discussed on the basis of a comparison with polymer solutions in low viscosity solvents.

To be read at the Conference on "Viscoelastic Behaviour," at King's College, Newcastle, on 29th and 30th April, 1955.

RHEOLOGY ABSTRACTS

3105. Symposium on metal-working oils.

Jour. Inst. Pet. **40** (369 and 370), 243-290, 291-346 (September and October, 1954).

3106. Lubricants for metal-working operation in non-ferrous metal industries.

Scientific Lubrication **6** (2), 22-25; **6** (3), 21-24, 36. (February and March, 1954).

Report of informal discussion by the Institute of Metals, January, 1954.

3107. Transient flow of non-ideal gases in porous solids—one-dimensional case.

J. S. ARONOFSKY AND O. D. FERRIS. *J. Appl. Phys.* 1954. **25**, 1289.

Calculations of pressure and production histories are presented for one-dimensional flow of non-ideal gases through porous media. The non-ideal properties considered in this paper are the gas viscosity and deviation factor (compressibility factor) which are assumed to vary as simple functions of pressure. The effect of each of these parameters is investigated independently as well as in combination. The results demonstrate that pressure declines and production histories in linear gas-flow systems are markedly influenced by variations in these parameters. Numerical solutions of the flow equations were obtained by solving the corresponding difference equations on an electronic digital computer. A.

3108. Residual viscosity of paint systems at infinite shear velocity.

W. K. ASBECK AND M. VAN LOO. *Industr. Engng. Chem.*, 1954, **46** (6), 1291-6.

Data for the viscosity at high rates of shear are reported for a number of house paints and titanium dioxide-linseed oil systems, and are employed to demonstrate the validity of the hypothetical term ν_{∞} , the residual viscosity at infinite shear velocity in practical viscometry. The shear velocities used were those operating in the brushing range for paints, viz, about 10^4 sec.⁻¹. At infinite shear velocity, all structure has been eliminated and the viscosity of the system is dependent on the viscosity of the liquid, pigment concentration, and pigment shape and size-distribution. Application of this concept to the Vand and Brailey equations indicates close conformity with the practical rheology of paint systems. The proportionality between the viscosity of a suspension at infinite shear velocity and the viscosity of the vehicle is shown. The theory of a viscometer with which the true viscosity of a non-Newtonian system can be determined directly is presented. B.S.A.

3109. Contraction and relaxation of collagen fibres.

I. BANGA, J. BALÓ AND D. SZABÓ. *Nature*, 1954, **174**, 788.

3110. Laboratory evaluation of metal-forming lubricants.

R. S. BARNES AND T. H. CAFCAS. *Lubrication Engineering*, 1954, **10** (3), 147.

A tensile-test machine has been adapted, by proper choice of test-piece size and die design, for use in evaluating lubricants for cup drawing, wire drawing and rolling. Effects of temperature can be determined. Although the usefulness of the test is somewhat limited by the low speed range of the machine, evaluation of several lubricants by this test agrees with performance in the field. A.

3111. On the functional equations of turbulent flow.

J. BASS. *Compt. Rend.*, 1953, **237** (13), 645-9.

3112. **Resistance to flow of liquids over solids by thin films extending from the edge of pools or from menisci.**

E. B. BIELAK, G. F. N. CALDERWOOD, E. W. J. MARDLES. *Nature*, **174**, 1009 (November 27th, 1954).

3113. **Theory of stress-strain relations in anisotropic visco-elasticity and relaxation phenomena.**

M. A. BIOT. *J. Appl. Phys.*, 1954, **25**, 1385.

A thermodynamic derivation is given for the representation of a system having viscoelastic or relaxation properties by means of a potential and dissipation function familiar in Lagrangian mechanics. This leads to modes of relaxation which are used as normal co-ordinates to derive general expressions for operational tensors relating stress and strain. A large variety of phenomena involving interaction of diffusion, chemical reaction, heat transfer, mechanical deformation, etc., is included in this theory. A.

