

BRITISH RHEOLOGISTS' CLUB



Hon. Sec. :

DR. E. W. J. MARDLES,
ROYAL AIRCRAFT ESTABLISHMENT,
FARNBOROUGH, HANTS.

Hon. Editor :

DR. G. W. SCOTT BLAIR,
THE UNIVERSITY, READING.

Hon. Treas. :

D. C. BROOME, ESQ.,
TRINIDAD WHARF, CARNWATH ROAD,
LONDON, S.W.6.

Bulletin No. 15.

June, 1947.

Price to non-members, 5/-

CLUB NOTES.

List of Members.

In future, the printed list of members will be brought up to date at about the time of the Annual General Meeting and circulated to members towards the end of the year.

Future Meetings.

Annual Conference and General Meeting.

The Annual General Meeting of the Club, together with a Conference on "Rheology of Minerals," will be held at Manchester, September 11th to 13th, 1947. Accommodation will be available at Hulme Hall, Victoria Park, from lunch on September 11th to lunch on September 13th inclusive, cost per person (excluding Conference Trips), £2 10s. Mr. W. A. Richardson, of the Shirley Institute, Didsbury, Manchester, is Conference Secretary, and will shortly be inviting members to send him particulars of their requirements of accommodation.

The following papers will be read :

PROF. H. JEFFREYS, F.R.S. (Cambridge) : "Strength of the Earth."

PROF. F. C. PHILLIPS (Liverpool) : "Preferred Orientation of Minerals and Mechanisms of Rock Flow."

DR. G. M. LEES (Anglo-Iranian Oil Co.) : "Formation of Rock Domes and Flowage of Rock Salt."

DR. R. SCHNURMANN (Manchester Oil Refining Co. Ltd.) : Shear Breakdown.

MR. A. W. SKEMPTON (Imperial College, London) : "Mechanical Properties of Soils and their Relation to Civil Engineering Practice."

The Club Committee will introduce a Discussion on "Technical Viscometry," and it is hoped to hold an informal meeting at which Dr. K. Weissenberg will describe further developments in the work on which he reported at the London Conference.

Visits to various places of rheological interest are being arranged.

Meeting at Kings College, Newcastle-on-Tyne, Wednesday, October 15th, 1947, 5.30 p.m.

A joint meeting of the Club, the Society of Chemical Industry, and the Oil and Colour Chemists' Association will include contributions from Dr. J. S. Gourlay, and Mr. J. Pryce-Jones.

"It may now be disclosed . . ."

It is planned to hold a meeting in London during the first week of December on "War-time Rheology." Speakers will include Dr. A. S. Laurence, on work for the Navy, Mr. A. G. Ward, on work for the Army, and Dr. E. W. J. Mardles, for the R.A.F. Details will be announced later.

Textile Rheology.

It is hoped to hold a meeting in February, 1948, at the University, Leeds. Details are not yet available.

International Rheology Conference, 1948.

We are delighted to learn that our Dutch colleagues are planning an International Conference in Holland for September, 1948—probably September 27th to October 2nd, to include excursions. The Club Committee is honoured to have been asked to help with the arrangements and it is hoped that the Conference will be as representative as possible. Full information will be circulated as soon as it becomes available.

New Members.

- MR. W. ALAN CATTE .. 2 The Gables, Station Road, Ossett, Yorks.
Principal interests : Rubber and plastics.
- PROF. EWEN M'EWEN .. 3 Kensington Terrace, Newcastle-upon-Tyne.
Principal interests : Metals, soils, penetrometers.
- DR. R. J. L. ALLEN .. Monkhouse and Glasscock Ltd., Snowfields, S.E.I.
Principal interests : Food, starch and gelatine gels, viscometry and thixotropy.
- MRS. E. B. CLARKE .. Farren House, Farnborough, Hants.
Principal interests : Viscometry, lubrication.
- MR. H. G. HOPKINS .. The Department of Mathematics, The University, Manchester.
Principal interests : Metals.
- MR. A. J. HUGHES .. John & E. Sturge Ltd., Lifford Lane, Kings Norton, Birmingham.
Principal interests : Fine powders, pastes and slurries, viscosity and thixotropy.
- MR. J. E. ADAMSON .. 15 Chatsworth Avenue, Hendon, N.W.4.
Principal interests : Electrokinetic aspects of rheology, textiles and fibres.

Short Summer Course in Rheology.

The Polytechnic, Regent Street, 11 a.m., July 28th to 4 p.m., July 31st, 1947. Lectures by Drs. G. W. Scott Blair, L. R. G. Treloar, M. Reiner and J. R. Scott will deal with general rheology as well as with certain special application. They are mainly designed for those engaged on rheological problems in industry, but others who wish to familiarize themselves with the theoretical side of rheology will be catered for. An exhibition is being arranged.

Reprints.

Reprints to our rheological library have been received from Mr. W. Lethersich, Dr. G. W. Scott Blair and J. G. Oldroyd.

Reports of Past Meetings.

Summarized reports of the conference on the rheology of solids (jointly with the Institute of Physics) at Birmingham University, and of the joint meeting with the Chemical Society on the chemistry and rheology of clay systems at the Washington Singer Laboratories, Exeter, are being prepared, and it is hoped to circularize members with copies when these are ready.

It is hoped that it will be possible to report on the very interesting visit which the Club recently paid to the Forest Products Research Laboratories at Princes Risborough.

Addresses Not Known.

B.R.C. correspondence to the following members has been returned through the dead letter office. The Hon. Sec. would be glad to obtain correct addresses:

Dr. J. A. Hetherington.

Mr. S. A. Polaine.

Dr. J. A. Sugden.

Mr. P. Temple.

Mr. H. M. G. Williams.

Change of Address.

Dr. G. E. van Gils, Netherland Indies Institute for Rubber Research, Buitenzorg, Java.

News of Members, etc.

Our heartiest congratulations to our President for the honours which have recently been conferred on him in France, to Dr. E. L. Bate-Smith on his appointment as Director of the Low Temperature Research Station, to Dr. H. O'Neill on his appointment to the Chair of Metallurgy at Swansea, and to Dr. H. Nissan who will shortly be taking charge of an Industrial Research Laboratory connected with the paper industry.

Mr. R. A. Acton Taylor has taken up the post of principal control officer, Fuel Efficiency Section at Headquarters, North German Coal Control.

(The Hon. Editor would be glad to be informed of changes of address and occupation of members.)

Rheologist required.

A vacancy exists in a London Industrial Research Laboratory. Plastics, hardness tests, etc. Senior position. Apply Hon. Secretary.

RHEOLOGY ABSTRACTS

574. The Effect of an Electric Field on the Viscosity of Liquids.

E. N. DA C. ANDRADE and C. DODD. *Proc. Roy. Soc. A.*, **187**, 296, 1946.

In the apparatus used, the liquid runs in a narrow channel between plane metal boundaries which are used as electrodes. Fields up to an average strength of 35 kV/cm may be used. With non-polar liquids or non-conducting polar liquids a field transverse to the line of flow has little effect. With polar liquids the field causes a considerable increase in apparent viscosity. The effect increases with increasing field strength to a limiting value, but only changes with frequency above a certain critical frequency, when a decrease occurs. The critical frequency decreases as the inter-electrode distance increases, and increases with temperature. There is no effect with a field parallel to the lines of flow. A theory of these phenomena is given. It is suggested that the effect is due to the accumulation of ions near the electrodes, and the ions act as centres round which polar molecules cluster.

SCI. ABSTR.

575. Elastic Constants of Diamond.

S. BHAGAVANTAM and J. BHIMASENACHAR, *Proc. Roy. Soc. A.*, **187**, 381, 1946.

A new (wedge) method was employed to determine the elastic constants. The values are $c_{11} = 9.5$, $c_{12} = 3.9$, $c_{44} = 4.3 \times 10^{12}$ dyne cm.⁻². The values are also calculated, using force constants derived from spectroscopic data. The agreement is very good.

SCI. ABSTR. (*vide* abstr. 310).

576. The System of Microstresses in Cold-worked Metal.

N. M. BLACKMAN, *Phys. Rev.*, **70**, 698, 1946.

The microstress theory of broadening of X-ray lines has been found to accord with experiment in many cases. In general, in substances which are elastically isotropic, line width does not depend on crystal direction in a systematic manner. The author assumes six possible models for the stresses, and finds that none of them agrees well with experiment. By assuming that the crystal may be divided into homogeneously strained domains, which are subjected to uniform normal stresses of random magnitude, and in addition, that a certain amount of anisotropic stress is introduced, a resultant stress system is derived which would account for the experimentally observed line broadenings.

I.D.I.B.

577. The Effect of Waves on the Thrust on an Obstacle in a Viscous Flowing Liquid.

H. DU BOSQ DE BEAUMONT; *C.R. Acad. Sci., Paris*, **222**, 44, 1946.

A theoretical study is made of the vortices set up when a cylinder is immersed in an infinite flowing viscous liquid, with the generators perpendicular to the direction of flow. A method for calculating the thrust on the cylinder is outlined.

SCI. ABSTR.

578. The Detonation of Liquid Explosives by Gentle Impact. The Effect of Minute Gas Spaces.

F. P. BOWDEN, M. F. R. MULCAHY, R. G. VINES and A. YOFFE, *Proc. Roy. Soc. A.*, **188**, 291, 1947.

Experiments are presented to illustrate the effect of entrapped small gas bubbles on the impact sensitivity of liquid or gelatinous explosives. On account of the effect of the entrapped gas the sensitivity of liquid explosives is profoundly

affected by the shape of the impacting surfaces or by the distribution of the explosive. If, for instance, the fall hammer contains a small cavity, nitroglycerine may be exploded when the potential energy of the fall hammer is as low as 20 g. cm. The question has been examined whether the stress concentration at the rim of the cavity initiates the detonation. Thus, if the cavity is drilled right through the striker so that it is open at the top, no initiation occurs, even with the heaviest impacts. Also no explosion occurred when sharp-pointed strikers or curved strikers were used, even with impact energies of the order of 10^6 g. cm. An apparatus for producing high rates of flow of the liquid as it escaped through the narrowing gap between the rim of the cavity and the anvil was constructed. With this apparatus some of the phenomena obtained in the cavity impact were reproduced. The authors state, however, that the flow was of secondary importance, and that the initiation of the detonation was really caused by the entrapping and compressing of very small gas spaces within the liquid. The suggestion is that adiabatic compression of a gas bubble of about 10^{-7} cm.³ at atmospheric pressure may generate about 10^{-7} cal. within the bubble. In addition, the chemical nature of the gas also seems to be important. If precautions are taken to prevent the entrapping of gas, nitroglycerine is comparatively insensitive to initiation by impact between curved or flat surfaces, and impact energies of the order of 10^5 – 10^6 g. cm. may be necessary to cause explosion.

The detonation of liquid explosive other than nitroglycerine was investigated, and an indication of a solvent effect was found. R.S. (*vide* abstr. 311).

579. **The Period of Impact, the Time of Initiation and the Rate of Growth of the Explosion of Nitroglycerine.**

F. P. BOWDEN, M. F. R. MULCAHY, R. G. VINES and A. YOFFE, *Proc. Roy. Soc. A.* **188**, 311, 1947.

Conductivity measurements on impacting surfaces show that the period of contact between the cavity striker and the anvil is of the order of 200 μ sec. Moving-film camera observations show that initiation of the detonation first becomes apparent as a pin-point of flame within the cavity and presumably in the vicinity of the gas bubble. This initiation occurs within the first 20 μ sec. of contact between the cavity and the anvil. The tiny flame spreads slowly through the cavity with a speed of about 20 m./sec. After about 50 μ sec. the flame and hot gases burst through the rim of the cavity and fire the main film. After the eruption the explosive inside the cavity may continue burning, but is finally extinguished when the hammer leaves the anvil. The explosion is propagated through the thin film of nitroglycerine, for instance, with a velocity of about 1000 m./sec.

Under flat impacting surfaces nitroglycerine in parallel coalescing strips flows rapidly (velocity about 100 m./sec.). The duration of the average time lag between coalescence and initiation in these experiments corresponds with that found in the cavity experiments. The flame first propagates radially outward through the film with a velocity of about 400 m./sec. and after a distance of about 0.5 cm. it transforms into a higher velocity and is propagated at about 1000 m./sec.

R.S. (*vide* abstr. 311).

580. **Effect of Hydrostatic Pressure on the Fracture of Brittle Substances.**

P. W. BRIDGMAN. *J. Appl. Phys.*, **18**, 246, 1947.

Fracture under combined tension and hydrostatic pressures up to 30,000 kg./cm.² is examined, for such brittle materials as pyrex glass, metals and alloys, and non-metallic crystals. The results include the observation that beryllium and phosphor bronze, as well as NaCl and Al₂O₃ show plastic deformation under these conditions. The discussion includes a consideration of the Griffith conception of fracture.

L.R.G.T. (*vide* abstr. 431–434).

581. **The Electro Viscosity Effect.**

D. R. BRIGGS. *Rec. Trav. Chim.* **65**, 591, 1946.

A description is given of some studies with solutions of gum arabic, casein, etc., to test the veracity of the Smoluchowski modification of the Einstein equation relating the viscosity of a suspension and volume of dispersed phase for the electrokinetic potential exhibited by a charged particle suspended in a liquid.

Deviations from values in conformity with the Smoluchowski equation are discussed. E.W.J.M.

582. **Kinetic Boundary Friction.**

BRISTOW, J. R. *Proc. Roy. Soc. A.*, **189**, 88, 1947.

It is shown that the exhibition of smooth sliding and relaxation oscillations, or "stick-slips," under conditions of boundary lubrication, when frictional forces are measured by the deflection of an elastic system, may be explained as due to the dependence of kinetic friction on velocity, and sliding under boundary conditions is never inherently discontinuous. In the cases giving smooth sliding, kinetic friction decreases as velocity decreases, at very low speeds; for the cases giving relaxation oscillations kinetic friction increases as velocity decreases. Curves of boundary friction against velocity, using various sliding surfaces, have been determined for a number of lubricants, which show both the above-mentioned types of friction-velocity relationship; and the dependence is shown of kinetic boundary friction on molecular weight for a series of esters of the fatty acids, on percentage of fatty oil in a compounded lubricant (actually oleic acid in mineral oil) and on temperature for a pure substance and a mineral oil. The measurements with the series of esters show some agreement with results given by Fogg. The mixtures of oleic acid with mineral oil give decreasing kinetic friction with increasing percentage of oleic acid right up to 100% oleic acid. The effect of temperature on the dependence of friction on velocity shows that the temperature at which relaxation oscillations first occur depends on the speed of sliding, from which it appears that measurements of the temperature at which relaxation oscillations start at constant sliding speed are not a measure of the temperature at which there is a discontinuity in the properties of the boundary layer. S.I. ABSTR.

583. **An Electron Diffraction Study of the Structure of Thin Films of Normal Paraffins.**

K. G. BRUMMAGE. *Proc. Roy. Soc. A.*, **188**, 414, 1947.

Hydrodynamic conditions of lubrication cease to apply at sufficiently heavy load for the lubricant film to be below a certain thickness. Lubrication is then effected by the residual film, and the behaviour of such films under a shearing stress and during heating is of considerable interest in the fundamental study of boundary lubrication.

The author examined in an electron diffraction camera of the Finch type the effect of rubbing on thin films of the normal paraffins tetracosane, triacontane, and tetratriacontane when deposited on stainless steel, copper or collodion. Both the reflection and the transmission techniques were employed.

Films for reflection were prepared by placing a known quantity of a solution in isohexane of one of the paraffins on one of the reflection disks, and adding sufficient pure solvent to spread the solution over the whole surface. An attempt was made to estimate the number of molecular layers from the quantity of solution deposited on the surface and the area occupied by a single molecule.

Rubbing of the films on filter paper seemed to produce change of crystal size and orientation. Other results illustrate disorientation temperatures as a function of both film thickness and nature of the substrate. R.S.

584. The Quantitative Interpretation of Radiographs in Terms of Mechanical Properties.

L. R. CARR. *J. Sci. Instrum.*, **23**, 221, 1946.

Tensile strengths and percentage elongations for test sections from a wide variety of sand- and die-castings of 4 Al alloys (DTD 287, 298, 304 and 300) are correlated with the results of radiographs of the castings (illustrated, including photomicrographs), which were used to classify them as: sound, showing intercrystalline porosity (3 grades), pinhole porosity (3 grades), and according to grain size. Mean and standard deviations are given. The results establish a definite correlation between radiographic evidence and mechanical properties. The limitations of the method (effect of sampling, section thickness, size of sample and the restriction of the tests to tensile strength measurements) are discussed.

SCI. ABSTR.

585. The Elastic Properties of Textile Fibres.

P. CHEVENARD and G. CHAMPETIER. *Bull. Soc. Chim.* **13**, 464, 1946.

The authors describe in detail (21 figs.) a photo micro method and study of the behaviour of fibres of silk, ramie, nylon, etc., under tension. The elasticity results obtained are in agreement with the molecular structural characteristics deduced from X-ray diffraction methods. The reversible elasticity is considered to be due to the temporary widening of the valency angles in the macromolecular chains (steel spring effect) while permanent deformation results from the relative slipping of the macromolecules.

E.W.J.M. (*vide* abstr. 370).

586. Investigation of German Researches on Fine Structure of Metals, with Especial Reference to X-ray Technique.

R. H. COOKE and Colleagues. *B.I.O.S., Final Report, No. 826*.

Investigation into mechanism of plastic deformation, using single crystals; strain hardening, attributed to arrest of dislocations at mosaic boundaries; internal stresses; X-ray line broadening; on measurement of stress by X-ray; and into variation of lattice parameter of metals subjected to stress.

E.W.J.M. (shortened from B.I.D.A.).

587. Two-dimensional Transport at Fluid Interfaces.

D. J. CRISP. *Trans. Faraday Soc.*, **42**, 619, 1946.

By means of a new technique, rates of flow and surface pressure gradients are measured simultaneously on moving films. Experiments were carried out to demonstrate the influence of various mechanical constraints, the viscosity of the substrate, and the type of film employed. The results agree with those predicted by hydrodynamical calculations based on the assumption that the film flows as a continuous sheet bound to the water. No evidence was found for molecular streaming or for "slip" across the substrate, even at the lowest surface pressures employed with liquid and vapour films. Since surface diffusion is normally masked by surface flow, the 2-dimensional Fick equation is not applicable at a mobile interface and an equation for 2-dimensional flow must replace it. The relation between the two equations is given and the conditions under which true diffusion might be observed are discussed.

SCI. ABSTR.

588. On the Viscosity of Some Glasses in the Annealing Range.

A. E. DALE and J. E. STANWORTH. *J. Soc. Glass Tech.*, **29**, 414, 1945.

It is shown that, in the range 10^{11} – 10^{13} poises, the viscosities of some borosilicate glasses take considerable time to become stabilised, whereas those of soda-lime-silica glasses rapidly approach equilibrium values. The viscous properties of the

stabilised borosilicate glasses, however, are closely similar to those of the soda-lime-silica glasses. The annealing temperatures of several glasses have been determined optically, by observing the temperature at which a rod becomes strain-free when heated at a uniform rate of 2° per minute. All the glasses, including the borosilicates, had a viscosity of about 10^{13} poises after 30 minutes heat treatment at their annealing temperature. B.R.R.A.

589. **Elastic Properties of Cork.—II. Stress-temperature Relationship of Compressed Cork.**

S. L. DART and E. GUTH. *J. Appl. Phys.*, **18**, 470, 1947.

The variation of stress with temperature, after suitable relaxation was found to be linear. From this, internal energy and entropy contributions to the stress were calculated. The elasticity appears to be due primarily to entropy changes (as for rubber). L.R.G.T. (*Vide* abstr. 280, 444).

590. **Elastic Properties of Cork.—III. Hydrostatic and Ordinary Load-compression Curves for Cork.**

S. L. DART, H. A. ROBINSON and E. GUTH. *J. Appl. Phys.*, **18**, 474, 1947.

Load-compression curves were taken for natural cork. The S-shape of the curves is discussed and a theoretical fit is made for the high end of the curve, assuming an initial stiffness and an incompressible part of the cork material. A comparison is made between repeated compressions, with and without a recovery period of time.