3114. **Note on Taylor instability.**

G. BIRKHOFF. *Quart. Appl. Maths.*, 1954, **12**, 306.

In a collapsing bubble, the denser liquid is being accelerated towards the lighter vapour, but the motion is nevertheless unstable. This result is unaffected by taking surface tension into account, though it may be affected by viscosity or thermodynamic considerations. R.R.

3115. **Redwood Lecture: The friction of non-metallic solids.**

F. P. BOWDEN. *Jour. Inst. Pet.* 1954, **40** (364), 89.

3116. **Approximate treatment of the viscosity of idealized liquids. I. The collisional contribution.**

F. C. COLLINS AND H. RAFFEL. *J. Chem. Phys.*, 1954, **22**, 1728.

The instantaneous transport of momentum across the bodies of molecules occurs upon molecular collision in a rigid sphere liquid undergoing viscous flow. The contribution of this effect to the viscosity is calculated on a quasi-equilibrium basis for a liquid consisting of hard spherical molecules. The calculation makes use of the free volume theory, a correction being introduced to take account of the blocking effect of third neighbours. The equation so obtained may be expressed in terms of the adiabatic compressibility of the liquid and its heat of vaporization. The calculated viscosity contributions are of the order of a quarter to a half of the experimental viscosities for various low molecular weight liquids investigated. The temperature coefficients of the viscosity contributions are also lower than those of the experimental viscosities. A.

3117. **Effect of pressure upon collagen.**

A. J. CRUISE. *Nature*, 1954, **174**, 888.

3118. **Photoelastic effects in microscopic fibres.**

A. J. CRUISE. *Nature*, 1954, **174**, 923.

3119. **Structural changes during the fatigue of copper.**

R. B. DAVIES. *Nature*, 1954, **174**, 980.

3120. **Measurement of effectiveness of cutting oils.**

F. EUGENE, *Scientific Lubrication*, 1955, **7** (1), 24.

3121. **Mixed friction conditions in lubrication.**

D. D. FULLER. *Lubrication Engineering*, 1954, **10** (5), 256.

A review of early work in this field is presented as background to a discussion of a recent valuable paper by W. Altroge. (Towards a theory of mixed friction. Dissertation for the School of Mechanical and Electrical Engineering of the Munich Institute of Technology, Munich, Germany, 1950, 47 pp.) A.

3122. **Comparison of viscosities of American grades of cutback bitumens.**
C. M. GOUGH. *Jour. Inst. Pet.* 1954, **40** (364), 122.

3123. **Observations on the theory of plasticity.**

E. GRUNER, *Ber. dtsch. keram. Ges.*, 1954, **31**, 135,

Although the term plasticity is applied to all systems in which permanent deformation is possible, the forces with which the system opposes the deforming pressure are very varied. The plastic phenomena noted in monocrystals and polycrystal monophase systems, in amorphous monophase systems and in solid/liquid systems, are difficult to compare with each other. In this article an attempt is made to attribute the plastic behaviour in solid/liquid systems (to which clay slip belongs) to a few causes, and on a statistical basis. The clay/water system is influenced by a number of factors, however, and the author therefore examined simpler systems of oxides, etc. From this study it is clear that in all solid/liquid plastic systems there is one dominant property: the capacity of the solid phase to yield a chemisorptive bond (exceeding simple moistening) with the liquid phase. The resulting plasticity (whether or not the ceramic workability is good or poor) is the true plasticity of this system. By means of activators (surface absorptions), a "conditioned" plasticity can accrue, whereas the plasticity of highly viscous, glutinous systems is mostly only apparent.

B.C.R.A.

3124. **Viscous flow in multi-particle systems. I. Motion of a sphere and fluid in a cylindrical tube.**

J. HAPPEL AND B. J. BYRNE. *Industr. Engng. Chem.*, 1954, **36** (6), 1181-6.

3125. **Viscous flow in multi-particle systems. II. Cubical assemblages of uniform spheres.**

J. HAPPEL AND N. EPSTEIN. *Industr. Engng. Chem.*, 1954, **46** (6), 1187-94.

3126. **Interpretation of plastic viscosities in terms of Newtonian viscosities.**

R. C. HARPER AND J. RISEMAN, *J. Colloid Sci.*, 1954, **9**, 81.

Refers to tests on suspensions of carbon black in petroleum oil.