Pressure-volume curves were also taken and their significance discussed in connection with the load-compression curves leading to an evaluation of Poisson's ratio. AUTHORS' ABSTR. (*Vide* Abstr. 444).

591. **A Note on the Theory of Dislocation in Metals.**

W. R. DEAN and A. H. WILSON. *Proc. Camb. Phil. Soc.*, **43**, 205, 1947.

Simple closed formulæ for the displacement and stress in the dislocation are given, and these allow Bragg's recent assumptions regarding work-hardening in metals to be discussed quantitatively. In the dislocation considered the medium is bounded internally by two long circular cylinders. The energy of strain of the dislocation is calculated and the energy of strain per unit volume is estimated. The latter is compared with experimental values of the energy of cold-work of copper. SCI. ABSTR.

592. **An Analysis of the Conditions for Rupture due to Griffith Cracks.**

H. A. ELLIOTT. *Proc. Phys. Soc.*, **59**, 208, 1947.

The problem of the growth of a crack in an isotropic elastic solid under tension is examined mathematically, taking into account the interatomic forces. The condition for instability (crack growth) is found. The conclusions are in agreement with the experimental results of Griffith. L.R.G.T. (*vide* abstr. 566, 647).

593. **Methods for Measuring Stress and Strain in Solids.**

W. A. P. FISHER. *Nature, Lond.*, **158**, 537, 1946.

A report of a conference held by the Institute of Physics. The subjects discussed were: physical characteristics of electrical resistance strain gauges; moisture-proofing with wax; use for dynamic measurements; the acoustic strain gauge; 3-dimensional photo-elastic studies, by the "freezing" and scattered light methods; X-ray methods. SCI. ABSTR.

594. **Kinetic Friction in or near the Boundary Region.—II. The Influence of Sliding Velocity and other Variables on Kinetic Friction in or near the Boundary Region.**

P. G. FORRESTER. *Proc. Roy. Soc. A.*, **187**, 439, 1946.

Tests were made upon a wide range of materials: (1) with no lubrication, (2) with lubricant films of varying thickness, (3) with rubber. Friction/velocity curves were obtained in each case. The variation of friction with velocity may be derived from at least 3 sources: (1) properties of the clean metal surfaces, (2) partial destruction of the boundary film, (3) fluid-film effects which may occur when there is excess of lubricant. Each of these is examined carefully.

SCI. ABSTR. (*vide* abstr. 541).

595. **On the Theory of Seismic and Seismoelectric Phenomena in a Moist Soil.**

J. FRENKEL. *J. Phys., U.S.S.R.*, **8**, 230, 1944.

A study is made of the elastic properties of a dry soil and of how these properties are modified when the soil becomes moist. A system of 5 equations is obtained for the motion of the soil, taking into account the friction between the solid and liquid phases. The equations are linearized and used to investigate the propagation of longitudinal and transverse vibrations in the soil. The simplest case, that of longitudinal harmonic waves, is studied in detail. Associated with these waves is an electrification of the soil and a formula is deduced for the strength of the electric field.

SCI. ABSTR.

596. **Properties of Cellulose as Applied in Plastic Materials.**

W. E. GLOOR. *J. Chem. Educn.*, **24**, 214, 1947.

Four factors, which are of importance when cellulosic materials are used in hot moulding processes, are discussed with reference to ethyl cellulose and to the nitrate, acetate and acetate butyrate esters.

These factors are degree of esterification, chain-length, colloidal properties and purity. Their effects are illustrated by changes in flow temperature, hardness and impact strength. Much of the data refer to cellulose acetate, and it is shown that its low impact resistance at sub-zero temperatures can be improved considerably by using material of higher chain-length.

F.H. (*vide* abstr. 85).

597. **Instrument for Measuring Rheological Properties of Elastic Fluids.**

H. GOLDBERG and O. SANDVIK. *Anal. Chem.*, **19**, 123, 1947.

An instrument is described with which the elastic constants of gels may be measured easily. The gel is placed in the annular space formed by two concentric cylinders, one of which is oscillated mechanically at frequencies ranging from 10 to 6000 cycles per minute. After the resonance frequency and maximum amplitude of the system have been observed the elastic constants of the system may be calculated. A modified apparatus allows measurements to be taken while the sample is being sheared at various rates, and rapid changes of shear modulus may be recorded photographically.

AUTHORS' ABSTR.

598. **A General Kinetic Theory of Liquids.—II. Equilibrium Properties.**

H. S. GREEN. *Proc. Roy. Soc. A.*, **189**, 103, 1947.

Previous work is extended. Boltzmann's *H*-theorem is generalized, and this allows the equilibrium properties of a fluid to be developed without appeal to statistical mechanics. The entropy of a fluid is first suitably defined, and it is proved that the entropy increases with time towards a certain maximum. The liquid state is distinguished from the gaseous state by the existence of real roots of a certain transcendental equation. Approximate expressions are found for the

virial coefficients in the gaseous phase and an equation of state with two branches is derived. The branches are identified with the gaseous and liquid states.

SCI. ABSTR.

599. On Creep and Relaxation.

B. GROSS. *J. Appl. Phys.*, **18**, 212, 1947.

The creep and the relaxation function of linear systems, for which the principle of superposition is valid, are mutually connected in a simple way. This makes it possible to calculate the distribution function of relaxation times of stress and the distribution function of retardation times of strain, when the relaxation function or the creep function is given. It also allows a transformation formula to be established for the conversion of one distribution function into another. The results of the theory are applied to a detailed discussion of the relaxation process in a particular case.

AUTHOR'S ABSTR.

600. Delayed Fracture in Glass.

C. GURNEY. *Proc. Phys. Soc.*, **59**, 169, 1947.

This theoretical discussion suggests that existing theories are inadequate to explain the delayed fracture of glass under stress. The rate of spread of Griffith cracks is too slow to account for the effects. The author considers the effect of the non-attainment of thermodynamic equilibrium in a glass to be a significant factor. In the approach to equilibrium two effects may be involved. The first, evaporation at the end of the crack is estimated to be unimportant for crack growth, while the second, atmospheric attack, may be very significant.

L.R.G.T.

601. The Origin of Excess Ultrasonic Absorption in Water.

L. HALL. *Phys. Rev.*, **71**, 318, 1947.

Assuming that the origin of the excess ultrasonic absorption in many liquids lies in a lag in the re-arrangement of the molecules during a compression, the author gives the result of the perturbation calculation of both the relaxational compressibility and the relaxation time. The theory upon which this approximate calculation of absorption in water has been made agrees with experimental values within their estimated accuracy of about 30 per cent.

The assumptions of the theory are that under acoustic compression some of the water molecules break their intermolecular hydrogen bonds and jump to sites of closer packing. The acoustic wave perturbs the transition rate to and from closer packing through the work performed by or against it in the volume change. The activation energy should be close to that for shear viscous flow.

R.S.

602. Determination of the Propagation Velocity of the Arterial Pulse Wave.

W. F. HAMILTON, J. W. REMINGTON and P. DOW. *Amer. J. Physiol.*, **144**, 521, 1945.

The rate of wave propagation found in excised aorta cannot be calculated from the classical tension-length relation exhibited when circular rings are stretched slowly, but considerations of viscous resistance to stretch can account both for the rapid propagation of the initial phases of the pulse wave and for the retardation of the later phases.

E.C. B.S.

603. On the Mechanical Behaviour of Metals in the Strain-hardening Range.

G. H. HANDELMAN, C. C. LIN and W. PRAGER. *Quart. Appl. Math.*, **4**, 397, 1947.

An analysis is made of general states of stress and strain which may be reached by a single loading followed by at most one complete or partial unloading. There is a sharp distinction between differential and finite stress-strain relations and the

assumption of the latter is incompatible with certain postulates about the mechanical behaviour under those stress changes which constitute neither loading nor unloading.
SCI. ABSTR.

604. **Pectin and Pectin-splitting Enzymes.**

A. HANSEN. *J. Chem. Educn.*, **24**, 223, 1947.

A review of the chemistry and behaviour in use of pectin is given. The most recent suggestions on the chemical formulæ for pectin and related substances are considered and the extreme dependence of gelling power on molecular weight is noted; theories of gel formation are discussed.

There follows an extensive general description of the extraction of pectin and of the numerous uses to which it may be put.
F.H.

605. **Damping Capacity, Strain Hardening and Fatigue.**

R. F. HANSTOCK. *Proc. Phys. Soc.*, **59**, 275, 1947.

An electromagnetic method of exciting torsional resonance vibrations is described.

For some alloys of aluminium, notably binary alloys containing 5% and 11% of magnesium, vibrational strains of sufficient magnitude to cause fatigue cracks can be developed by this method at frequencies of the order of one kilocycle per second. During vibration measurements are made of the damping capacity of the specimens to provide information concerning strain hardening and energy conversion within the specimens up to the time when failure occurs by fatigue.

Fatigue failure of the two binary alloys containing magnesium is shown to be preceded by strain hardening. The endurance of individual specimens is related to the amount of irreversible strain imposed per cycle, failure occurring when the cumulative internal strain approaches a limiting value.
AUTHOR'S ABSTR.

606. **A Viscometer with Constant Working Volume suitable for Measurements over a Wide Range of Viscosities.**

W. D. HARGREAVES. *Phil. Mag.*, **36**, 756, 1945.

A diagram and constructional details of the viscometer are given. The instrument is an improvement on the simple Ostwald type in that it may be used over a wide range of viscosities, e.g. 2 to 100 millipoises.
SCI. ABSTR.

607. **The Morphology of Lyogels.**

E. A. HAUSER and D. S. LE BEAU. *J. Phys. & Coll. Chem.*, **51**, 278, 1947.

The application of ultramicroscopy by incident light in studying the morphology of lyogels is discussed. Special attention is paid to organophilic elastomers and plastics and to lyophilic anionic and cationic soaps. The changes these gels undergo during storage are critically reviewed, and an explanation is offered for their similar morphology on the basis of colloid-chemical reasoning.
AUTHORS' ABSTR.

608. **The Elastic Constants of Anisotropic Materials.**

R. F. S. HEARMON. *Rev. Mod. Phys.*, **18**, 409, 1946.

A review. The mathematical relations between stress and strain are quoted and the number of independent coefficients for each crystal class derived. "Pure" elastic constants are applicable when constraints are applied to suppress all strains except that corresponding with the measured stress, and "free" elastic constants are applicable when one stress only is applied. Static, dynamic, sonic and supersonic methods of measurement are described briefly. Expressions for the variation of Young's modulus and of the modulus of rigidity with direction are derived for some important special cases. Experimental results up to the end of 1944 are collected in a table. There are 125 references.
SCI. ABSTR. (*vide* abstr. 456).

609. Photo-elastic Apparatus, Technique, and Materials.

A. W. HENDRY. *J. Instn. Civ. Engrs.*, **27**, 85, 1946.

A detailed description of apparatus and technique used at Aberdeen University for determination of stresses in cases where calculation would be difficult. A model is constructed (a plastic, "Catalin," is particularly suitable) which may be examined for strain under white or monochromatic plane-polarized light, or monochromatic circularly polarized light. An investigation of the creep properties of Catalin is described, and it is concluded that these do not invalidate the results obtained.

SCI. ABSTR.

610. The Theory of Wedge Indentation of Ductile Materials.

R. HILL, E. H. LEE and S. J. TUPPER. *Proc. Roy. Soc. A.*, **188**, 273, 1947.

A rigid frictionless wedge penetrates a plastic material. The form of the lip and the deformation in the material squeezed out towards the surface is determined theoretically, and the variation with wedge angle of the force required for penetration is found in terms of the yield stress in a tensile stress. The theory is compared with experiments in which lead blocks are indented by steel wedges coated with vaseline, and it predicts satisfactorily the deformation of a grid of squares ruled on a cross-section of the block.

SCI. ABSTR.

611. Plastic Flow of Metals.

J. H. HOLLOMON and J. D. LUBAHN. *Phys. Rev.*, **70**, 775, 1946.

A general relation is derived for plastic flow in metals relating the stress, strain, strain rate and temperature, which is found to conflict with some accepted ideas, but to agree with certain experimental results.

SCI. ABSTR.

612. Recording Viscometer for Starches.

C. C. KESLER and W. G. BECHTEL. *Analytical Chemistry*, **19**, 16, 1947.

A continuous recording viscometer for routine and research testing of starch products is described. Variations in cooking procedure which cause errors in viscosity determinations are prevented through automatic control of rate of heating, maximum temperature, rate of stirring, and loss of water by evaporation. Viscosity is measured as the force which the paste exerts against a propeller driven through it at constant speed. A gear differential transmits the force to a dynamometer attached to the pen arm of the recorder. Interchangeable weights on the dynamometer permit measurements in several viscosity ranges with equal sensitivity and without requiring recalibration of the viscometer. Viscosities of one poise or more can be measured throughout any desired length of time, and during both heating and cooling periods. Variations between samples and differences between commercial types of starch may be readily observed. Starches from different sources and of different kinds and degrees of modification give characteristically different curves which are of value in their identification and study.

P.A.T.R.A.

613. Elasticity Measurements on Polychloroprenes.

P. KINELL. *J. Phys. & Coll. Chem.*, **51**, 70, 1947.

The stress strain curves of a number of varieties of unvulcanised polychloroprene are compared with corresponding curves for a vulcanised rubber. The polychloroprene agrees less well with the formulæ derived from the statistical theory, due to the effects of relaxation and flow.

L.R.G.T.

614. Elasticity of the Aortic Wall.

A. L. KING. *Science*, **105**, 127, 1947.

The ratio of the effective thickness of the wall (e_0) to the external diameter (d_0) of the aorta varies from 0.094 in age-group 20-24 to 0.052 in age-group 71-78,

suggesting a thinning out of elastomeric constituents as collagenous and other deposits increase. The product $e_0 d_0$ is constant, however, indicating stability of elastin and other elastic constituents with increasing age. E.C. B.-S.

615. Penetration-velocity Test, New Hardenability Measure.

E. S. KOPECKI. *Iron Age*, **158**, 66, 1946.

The P.V. test, i.e. designed for steels with critical cooling rates above 100°F. per sec. Hardness testing arrangement is connected with micrometer attachment. Rockwell hardness values and P.V. values are correlated.

E.W.J.M. (shortened from B.I.D.A.).

616. On the So-called Principle of Least Work Method.

M. Z. KRZYWOBLOCKI. *J. Franklin Inst.*, **243**, 187, 1947.

The usual presentation of the least work method may lead to approximate results lying too far from actual conditions. Consequently the results cannot be reliable. The author proposes a different presentation of this method which follows.

When applying Castigliano's theorem of least work to specific problems, we must be assured *a priori* that the redundant generalized forces or unknown stress distributions are expressed by functions among which there is one and only one function which gives a smaller value to the total strain-energy than any other gives having first taken the given values on the boundary. Being assured that such a minimum exists, we present the total strain-energy as a function of the redundant generalized forces or unknown coefficients and next we express in an analytical form the statement that the total strain-energy has a stationary value for small variations in the redundant forces, by equating to zero the first partial derivatives of the strain-energy with respect to each of the redundant forces or unknown coefficients. The last equations give us the values of the redundant forces or of the unknown coefficients. M.W.T.

617. Stress-strain Relations in Ceramic Materials.

M. LASSETTRE and J. O. EVERHART. *J. Amer. Ceram. Soc.*, **29**, 261, 1946.

Ceramic materials may be considered as elastic materials from the viewpoint of the engineer, and the formulæ for modulus of elasticity and modulus of rupture may be accepted as valid. Other engineering formulæ, based on the theory for elastic materials, may be applied with exactitude. The stress-strain curves for ceramic materials in most respects resemble those for timber, concrete, and cast iron, rather than those for steel. They obey Hooke's law up to the proportional elastic limit. Softer fired materials show a proportional elastic limit but do not have a definite yield point. Hard-fired materials show little or no evidence of a proportional elastic limit; their stress-strain curves are straight, or nearly so, to the point of ultimate failure. Ceramic materials show a hysteresis characteristic. Strain equilibrium lags behind a change in stress (either increasing or decreasing), and this lag decreases with increased firing temperature. Prolonged stressing, even with stresses below the proportional elastic limit, will produce a permanent set in ceramic materials. The electric strain gauge offers a means of studying strains in ceramic materials with possibilities far beyond those afforded by any other previously available gauge. It may be used in structural units and assemblies as well as on individual specimens. B.R.R.A.

618. The Fluidity of Binary Mixtures of Hydrocarbons.

R. LAUTIÉ. *Bull. Soc. Chim.*, **13**, 353, 1946.

A useful empirical relation for the fluidity of a mixture of two fuels or light hydrocarbons is that the cube root of the fluidity of the mixture is a linear function of the molecular concentration. E.W.J.M.

619. Phenomenological Theory of Transport Processes in Fluids.

B. LEAF. *Phys. Rev.*, **70**, 748, 1946.

A general theory of transport processes in fluids, developed from equations of hydrodynamics and thermodynamics generalized for application to multi-component systems, is presented. The equations for the flow of entropy and masses of components of the fluid, obtained from the local entropy dissipation, are used to treat the processes of viscosity, mobility, diffusion, electrical and thermal conductance, thermal transpiration, thermal diffusion, and the homogeneous thermoelectric effect. Reciprocal relations and other properties of the coefficients associated with each process are obtained, and also inter-relationships, between the coefficients of the various processes. The special conditions for the steady state, the state of pure thermal conduction, and the state of equilibrium are considered. Investigation of the steady state in thermal diffusion indicates that mass flow may persist, contrary to the usual assumption in treatment of experimental data. SCI. ABSTR.

620. Apparatus for the Study of the Rheological Properties of Dielectrics.

W. LETHERSICH. *J. Sci. Instrum.*, **24**, 66, 1947.

An apparatus is described which will measure the compressive strain on specimens 3 cm. long and 1.3 cm. dia. Strains up to 0.12 can be measured to an accuracy of 10^{-5} , and the apparatus can be used without modification for tensile tests. The lateral strain can be determined at the same time and to a similar order of accuracy. The shear properties are measured on thin-walled cylinders of material and an apparatus has been constructed for applying the shear stress and measuring the shear strain. This apparatus is particularly suitable for studying relaxation phenomena, since there is no friction after the stress has been removed.

SCI. ABSTR.

621. Creep Deflections in Columns.

J. MARIN. *J. Appl. Phys.*, **18**, 103, 1947.

The determination of column deflections and column buckling loads has been considered for many years. The available theories, however, do not provide for materials which creep with time under constant loads. For the design of structural members made of these materials, a consideration of creep may be of practical importance. Plastics, concrete, and some metals creep at normal temperatures while other metals creep only at high temperatures and at stress values beyond the yield point. A consideration of creep in the design of some structures appears appropriate in view of the modern developments in plastics and the presence of high stress values which are sometimes beyond the yield stress. This paper gives a rational theory for predicting creep deflections in columns. A special case using this theory is applied to the interpretation of some preliminary tests of an aluminium alloy.

AUTHOR'S ABSTR.

622. Effect of Type of Test Specimen on Apparent Compressive Strength of Concrete.

B. MATHER. *Proc. A.S.T.M.*, **45**, 802, 1945.

Two programmes of strength testing are reported, in each of which concrete from the same sample or batch was tested, using either drilled cores or moulded cylinders for comparison with modified cubes. A total of 2,375 strength tests was made and from the resulting data it is suggested that the choice of type of specimen may considerably affect the compressive strength value obtained for the concrete.

B.R.R.A.

Exploratory work shows that these relationships are different for different types of pulp and that some may vary from pulp to pulp of the same type. P.A.T.R.A.

623. A New Explanation of Liquid Helium II.

D. B. MACLEOD and H. J. YEABSLEY. *Trans. Faraday Soc.*, **42**, 601, 1946.

An attempt has been made to explain Helium II as a mixture of the ordinary liquid Helium I and the intermediate form of a fluid, indicated by Van der Waals' equation. On the basis of the volume of the atoms being a function of the total pressure within a fluid, this intermediate form has been shown to be mathematically possible below a certain temperature. The composition of Helium II at various temperatures down to 1.2° K has been worked out approximately. The anomalous specific heat has been explained and calculated and values for the latent heat obtained. SCI. ABSTR.