B.C.R.A.

3127. **"Steric protection" of hydrophobic colloidal particles by adsorption of flexible macromolecules.**

W. HELLER AND T. L. PUGH. *J. Chem. Phys.*, 1954, **22**, 1778.

The mechanism of steric protection is discussed on the basis of a suggested type of adsorption.

S.T.

3128. **Performance and testing of lubricating greases under wet operating conditions.**

H. L. HENDRICKS AND J. D. SMITH. *N.L.G.I. Spokesman*, **18** (4), 12, (July 1954).

3129. **The dropping-ball test for determining the consistence of concrete.**

R. W. HOFMANN. *Bauingenieur*, 1954, **29** (5), 160-3.

The standard German method of testing the consistence of fresh concrete, in DIN 1048, involves a penetration test with a heavy plunger, provided with a hemispherical over end, and apparatus that is clumsy to transport and is, in fact, not widely used, except perhaps by a few larger operators. It is suggested here that a simpler and more generally applicable test is a dropping-ball penetration test, that requires only a ball, a cubical mould (30 cm), a frame or stool 50 cm high to sit on the mould (from which the ball is rolled off in the test), and a metre rod. A cast iron ball of 7250 g weight which is used commonly in field athletics and can be procured from any large sports emporium in Germany, has been found to give penetrations that correspond with those of the standard DIN 1048 plunger test.

B.S.A.

3130. On the theory of transformation stress.

K. HONDA AND M. SATO, *Proc. Int. Symp. "Reactivity of Solids"* (Gothenburg, 1952), Pt. 2, p. 847, 1954.

An internal stress accompanying the single phase transformation of a substance is considered quantitatively, on the basis of the elastic theory of a thick-walled sphere or cylinder under hydrostatic pressure, in order to investigate the change of its physical properties during the transformation. From the point of view of this stress theory, it can be deduced that the cause of irreversibility observed in single phase transformation of a solid treated by cyclic heating and cooling is due to the presence of a high internal pressure and tension accompanying the transformations. As an example, the hysteresis loop in the A_3 transformation of pure iron is explained, showing that the agreement between theory and experiment is very satisfactory.

B.C.R.A.

3131. The Einstein relation between relative viscosity and volume concentration of suspensions of spheres.

A. J. HUGHES, *Nature*, 1954, **173**, 1089.

3132. Plane plasticity (of metals).

B. B. HUNDY, *Metallurgia*, 1954, **49**, 109-18.

Experimental work is presented to show that the theory of plasticity is often capable of predicting correctly the mode of deformation and the applied loads during the deformation of metal bodies. The plastic-rigid theory can predict accurately the onset of yielding, even in a metal that is far from the ideal plastic-rigid material (such as stainless steel). The correlation between theory and practice, in the case of the continuous-forming processes involving large plastic deformations, is probably not so good, especially for non-ideal metals. However, even in such cases, the theory can probably predict the loads and forces to an accuracy of about $\pm 10\%$. Application of the theory of plasticity should give much better process control than the empirical methods that are used to a great extent today.

B.S.A.

3133. Surface tension overcomes viscosity: the mobile point as a constant for glass.

H. JEBSEN-MARWEDEL, *Glastech. Ber.*, 1954, **27**, 172.

With the aid of the "heating" microscope the temperature at which the surface tension overcomes the inner friction of the glass is established. The name "mobile-point" has been proposed for this characteristic temperature. As the glass begins to flow sharp corners become rounded, and this becomes visible in the heating microscope through the ray of light which shoots out in the suitably covered dark field.

B.C.R.A.