624. Stability of Viscous Flow between Rotating Cylinders.—II. Cylinders Rotating in Opposite Directions.

D. MEKSYN. *Proc. Roy. Soc. A.*, **187**, 480, 1946.

The solution obtained in a previous paper is extended to the case where the cylinders rotate in opposite directions. The spacings of the vortices and the critical angular speed of the inner cylinder are found. The agreement with Taylor's experimental results is good, but depends greatly upon the accuracy of the measurement of the radius of the inner cylinder when the distance between the cylinders is small and the ratio of the speeds of the cylinders is large. SCI. ABSTR.

625. Stability of Viscous Flow between Rotating Cylinders.—III. Integration of a Sixth Order Linear Equation.

D. MEKSYN. *Proc. Roy. Soc. A.*, **187**, 492, 1946.

The asymptotic integrals of the differential equation arising in the theory are derived. When the cylinders rotate in opposite directions the integrals become infinite at approximately the point where the mean velocity of rotation is zero. The asymptotic expansions change their form in passing through this point, and the transformation law is obtained. SCI. ABSTR. (*vide* abstr. 557, 558).

626. The Break-up of Liquid Jets.

A. C. MERRINGTON and E. G. RICHARDSON. *Proc. Phys. Soc., Lond.*, **59**, 1, 1947.

Experiments have been carried out with fixed nozzles and with moving nozzles (attached to an aircraft) discharging backwards into the atmosphere. A relation expressing drop size in terms of viscosity and the relative velocity between jet and surrounding air, applicable to both cases, is given. At low velocities this relation ceases to apply, and drop size reaches a limiting value. Factors influencing this limiting figure are discussed; information has also been obtained on the stability of large drops. Measurements made on the length of the jet confirm the work of Tyler and Richardson, but also disclose a hitherto unsuspected anomaly in the case of very viscous liquids. Similar results were obtained when a jet issued into another liquid with which it did not mix, but showed the effect of the relative viscosity of the liquids on the break-up. SCI. ABSTR.

627. The Rapid Measurement of an Index of Fiber Length.—Part II. Some Relationships of the Index to Pulp Properties and Indications of Its Use for Stock Preparation Control.

R. DE MONTIGNY and P. ZBOROWSKI. *Paper Trade J.*, **123**, 29, 1946.

A single bleached sulphate pulp has been extensively studied and empirical relationships derived which show that, for a given pulp, bulk and tearing strength are simple straight-line functions of fibre length index independent of slowness, but that bursting and tensile strengths are more complex properties involving both fibre length and slowness as measured by the Schopper-Riegler instrument.

628. **The Effect of Repeated Loading on the Bond Strength of Concrete.**
C. W. MUHLENBRUCH. *Proc. A.S.T.M.*, **45**, 824, 1945.

A repeated-loading machine accommodating six pull-out type specimens to which load is applied through levers at a rate of 52,000 repetitions per 24 hours is described. Rectangular specimens varying from 5 to 10 in. in length and using a $\frac{5}{8}$ -in. round reinforcing bar were subjected to as many as 5,000,000 cycles of load. It has been found that, as the number of repetitions of loading increases, the static pull-out strength decreases. The ratio of the static pull-out strength, after 5,000,000 cycles, to the static pull-out strength of pilot specimens not subjected to repeated loading, was found to be about 50% for specimens 5 in. long and subjected to a load equal to approximately 50% of the static pull-out load. When the load applied to the specimen was reduced to 37%, this ratio increased to approximately 87%. Values are also reported for the other embedment lengths. Early investigations into the fatigue strength of both plain and reinforced concrete is briefly summarised in the paper, and an extensive bibliography is given. B.R.R.A.

629. **Dislocations in a Simple Cubic Lattice.**

F. R. N. NABARRO. *Proc. Phys. Soc.*, **59**, 256, 1947.

The properties of dislocations are calculated by an approximate method due to Peierls. Among other results, it is shown that the energy and effective mass of a dislocation increase with size of specimen, that a dislocation causes a large reduction in the yield stress, and that a pair of dislocations of opposite sign must be at least 10,000 lattice spacings apart. The energy of activation for the formation of a pair is calculated. L.R.G.T. (*vide* abstr. 560).

630. **Dislocation Theory as Applied by N.A.C.A. to the Creep of Metals.**

A. S. NOWICK and E. S. MACHLIN. *J. Appl. Phys.*, **18**, 79, 1947.

An equation for the steady-state rate of creep of pure annealed polycrystalline metals is derived through dislocation theory and the theory of rate processes. The rate of generation of dislocations is shown to be the rate-determining process. A specific mechanism for the generation of a dislocation is presented, from which the heat and entropy of activation of the process are expressed in terms of physical constants of the material. In addition the lowering under stress of the potential energy barrier, which yields the stress-dependent term, is given in terms of constants of the material and a "back-stress" term. The creep equation thus obtained is found to be in good agreement with data in the literature. AUTHORS' ABSTR.

631. **Deformation in Relation to Time, Pressure and Temperature.**

P. G. NUTTING. *J. Franklin Inst.*, **242**, 449, 1946.

The Nutting equation is derived in a modified form which includes the temperature from the thermodynamic considerations. The form is

$$y = at^n p^m T^r$$

where y is the variable associated with strain,

a is a constant,

t the time,

p the pressure or force, and

T the temperature.

The Thompson equation

$$\frac{dT}{dp} = \frac{T\alpha v}{C_p}$$

$$\frac{dp}{C_p}$$

is also derived from thermodynamic considerations.

From these equations the cooling of a wire by stretching and the warming of rubber is derived. It is shown that in elastic deformations, the heating or cooling may be many times the work done. In pure physics, however, the heat and work are equal, while in deformation beyond the elastic limit the thermal energy contains an additional factor, the heat of rupture or depolymerization similar in nature to the latent heat of change of phase. It is suggested that with precise calorimetric methods it should be possible to separate the elastic and physics effects in such bodies as twisted bars of lead. Some experiments on the stretching of a steel tape within the elastic limit are analysed, and show that the temperature change obeys the relation, the stretch caused by loading being about 530 times the change in length caused by the drop in temperature and of opposite sign. The

curve for $\frac{dT}{dF}$ is shown to rise to a peak of twice the normal value at a certain

load. Another series of experiments on the tape in which time curves were plotted could be fitted after suitable adjustment of the zero by the first formula with a value of n about 0.24. M.W.T. (*vide* abstr. 58).

632. **Standardized Tests for Determining the Physical Properties of Mine Rock.**

L. OBERT, S. L. WINDES, W. I. DUVAL. *Report of Investigations R.I.* 3891, 1946.

Fifteen physical tests are described which were performed to determine the physical properties of mine rock including abrasive hardness, impact toughness, grindability and scleroscope hardness, etc. Test specimens were obtained from diamond drill core supplied for field drilling or from rock in the laboratory. Coring drill and diamond are shown. I.D.I.B.

633. **A Rational Formulation of the Equations of Plastic Flow for a Bingham Solid.**

J. G. OLDROYD. *Proc. Camb. Phil. Soc.*, **43**, 100, 1947.

The equations of plastic flow for a Bingham solid are developed in tensor form. It is then shown that such a solid in a state of flow can be regarded as a fluid with a variable viscosity, which is a scalar function of the stress tensor involving two physical constants, the reciprocal mobility and the yield value of the material. The energy equation is deduced, and the significance of the various terms of this equation is explained. Finally, it is shown that plastic flow of a Bingham solid occurs in such a manner that the rate of dissipation of energy is a minimum.

SCI. ABSTR.

634. **Equations for Computing Elastic Constants from Flexural and Torsional Resonant Frequencies of Vibration of Prisms and Cylinders.**

G. PICKETT. *Proc. A.S.T.M.*, **45**, 846, 1945.

The equations of Mason, Love, etc., which do not take into account the effects of shear are not so satisfactory as Timoshenko's differential equation for flexural (transverse) vibration of prismatic bars. Goens' solution of Timoshenko's differential equation for bars with free ends is in very close agreement with results obtained by means of the mathematical theory of elasticity, if the shear constant K' is given the proper value. The proper value depends on Poisson's ratio, being about $\frac{5}{8}$ for $\mu = 0$, $\frac{8}{9}$ for $\mu = \frac{1}{6}$, and 0.85 for $\mu = \frac{1}{3}$. The radius of gyration r adequately describes the cross-section of a prism for the computation of resonant flexural vibration. The approximate equation given by Goens for the correction factor T_1 can be made accurate to at least three figures by subtracting the quantity $125(r/T)^4$. Equations are given for computing Young's modulus and the shear modulus from

flexural and torsional resonant frequencies respectively, as well as graphs from which the size and shape factor C in the equation for Young's modulus, and Goens' correction factor T are readily determined. An equation is given for obtaining Poisson's ratio from the flexural and torsional resonant frequencies, and the limitations of the equation are discussed. B.R.R.A.

635. Introduction to the Mathematical Theory of Plasticity.

W. PRAGER. *J. Appl. Phys.*, **18**, 375, 1947.

The paper aims at introducing the reader to the principal theories of plasticity. Since a presentation of the general stress-strain relations used in these theories would require too much space, the discussion is restricted to the mechanical behaviour of plastic materials under shear. Theories of plastic deformation (Hencky, Nadai) and theories of plastic flow (Saint Venant-Levy-Mises, Prandtl-Reuss, Prager) are illustrated by the example of a prismatic bar under torsion. AUTHOR'S ABSTR.

636. Behaviour of Elastic Materials used as Insulators for Mechanical Vibrations.

S. RAMA. *Alta Frequenza*, **11**, 5, 1942.

An elastic wave is propagated in an elastic porous material by two distinct media, the solid body itself and the air within the pores. The propagation can be represented by a system of equations which regard the body as one compact material. The equations are then analogous to those for the propagation of electrical energy along a line, the equivalent quadripole being applicable. A device for measuring the elastic constants of a body is described, in which one face can be loaded with a given weight m and the other set in vibration. Curves giving the ratio between the amplitudes of the exciting and excited vibrations show that the internal friction $\propto m^{\frac{1}{2}}$. Values are given of the damping and rigidity coefficients for various materials and of the velocity of sound through them. SCI. ABSTR.