3134. Flow potentials in hyaluronate solutions.

C. E. JENSEN, J. KOEFOED AND T. VILSTRUP. *Nature*, 1954, **174**, 1101.

Solutions of potassium hyaluronate give elastic recoil by the oestroscope technique. The endolymph of the inner ear in sharks contains hyaluronic acid and the possibility of flow potentials accounting for microphonic potentials in the inner ear was investigated. Potentials of 6 to 10 mV were obtained.

E.W.J.M.

3135. A proposal for fundamental equations of dynamics of gases under high stress. (A proposal for statistical mechanical treatment of systems not in thermal equilibrium associated with transport phenomena.)

T. KOGA. *J. Chem. Phys.*, 1954, **22**, 1633.

In order to derive the fundamental equations of gas dynamics which are valid for the flow at high shearing stress and low gas pressure, an attempt was made to eliminate the assumption that the state concerned departs only slightly from thermal equilibrium, as we frequently find phenomena which cannot be treated under this assumption.

First, the state of gas in an intermediate volume element was microscopically re-

presented in terms of the quantities of transport. Considering their averages over an intermediate time interval, an attempt was made to find the statistical character of the system. In other words, under the assumption that the macroscopic observation is possible or that the macroscopic law can be established, it was shown that the Boltzmann-Planck method in a new sense is applicable to the present systems. The new distribution function thus derived, $f = \exp(\alpha + \sum \beta_{\xi} c_{\xi} + \sum \gamma_{\xi}^{\epsilon} c_{\xi} c_{\eta})$ (where c denotes the velocity of a particle), should satisfy the Boltzmann-Maxwell equation. This can be shown by means of Kirkwood's verification accepted in some extended meaning.

In solving the Boltzmann-Maxwell equation from this new standpoint, the stress components were taken together with mass density and velocity of mass motion as the independent variables in the zero'th approximation, although usually temperature is taken in place of stress. This method of treatment is analogous to that of Enskog and Chapman, although some important modifications are found in the latter half of the treatment. The fundamental equations of gas dynamics have been derived. Instead of viscosity and thermal conductivity, a new conception arises in the equations. That conception is conductivity of stress. A.

3136. The elastic properties of a certain type of glass and their influence on the relaxation of internal stresses.

A. M. KRUIHOF AND A. L. ZIJLSTRA, *Verres et Réfr.*, 1954, 8, 3.

After calling attention to the influence of delayed elasticity on the relaxation of internal stresses in glass, the authors describe the measurement of this elasticity, of instantaneous elasticity and of viscosity. From the delayed elasticity data a formula is derived based on the sum of two exponential functions. This formula shows, in the case of glass stabilised at a fixed temperature, how delayed elasticity varies as a function of time: the indices depend on the temperature. Part 2 contains a formula which enables a calculation to be made at fixed temperatures, and, for the type of glass examined in Part 1, of the relaxation of tensile stresses. During the experiments, elongation of the test-piece caused by a load was limited by a stopping device which supported more and more of the load so that the tension in the test-piece decreased. This decrease was followed by measurement of the birefringence. Complete agreement was found between the decrease of stress as calculated and as measured. B.C.R.A.

3137. Developments in the theory of particle mixing.

P. M. C. LACEY. *J. Appl. Chem.*, 1954, 4 (5), 257-68.

It is shown that there are three components in a mixing process: convection, diffusion and shear. The concepts involved in analysing complete and partial mixtures are examined and a statistically satisfactory expression is evolved for the state of a mixture. A number of theories of mixing rate are examined and compared with the few published experimental results, and a new theoretical treatment is offered based on diffusion theory. This is shown to be in at least as good agreement with fact as existing theories, and to provide a better basis for extension to more complex cases. It will be necessary to determine more accurately the dependence of the rate constant of proportion (of one component of a mix), on particle size, and, for non-diffusional mixing, on the number of particles in a sample. Although present data provide a method of analysis which permits the performance of actual mixers to be assessed quantitatively, it is thought that further theoretical and experimental studies are needed before the data are sufficient and precise to influence mixer design and use. B.S.A.