637. Effect of Sodium Hexametaphosphate on the Yield Value and Viscosity of a Hydrogen Bentonite Suspension.

A. REID and N. C. SEN GUPTA. *Nature*, **159**, 336, 1946.

From tests with a rotary viscometer it appears the phosphate has a greater effect in reducing the yield value than the viscosity, and while with 0.6 to 0.8% of phosphate the viscosity increases on standing, the yield value does not. E.W.J.M.

638. The Measurement of Pressure on the Sea Bed.

E. G. RICHARDSON. *Phil. Mag.*, **37**, 25, 1946.

A rubber diaphragm manometer for measuring the pressure is described. The pressure of waves rather than tidal motion had to be recorded and for this the principle of the equalization chamber and pressure leak was used. The instrument is calibrated by using classical hydrodynamical theory. The results of some experiments made in the English Channel illustrate the use of the apparatus for wave-height recording. Pressure records of ships were also obtained. SCI. ABSTR.

639. Torsion of a Rubber Cylinder.

R. S. RIVLIN. *J. Appl. Phys.*, **18**, 444, 1947.

It has been predicted theoretically that, in general, a right-circular cylinder of incompressible, highly elastic material, which is isotropic in its underformed state, cannot be held in a state of pure torsional deformation by means of a torsional couple alone. In addition, normal surface tractions must be exerted over the plane ends of the cylinder. These normal surface tractions depend on the amount of torsion and on position on the plane ends of the cylinder. Experiments are reported here in which this phenomenon is observed in a right-circular cylinder

of pure gum compound. The dependence of the surface traction on amount of torsion and its distribution over the surface of the cylinder is studied by measuring the bulging of the rubber into small holes in a metal plate on one end of the cylinder.

AUTHOR'S ABSTR.

640. Surface Hardening of Aluminium and Its Alloys.

K. G. ROBINSON and B. W. MOTT. *Metallurgia*, **35**, 201, 1947.

Work carried out to produce a suitable surface layer of copper-rich constituent shows a hard surface layer of good uniformity. Hardness of the coating was determined by Tukon micro-hardness tester using Vickers and Knoop indenters. The Knoop indenter uses the rhomb diagonal; ratio approximately 7:1. American manufacturers claim that Knoop indentation as measured on the long diagonal is free from error due to "brink" effect. Combination of light load and shape of Knoop indentation has little tendency to crack or spall brittle material and the long diagonal is little affected by elastic recovery, while Vickers diamond impressions show some distortion, probably arising from local variations in hardness. The Knoop hardness values are in fairly close agreement with values obtained with the Vickers diamond indenter.

I.D.I.B.

641. The Plasticity of Brittle Materials.

E. RYSCHKEWITSCH. *Industr. Diamond Rev.*, **6**, 339, 1946.

The author states that ceramic materials, as well as metals, show non-reversible plastic deformations well below their melting point. As evidence of this is cited the scratching by diamonds and rubies of polished surfaces of substances such as glass, sintered ruby, silicon carbide and sintered ZrO_2 , in which curled chips are produced. Photo-micrographs of such scratches are given.

SCI. ABSTR. (*vide* abstr. 411).

642. Elastic Losses in Some High Polymers as a Function of Frequency and Temperature.

H. S. SACK, J. MOTZ, H. L. RAUB and R. N. WORK. *J. Appl. Phys.*, **18**, 450, 1947.

The frequency and temperature dependence of the elastic losses of polyvinyl chlorides (0° to 80° C., 60 to 1400 c.p.s.) and of natural rubber and butadiene-styrene copolymers (GRS) of different relative concentration (-50° to 35° C., 20 to 3500 c.p.s.) was studied by three methods, in which the motion of a reed in free or forced vibration is observed. Natural rubber at temperatures above 20° C., and polyvinyl chloride exhibit frequency independent losses, the mechanism of which is not yet clear. The results for rubber below 20° and for GRS can be explained by a relaxation theory. The behaviour of the elastic losses also reflects the existence of a second-order transition, below which rotation of chain segments is hampered.

AUTHORS' ABSTR. (*vide* abstr. 223).

643. Influence of Tension during Drying upon Paper Strength.

J. E. SAPP and W. F. GILLESPIE. *Paper Trade J.*, **124**, 120, 122, 124, 126, 1947.

The loss in bursting strength on a Fourdrinier machine, taking laboratory handsheets as standard has been found to be 16% on the wet end and 20% in the driers. The effects of increased tension during drying upon the strength properties of handsheets are: (a) bursting strength decreases rapidly, approximately as a straight line function of the extent of stretching; (b) tensile strength in the direction in which tension is applied at first increases, reaches a maximum value of 5 to 10% greater than that of the unstretched sheet, then decreases; (c) tensile strength in the cross direction diminishes, at first slowly, and then more rapidly as stretching is increased; (d) elongation in the direction in which tension is applied falls sharply

at first then at a slower rate with increasing tension; (e) elongation in the cross direction is not greatly affected. The major cause for loss in bursting strength is the decrease in machine direction elongation, with loss in machine direction tensile strength a contributing factor at high degrees of stretching. The loss of bursting strength caused by drying under tension is apparently somewhat dependent upon the degree of refining, a slow pulp losing strength less rapidly than a free one. The properties of handsheets dried under tension resemble those of machine-dried paper much more closely than do the properties of handsheets made in the usual manner.
P.A.T.R.A.

644. Limitations of the Newtonian Time Scale in Relation to Non-equilibrium Rheological States and a Theory of Quasi-properties.

G. W. SCOTT BLAIR, B. C. VEINOGLU and J. E. CAFFYN. *Proc. Roy. Soc. A.*, **189**, 69, 1947.

To describe the behaviour of complex materials under stress, "quasi-properties" are introduced, which do not have integral time-exponents on the Newtonian time-scale; they represent an ordered process towards equilibrium rather than a state of equilibrium. In order to retain the Newtonian time-scale, fractional differential equations are used. The simplest of these, relating stress, strain and time, integrates to a series equation whose first term is the familiar Nutting equation; the introduction of the second and (very rarely) the third term improves the fit of experimental results for many materials not following Nutting's equation. The apparatus used for obtaining the experimental results is described, and the results on 38 materials quoted. The form of the series equation indicates that the relative importance of the second term may sometimes disclose the presence of undissipated stresses in the materials.

SCI. ABSTR. (*vide abstr.* 154, 194).

645. A Photo-elastic Study of Stress Waves.

D. A. SENIOR. *Phil. Mag.*, **37**, 463, 1946.

Stress waves set up by impact were examined by flash photography of the associated photo-elastic fringes using an Arditron discharge tube. The method is described.

SCI. ABSTR.

646. A Capillary-type Viscometer:

D. P. SHOEMAKER, E. HOERGER, R. M. NOYES and R. H. BLAKER. *Anal. Chem.*, **19**, 131, 1947.

The viscometer is designed for use with volatile solvents. It has the advantages of avoiding the necessity of removing the solution under examination from the vessel in which it is prepared, and of requiring only a small volume of liquid.

L.R.G.T.

647. The Opening of a Griffith Crack under Internal Pressure.

I. N. SNEDDON and H. A. ELLIOTT. *Quart. Appl. Math.*, **4**, 262, 1946.

An analysis is made of the distribution of stress in the neighbourhood of a Griffith crack subject to an internal pressure, which may vary along the length of the crack. A Fourier cosine transform method is used. A method is given for finding the shape of the crack resulting from the application of a variable internal pressure to a very thin crevice in the interior of an elastic solid, and for finding the stress distribution throughout the solid. As an example, expressions for the stress components due to the opening of a crack under a uniform pressure are derived.

SCI. ABSTR. (*vide abstr.* 566).

648. **Relaxation Methods applied to Engineering Problems.—XII. Fluid Motions characterized by "Free Streamlines."**

R. V. SOUTHWELL and G. VAISEY. *Philos. Trans.*, No. 815, 117, 1946.

In the type of problem dealt with a double condition is imposed at a boundary initially unknown. The basic theory for laminar and axially symmetric flow is presented and the application of relaxation methods to the equations obtained is discussed. The first set of examples, worked out in detail, relates to jets uninfluenced by gravity, e.g. the Borda mouthpiece in laminar or axially symmetric flow, and an orifice plate in a circular tube. Jets subject to gravitational forces are next studied. The first example is a waterfall (2 free surfaces) and the second is a 2-dimensional planing surface (seaplane). Lastly, examples of free stream lines forming boundaries of waves are discussed. These include the waves behind a circular cylinder and a sphere.

SCI. ABSTR.

649. **Structure of the Keratin Molecule.**

J. B. SPEAKMAN. *Nature*, 159, 338, 1947.

When wool fibres of uniform cross sectional area are stretched extremely slowly in saturated air at 18° C. they break at 70% extension. Extension occurs by the transformations of the crystalline phase from the α to the β -configuration at extensions above about 25%. It has been found possible to obtain a closer insight into the α - β -transformation process by studying the extension of wool fibres under constant stress. By plotting $\log (70 - E)$ against time, the slope k is a measure of the rate of unfolding and by determining k at different temperatures with wool fibres under various stresses, the activation energy associated with the α - β -transformation can be calculated. This was found to be about 20 kcal, which agrees with Astbury's conception of the nature of the intramolecular fold in α -keratin, for the opening of such fold involves the breakdown of three hydrogen bonds between $-\text{CO}-$ and $-\text{NH}-$ groups.

E.W.J.M.

650. **"Bending Properties" as an Index to the Quality and Character of Paper.**

J. STRACHAN. *Paper-Maker*, 113, 9, 1947.

"Handle" is defined and the importance of rigidity or resistance to elastic bending in office printing and packaging papers and boards is discussed. Methods devised for measuring the elasticity of papers and boards are reviewed.

P.A.T.R.A. (*vide* abstr. 413).

651. **Electrical Resistance Wire Strain-gauges to Measure Large Strains.**

K. H. SWAINGER. *Nature, Lond.*, 159, 61, 1947.

The linear range can be increased up to 7 or 8% strain by using "Minalpha" wire, and ensuring that the joints to the heavy lead wires are not strained.

SCI. ABSTR.