3138. Effect of sodium carbonate and quebracho-extract on casting of clay suspensions and on dry bending strength of cast bodies.

H. LEHMANN AND G. MARX. *Tonind. Zeitung*, 1954, 78, 323-325.

When 0.3% quebracho-extract was added to a clay suspension already "thinned" with the optimal proportion of Na_2CO_3 , the viscosity was reduced by a further 25% in one clay, 18% in another. The dry bending strength of the cast bodies was increased on account of the lower water content of the original slip. R.H.S.R.

3139. The measurement of the workability of ceramic bodies and raw materials
M. LINSEIS, *Sprechsaal*, 1954, **87**, 206.

Further uses of Linseis' device for measuring plasticity are indicated. Pressures can build up to cause plastic deformation and by means of the measured characteristic curve it is possible to determine how far a body can be "worked" and to measure the influence of plasticizers. The workability of various bodies is discussed, and clay with a higher illite content has a better workability. Finally the influence of temperature on workability is briefly mentioned. B.C.R.A.

3140. A method for the approximate determination of viscosity-pressure-temperature relationships for oils.

S. LUNDBERG. *Jour. Inst. Pet.*, 1954, **40** (364), 104.

3141. The dynamic bulk viscosity of polyisobutylene.

R. S. MARVIN, R. ALDRICH AND H. S. SACK. *J. Appl. Phys.*, 1954, **25**, 1213.

The dynamic bulk modulus of a high molecular weight polyisobutylene is calculated from measured longitudinal wave and shear moduli. A viscous or energy-dissipating process associated with pure volume deformation is found, which appears to be a relaxation process. The peak in absorption of the shear and bulk moduli and the apparent activation energies associated with the two types of deformation are at least approximately the same, suggesting that the fundamental molecular mechanism involved in the two types of deformation may be the same. A.

3142. A co-axial cylinder viscometer for the study of fluids under high velocity gradients.

E. W. MERRILL, *J. Colloid Sci.*, 1954, **9**, 7.

A coaxial cylinder viscometer is described for the absolute measurement of shearing stress/velocity gradient up to high values of gradient. Principal features of construction are: bottomless cylindrical shearing surfaces, very small annular clearance, rigid mechanical alignment of the cylinders, and a pressure-feeding system. Several advantages are thereby achieved, not found together in other cylindrical viscometers: (1) versatility in testing a wide range of viscous fluids, including gels; (2) measurement of shearing stress and corresponding velocity gradient as essentially point values; (3) variability of velocity gradients up to high values; (4) good control of fluid temperatures; and (5) ease of introduction of fluids for test. Typical experimental results are presented for viscous Newtonian fluids, a commercial paint, and a varnish. B.C.R.A.

3143. Estersils—a new class of siliceous thickening agents.

G. C. MEYER AND R. O. BRAENDLE. *N.L.G.I. Spokesman*, **18** (9), 8, (December, 1954).

3144. Mechanics of two immiscible fluids in porous media.

H. I. MEYER AND A. O. GARDER. *J. Appl. Phys.*, 1954, **25**, 1400.

Flow of two and three immiscible fluids in porous media is considered in which the various fluids are separated into different saturation zones by gravity. An equation of flow for any one fluid is derived with the condition that the other fluids must be stationary. This equation is then applied to solve the question of the maximum rate of flow of one fluid into a well from a radially symmetrical porous medium without producing the other fluid or fluids present in the formation. Different well geometries and fluid systems are considered. These problems are sometimes called "coning" problems. A.

3145. Thickness-shear and flexural vibrations of a circular disk.

R. D. MINDLIN AND H. DERESIEWICZ. *J. Appl. Phys.*, 1954, **25**, 1329.

Equations governing the coupled thickness-shear and flexural vibrations of isotropic, elastic plates are solved for the case of a circular disk with free edges. The results of computations are given for the resonant frequencies analogous to those which would be excited in the AT-cut quartz disk with full electrode coating. A marked difference is

observed between the frequency spectrum of the disk and the spectrum of cylindrical vibrations of a rectangular plate. The difference is due to the presence of thickness-twist modes of motion, in the disk, which, along with the thickness-shear modes, are coupled to the flexural modes. A.