652. **A New Criterion of Yielding in Metals.**

K. H. SWAINGER. *Nature*, 159, 741, 1947.

The author, considering the ellipse of stress, suggests the equation

$$(T + S) = a \cdot \left[\frac{\mathbf{m} \cdot \mathbf{m}}{\sqrt{2} (1 + q)} + \mathbf{n} \cdot \mathbf{n} \right] S_0$$

for any general point stated in terms of the radial vector $\mathbf{a}$ and the vector stresses S , T , where the dot indicates the scalar product of the unit vectors $\mathbf{a}$, $\mathbf{m}$, $\mathbf{n}$, where S_0 is the simple tensile stress and q Poisson's ratio, as a new criterion of yielding in the general complex stress case.

It is suggested tentatively that the criterion may apply to rupture, in which case S_0 is the simple tensile rupture stress for the metal.

E.W.J.M. (*vide* abstr. 506).

653. Plastic Strain in Isotropic Strain-hardening Material.

H. W. SWIFT. *Engineering*, **162**, 381, 1946.

This paper is concerned with the characteristics of plastic strain in a hypothetical material which "hardens" under strain, but remains isotropic. An attempt is made to ascertain what features of strain-hardening as revealed by experiment are consistent, and what inconsistent, with isotropy in the material. The Mohr circle diagram for stress is extended to cover large and small strains, and in particular to show the directions of shear stresses and strains. Stress-strain relationships in the plastic region are discussed with reference to: (1) The conditions for inception of plastic strain. (2) The geometry of plastic strain in relation to the stress system. (3) The amount of overstrain induced by a given excess of stress. In a discussion of strain-hardening characteristics, it is pointed out that isotropy does not require that the strain-hardening rate for a given material should be independent of the condition. In a final section formulæ are developed for reduction of experimental results.

SCI. ABSTR.

654. Internal Friction of Zinc Single Crystals.

I. H. SWIFT and J. E. RICHARDSON. *J. Appl. Phys.* **18**, 417, 1947.

Measurements of internal friction in single crystals of zinc were carried out at a frequency of 45 kc/s and at varying amplitudes. For annealed crystals the friction was nearly independent of strain amplitude up to and beyond the static elastic limit, then rose rapidly. The effects were very dependent on the prior history of the sample. The phenomena are interpreted with the use of dislocation theory.

L.R.G.T.

655. The Testing of Materials at High Rates of Loading.

G. I. TAYLOR. *J. Instn. Civ. Engrs.*, **26**, 486, 1946.

Describes and analyses a number of experiments made on the stress/strain behaviour of materials tested at high speeds. The design of machines for high-speed testing is difficult because, as the rate of straining increases, the inertia forces of moving parts of the machine become of importance. At very high speeds the inertia of the specimen itself gives rise to changes of stress along its length, which must be taken into account.

SCI. ABSTR.

656. Stress Conditions for the Failure of Saturated Concrete and Rock.

K. TERZAGHI. *Proc. A.S.T.M.*, **45**, 777, 1945.

Concrete or rock specimens acted upon by a confining pressure supplemented by a unidimensional pressure may fail by splitting, pseudo-shear or shear.

Experiments have shown that the unidimensional excess pressure q_c required to break a given specimen depends both on the total confining pressure p_c and on the pore water pressure u_w . If the pore water pressure u_w is zero, q_c increases very rapidly with increasing values of p_c . On the other hand, if the pore water pressure u_w is equal to the total confining pressure, $u_w = p_c$, the effect of p_c on the compressive strength q_c is imperceptible.

An inquiry into the physical causes of the striking influence of the pore water pressure u_w on the strength q_c of a specimen at a given confining pressure p_c leads to the conclusion that the individual constituents of saturated concrete and rock in a stress-free state are almost completely surrounded with liquid. In other words, the solid constituents of these materials are interconnected only over very small areas of their total surface. The corresponding boundary porosity is almost equal

to 100%. In a material with such a high boundary porosity, the hydrostatic uplift is almost as active as in a cohesionless sand.

By comparing the results of volume compression tests on jacketed specimens with those of specimens without any cover, it is found that the effect of confining pressures up to 15 or 20 tons per sq. ft. on the boundary porosity of concrete and rock is negligible. Since the boundary porosity of stress-free specimens is almost equal to 100%, the corresponding boundary porosity of specimens under effective confining pressure of less than about 20 tons per sq. ft. is also very close to 100%, and the constituents of the confined specimens are also almost completely surrounded with liquid. Therefore the common conception that the hydrostatic uplift acts only on one-half or two-thirds of the base of concrete storage dams appears to be erroneous. However, the results of such an investigation can be predicted fairly closely on the basis of the existing experimental data which have been analysed in this paper.

The compressive strength q_c of saturated concrete acted upon by a confining pressure p_c is roughly equal to $q_c = q_u + 4.1 (p_c - u_w)$ wherein q_u is the standard strength and u_w the pore water pressure. The equation is certainly valid for values of $p_c - u_w$ of less than about 20 tons per sq. ft. and it is probably approximately valid for much higher values.

The effect of the pore water pressure on the strength of rocks located between a depth of about 100 ft. and 20,000 ft. could be determined by means of a test arrangement which is illustrated. Within a depth of about 100 ft., the hydrostatic uplift is almost fully active; at a depth of more than 20,000 ft. it may be negligible, but is not necessarily so.

B.R.R.A.

657. **The Dependence of the Viscosities of Liquids on Reduced Temperature, and a Relation between Viscosity, Density, and Chemical Constitution.**

L. H. THOMAS. *J. Chem. Soc.*, 573, 1946, *Nature, Lond.*, **157**, 622, 1946.

An exponential equation is proposed representing the variation of the viscosities of liquids with reduced temperature in terms of two constants, one being characteristic of each liquid, and the other being approximately constant for all normal, non-associated liquids. The values of the constants for a large number of liquids are tabulated and the relation between the characteristic constant and molecular constitution is discussed.

SCI. ABSTR.

658. **Experimental Evidence of the Viscous Behaviour of Grain Boundaries in Metals.**

T'ING-SUI KÊ. *Phys. Rev.*, **71**, 533, 1947.

A simple torsional apparatus was devised for measuring anelastic effects at very low stress levels in polycrystalline Al; these effects were practically absent in single crystal Al. The effects observed are consistent with the viewpoint that the grain boundaries behave in a viscous manner. The maximum amount of shear stress relaxation is $\sim 33\%$, in good agreement with the theoretical value of 36% calculated by assuming the grain boundary to be viscous. Similar anelastic effects have been also observed in polycrystalline magnesium, indicating that the viscous behaviour is common to all metals.

SCI. ABSTR.

659. **Relation between Inelastic Deformability and Thermal Expansion of Glass in Its Annealing Range.**

A. Q. TOOL. *J. Amer. Ceram. Soc.*, **29**, 240, 1946.

As a result of experience with the behaviour of glass at temperatures within its annealing range, an equation is proposed which relates the various extraordinary heat effects to inelastic deformability and to the degree of superheating or under-

cooling. By using this equation in connection with the thermal-expansion curves of a glass within its annealing range, certain constants that are related to the coefficient of viscosity, and its changes with temperature and the degree of superheating or under-cooling, have been determined with reasonable results. Such results make it possible to estimate the inelastic deformability of a glass in its various conditions at all annealing temperatures, and are therefore valuable in connection with problems that are encountered in the process of annealing glass. The apparent success achieved in applying the proposed equation to experimental data suggests that the concepts underlying this equation are fundamental, and must be considered in any theory concerning the constitution of glass or of any other extremely viscous liquid.

B.R.R.A. (*vide* abstr. 360).

660. Viscosity and the Extraordinary Heat Effects in Glass.

A. Q. TOOL. *J. Res. Nat. Bur. Stand., Wash.*, **37**, 73, 1946.

Discusses viscosity of glass in the annealing range, referred to actual and "equilibrium" or "fictive" temperatures, in relation to exothermic effects shown on heating chilled samples, and thermal expansion properties. An analysis is based on the equation: $d\tau/dt = K_\tau(T - \tau)$, giving the rate of approaching equilibrium in terms of the actual temperature T and the fictive temperature τ , K_τ being a factor inversely proportional to the viscosity. The theory is applied to the question of thermal expansion in this temperature region on the assumption that viscosity is a function of τ as well as of T . Estimates are also made of heat effects from equilibrium temperatures obtained from thermal expansion curves. Reasonable agreement with experiment is suggested. Results are discussed in terms of thermal and intrinsic pressures and other data on structure of glass.

SCI. ABSTR.

661. Effect of Dimensions of Specimens upon the Precision of Strength Data.

J. TUCKER, JR. *Proc. A.S.T.M.*, **45**, 952, 1945.

Statistical theories on the strength of materials are used to estimate the effects of change in the dimension of one specimen on the mean strength and dispersion of the strength within a group of like specimens. The weakest link theory predicts the effects of an increase in the length of specimens subjected to tension, compression, flexure, or torsion and in the depth of specimens subjected to flexure. The strength-summation theory appears to predict reasonably well the effects of an increase in the cross-sectional areas of specimens subjected to tension or compression, and of an increase in width of the flexural specimen. Analyses based on the statistical theories of strength and the results of some tests indicate that reliable measures of the strength and uniformity of the strength of concrete may be obtained by testing a larger number of specimens much smaller than those commonly used.

B.R.R.A.

662. The Maximum Stresses Present at Failure of Brittle Materials.

J. TUCKER, JR. *Proc. A.S.T.M.*, **45**, 961, 1945.

It is shown by a statistical theory of strength, how stresses with magnitude much beyond those usually considered as the strength of the material may be present in a portion of a test specimen. It is theoretically demonstrated that the modulus of rupture as usually calculated should be much greater than the tensile strength. Analysis demonstrates that the load at failure of a cement briquette does not have a fixed ratio to the tensile strength of the material, and it is also shown that in a concrete cylinder tested in compression, with ends restrained against lateral expansion, the tensile stresses present in a small portion of the volume are too small to cause a tensile failure.

B.R.R.A.