3146. Vapour pressure and viscosity of liquids.

S. S. MITRA AND D. N. CHAKRAVARTY. *J. Chem. Phys.* 1954, **22**, 1775.

A letter in which empirical formulae relating vapour pressure and viscosity are given. S.T.

3147. Effect of crystallinity on the dynamic mechanical properties of polyethylenes.

L. E. NIELSEN. *J. Appl. Phys.*, 1954, **25**, 1209.

Six polyethylenes which differed widely in the degree of crystallinity were studied. The crystallinity was determined from density measurements. Both the density and the dynamic mechanical measurements were made over the temperature range from 25°C to above the melting point of the material. The dynamic shear modulus drops rapidly as the melting point is approached. The mechanical damping goes through a maximum near 60°C and then through a minimum just below the melting point. It is possible to predict the density of any of the polyethylenes at any temperature below the melting point from the value of the shear modulus at the same temperature. The more crystalline materials have the higher shear moduli and the higher melting points. A.

3148. Chemical stress-relaxation of polydimethylsiloxane elastomers.

R. C. OSTHOFF, A. M. BUECHE AND W. T. GRUBB. *J. Amer. Chem. Soc.*, 1954, **76**, 4659.

Acids and bases both catalyse a siloxane rearrangement reaction which cause stress-relaxation to occur. An activation energy of 22.8 kcal. mole⁻¹ was obtained. E.W.J.M.

3149. The viscoelastic properties of aqueous soap gels.

N. PILPEL. *Trans. Faraday Soc.*, 1954, **50**, 1369.

3150. The activation energy for viscous flow and Sutherland's constant.

C. J. G. RAW. *J. Chem. Phys.* 1954, **22**, 1946.

From two proposed approximate relations involving the activation energy of viscous flow and Sutherland's constant, further relations are derived for the free energy of activation for viscous flow and for the energy of vaporisation of liquids with simple non-polar symmetrical molecules. S.T.

3151. Determination of the bending of ceramic raw materials and bodies during firing.

O. REUMANN, *Ber. dtsh. keram. Ges.*, 1954, **31**, 143.

A method of testing the softening of ceramic raw materials and bodies during firing is discussed. Test-pieces of simple shape should be used. Comparisons between the sections of the test-pieces previously used and the standard test-piece are adjusted to various raw materials, etc., with different preliminary treatments and methods of firing. A special method to determine the bending of porcelain or fine ceramic bodies is described. Suggestions for further standardization of transverse testing are given. B.C.R.A.

3152. Mechanical properties of bitumen.

R. N. J. SAAL. *Erdol und Kohle*, 1954, **7**, 70-2; *J. Appl. Chem.*, 1954, **4** (7), 11-25.

Under stresses of short duration (**t**) bitumens behave like elastic solids with a modulus or "stiffness" of about 3×10^4 kg per sq.cm. At a certain value of **t**, which is greater for bitumens of high softening point and is affected by temperature, viscous deformation sets in and the stiffness is no longer entirely elastic. The range of **t** for complete transition to viscous stiffness is short for bitumens of low penetration index (**p**) but much longer for those of high **p**, e.g. blown bitumens. The breaking stress of bitumens of both types also depends on **t**; for short **t** it is about 30 kg per sq.cm. at 25°. B.S.A.

3153. Wave propagation in a viscoelastic medium.

E. J. SCOTT. *Quart. Appl. Maths.*, 1954, 12, 300.

The medium is supposed to be confined between two parallel planes, one of which suddenly starts to move away from the other with a fixed velocity. The motion of the medium is studied on the assumption that its elastic behaviour is representable by a number of Maxwell elements in parallel. R.R.

3154. Method for determining the viscoelastic properties of dilute polymer solutions at audio-frequencies.

K. SITTEL, P. E. ROUSE AND E. D. BAILEY. *J. Appl. Phys.*, 1954, 25, 1312.

A sensitive instrument for the measurement of the viscoelastic properties of dilute polymer solutions is described. It makes use of torsion pendulums with resonant frequencies in the range between 200 cps. and 2300 cps. The test liquid is contained in a hollow oscillating disk. The shearing stress which is exerted at the liquid-metal interface alters the frequency and rate of decay of the free oscillations of the pendulum. By means of an optical system, the oscillations of the pendulum are caused to modulate the light striking the cathode of a phototube. The frequency and the rate of decay of the resulting alternating voltage are measured electronically. The operation of the instrument and the factors affecting the precision of measurement are analysed. A.

3155. The temperature dependence of the viscosity of liquids and molten glasses.

V. T. SLAVYANSKIĬ, *Zh. Fiz. Khim.*, 1953, 27, 1776.

If in the viscosity (η)-temperature (t) diagram the η co-ordinate is distorted to make the η - t curve a straight line for a "standard substance," then the η - t lines of chemically similar substances also are straight. Thus, Hg is a suitable standard substance for molten metals, LiNO_3 for molten salts, $\text{C}_2\text{H}_5\text{OH}$ for alcohols and acids, salol for esters, etc., and $\text{Na}_2\text{Si}_2\text{O}_5$ for silicate glasses. Such graphs are suitable for interpolation and extrapolation of η . B.C.R.A.

3156. Reduced equation for viscoelastic behaviour of amorphous polymers in the transition region.

A. V. TOBOLSKY AND E. CATSIFF. *J. Amer. Chem. Soc.*, 1954, 76, 4204.

A law of corresponding states is proposed for the viscoelastic properties of amorphous polymers in the transition region. Tables are presented from which the modulus-temperature curve can be constructed for many polymers. E.W.J.M.

3157. A general system describing the viscoelastic properties of bitumens and its relation to routine test-data.

C. VAN DER POEL. *J. Appl. Chem.*, 1954, 4 (5), 221-36.

After dynamic and static experiments on the mechanical behaviour of bitumens an attempt was made to incorporate all the essential factors into a simple system. This was found to be possible in the form of a nomograph, by means of which the deformation of bitumens can be calculated as a function of stress, time and temperature (over a range of 300°). Origin or method of manufacture proved to be of less importance than hardness and rheological type. For correlation with standard test-methods, the ring-and-ball temperature and the penetration index are suitable parameters. The nomograph enables the average behaviour of a given grade to be calculated with an accuracy sufficient for engineering purposes. The nomograph also enables other routine tests to be interpreted reasonably. The penetration and the Fraass breaking tests are discussed. The penetration of a bitumen corresponds to its stiffness at 0.4 sec., whilst the Fraass test is essentially an equi-stiffness test giving the temperature at which the stiffness is $1.1 \times 10^8 \text{ N/m}^2$ (1.1×10^9 dynes per sq.cm.) at 11 sec. At low temperatures all bitumens behave elastically in the classical sense, their Young's modulus (stiffness) being $3 \times 10^9 \text{ N/m}^2 = 3 \times 10^{10}$ dynes per sq.cm. B.S.A.

3158. Grease structures indicated by x-ray orientation analysis and electron microscopy.

M. J. VOLD, V. A. ELSERICH, R. F. BAKER AND R. D. VOLD. *N.L.G.I. Spokesman*, 18 (5), 8 (August 1954).

3159. Studies of commercial borosilicate glasses from the viewpoint of their oxide compositions. II.

J. YAMAMOTO, *J. ceram. Ass. Japan*, 1954, 62, 271.

The effects are studied on viscosity, electrical resistivity, and thermal expansion of replacing SiO_2 by 8% of PbO , ZnO , BaO , CaO or MgO in a glass containing 80% SiO_2 , 15% B_2O_3 and 5% Na_2O .
B.C.R.A.