663. **Effect of Length on the Strength of Compression Test Specimens.**

J. TUCKER, JR. *Proc. A.S.T.M.*, **45**, 976, 1945.

When compression test specimens of concrete are shorter than twice their least width, it is customary to adjust the test values by the use of a single set of correction factors, such as those in "Standard Methods of Securing, Preparing, and Testing Specimens from Hardened Concrete for Compressive and Flexural Strengths" (C42-44), the corrections depending only upon the ratio of length to least width. This paper demonstrates that the extent of the variation in strength with length is dependent upon several distinct factors. For example, the relation between strength and slenderness of specimen varies with the strength of the concrete and therefore the use of a single set of correction factors is not warranted. Much more reliable estimates of strength may be obtained by limiting the range of slenderness values to those for which the correction is small, even though this may require diameters less than those usually considered acceptable. Although the numerical values which are given apply to concrete, the principles are applicable to other brittle materials.

B.R.R.A.

664. **Micelle Structure in Aqueous Solutions of Colloidal Electrolytes.**

R. J. VETTER. *J. Phys. & Coll. Chem.*, **51**, 262, 1947.

The viscosity of aqueous solutions of the sodium salt of sulphonated di(2-hexyl) succinate, (Aerosol MA) was studied over a range of concentrations. A hypothesis is advanced to account for the micellar structure within a limited range of concentration.

L.R.G.T.

665. **The Intrinsic Viscosities of Polymers as Function of Conversion.**

F. T. WALL, R. W. POWERS, G. D. SANDS and G. S. STENT, *J.A.C.S.*, **69**, 904, 1947.

Intrinsic viscosity data obtained during polymerisation at 50° C. for a number of polymers, including polybutadiene and copolymers of butadiene with styrene, etc., are presented in form of curves. The intrinsic viscosity diminishes during some stage of the conversion, and this considered to be due mainly to cross-linking reactions.

E.W.J.M.

666. **Measurement of Elasticity in Fluids of Low Viscosity.**

J. R. VAN WAZER and H. GOLDBERG. *J. Appl. Phys.*, **18**, 207, 1947.

By means of an apparatus applying an alternating shearing motion to a liquid, it was shown that fluids with a viscosity of around one poise have elastic properties. A discussion of the variation of the resonance maxima with the amount of damping is given, and the shear modulus and damping* viscosity are calculated for some dilute solutions of high polymeric materials.

AUTHORS' ABSTR.

667. **A Continuum Theory of Rheological Phenomena.**

K. WEISSENBERG. *Nature, Lond.*, **159**, 310, 1947.

Liquids are classified as *general* if a finite proportion of the strain existing in an energized state caused by the application of mechanical forces is recoverable after the release of these forces, and *special* if it is zero. Experimental tests to investigate these properties are briefly described and an extension of an earlier theory is applied in outline to explain them.

SCI. ABSTR.

668. **Relation between the Impact and Flexural Tests for Moulded Plastics.**

L. E. WELCH and H. M. QUACKENBOS. *Trans. Amer. Soc. Mech. Engrs.*, **68**, 547, 1946.

A theoretical treatment of the phenomena of impact indicates that rupture under dynamic stress/strain conditions results from the same basic considerations

as those governing static or flexural failure. This is proved experimentally by reducing the problem to one of stress. Using high-speed electronic techniques, it is shown that impact loading is merely a special case of static loading whereby for stress/strain conditions are identical except for a slight elevation in strength under dynamic conditions. The existing methods of impact-strength evaluation such as the standard Izod and Charpy tests lead to erroneous results since the machines in use are apparently of too light a construction, and the technique is over-simplified. It is suggested that the static flexural-test technique when properly carried out to evaluate the energy required for fracture and the notch sensitivity, is sufficient to predict the service characteristics of essentially brittle materials under conditions of both static and impact loading.

SCI. ABSTR.

669. **Stress Induced Preferential Orientation of Pairs of Solute Atoms in Metallic Solid Solution.**

C. ZENER. *Phys. Rev.*, **71**, 34, 1947.

In a non-stressed cubic crystal the axes of pairs of adjacent solute atoms are randomly orientated along the several permissible crystallographic directions. It is shown that in the presence of a stress the equilibrium orientation is no longer random, but certain directions become preferred, and that the continual striving of the crystal to maintain equilibrium causes it to manifest all the characteristic anelastic effects, stress relaxation, internal friction, etc. In particular, its internal friction will be anomalously high in that temperature range where the time of relaxation for the establishment of equilibrium is comparable with the period of oscillation.

SCI. ABSTR. (*vide* abstr. 518, 519).

670. **Critical Remarks on the Technical Bending Theory.**

H. ZIEGLER. *Schweiz. Bauztg.*, **128**, 187, 1946.

Modifications must be made in classical bending theory to make it applicable to rods with varying cross-section and where the loads are inclined to the axis of the rod, so that tensile, shearing and bending stresses occur in sections perpendicular to the axis. The ratio ϵ between breadth and length is supposed to be small. The orders of magnitude of the stress components and their derivatives are expressed as powers ϵ^{-1} , ϵ^0 , ϵ^1 , ϵ^2 . . . of ϵ . The axial normal stresses are developed into a power series in ϵ , and to a first approximation, confined to ϵ^{-1} , the classical values are obtained. Further approximations furnish the required generalizations.

SCI. ABSTR.

BOOK REVIEW.

Dynamic Method for Determining Average Elastic Properties of Surface Soil Layers.

By SVEN G. BERGSTRÖM and SVEN LINDERHOLM. *Proceedings No. 7 of the Swedish Cement and Concrete Research Institute, Royal Technical University, Stockholm.* [Price 5 Kr.]

The investigations described in this little book were part of fairly extensive studies made in the autumn of 1945 by the Swedish Cement and Concrete Research Institute in connection with the design of concrete pavements for airports. The book reports the tests made by a dynamic method for the direct field determination of the average elastic properties of surface soil layers. The soil was subjected to vibration and the resonance frequency was measured. The moduli of elasticity in shear and tension were computed from the velocity of wave propagation at the resonance frequency, according to a method evolved by the Japanese investigators, Sezawa and Kanai. Values of these moduli were also obtained for comparative purposes by laboratory tests by both static and dynamic methods, and by static

loading tests in the field. In the field tests, loading plates of two general sizes were used; some were 6 m. square, while others varied from 0.28 m. to 1.12 m. in circumference.

The mathematical theory of the dynamic field method is given briefly—perhaps a little too briefly—and the apparatus and methods used are described in detail. In addition to the main test results of the resonance frequency and the wavelength measurements, results of preliminary and control tests are also given showing variation of wave amplitude with distance from the vibrator, the effect of pick-up depth, and the variation of wavelength with frequency. These are presented in graphical and tabular form. In some cases, wide divergence occurred between the values obtained by field vibration methods and the static loading methods. These differences are discussed without bias and possible explanations are suggested.

The book will be of great interest to research workers engaged on soil mechanics problems. Although it is obvious that more testing and research are essential before the methods described can become widely accepted, nevertheless, to engineers engaged on site exploration, an interesting indication is provided of the possibilities offered by the dynamic method of field soil testing with its attendant advantages of easily transportable site-testing equipment.

Review, *Engineering*, March 21st, 1947.

CONFERENCE ON "MACHINABILITY"

A whole-day conference was held at the Institution of Mechanical Engineers on May 24th to discuss papers dealing with machinability. The main purpose of the conference was to consider the reason why certain materials have been found to present very serious difficulties in machining, by determining what were the fundamental physical properties of a material which decide how easy it is to machine, how standard methods can be developed for testing the machinability and the effect of variables in the machining process.

Machinability appears to be assessed from an engineering point of view by the energy required to remove a given volume of metal and the rapidity with which a standard tool is blunted by it. Various standardised methods of measuring those factors have been developed. On the fundamental side, Dr. Sykes suggests that the ideal machinable material must be, on the one hand, easy to shear, and on the other hand, ductile, since a ductile material gives a long chip with low resultant friction on the tool. Mr. Murphy connects the micro and micro-crystal structure of non-ferrous metals with machinability: for example, hexagonal close-packed magnesium alloys are very easily machined because they have slip planes only on the basal plane of the lattice, giving a limited facility for cold working which, in turn, results in discontinuous chips. The addition of small quantities of sulphur and lead makes a material very easily machinable because it forms an emulsion of sub-microscopic particles which break up the chips.

Professor Arnold and Dr. Hankins discuss the form of distortion which the material undergoes as a chip is being sheared from the surface and connect this with the stress/strain diagram obtained in the standard tensile apparatus.

Measurements of the energy required to remove a given volume of material (Kenneford) have shown that the energy consumption per unit volume of metal removed on any one material varies inversely as some power of the feed, inversely as some power of the depth of cut, and inversely as the top rake of the cutting tool at constant speed with any one cutting fluid and tool material.

Other papers contain a great deal of information about the shape of the chip formation and the effect of various factors such as lubrication and tool design on the work required. It would appear that the application of the rheological viewpoint to the subject of machinability might be able to suggest some interesting lines of thought. For example, the actual nature of the flow in moving from the

surface to the chip does not seem to have been investigated mathematically by the methods used in problems of rolling,¹ and the estimations of the work required to remove material in terms of the total plastic deformation produced, or the surface area produced, might lead to a more complete theoretical background.

M. W. THRING.

REFERENCE

- ¹ OROWAN. *The Calculation of Roll Pressure in Hot and Cold Flat Rolling.*

THE PROBLEM OF LARGE ELASTIC DEFORMATIONS

L. R. G. TRELOAR.

In science, as in other fields of activity, the germ of a new idea frequently lies dormant for many years, until some change in the environment provides a stimulus to active development. A striking illustration of this effect is referred to in a recent article by Guth, James and Mark, in *Advances in Colloid Science*, Vol. II, dealing with the theory of rubber elasticity.

It is here pointed out that the peculiar thermo-elastic properties of rubber were first reported by Gough¹ as long ago as 1805, while rubber was still almost unheard of as a commercial commodity. Gough observed (a) that heat is generated on stretching rubber, and (b) that a length of rubber loaded with a weight contracts on heating. It was Kelvin² who, half a century later, showed by thermodynamic reasoning that (b) follows from (a), and this inspired Joule³ in 1859 to repeat Gough's experiments, using for the purpose the more perfectly elastic *vulcanised* rubber which had by that time become available. Joule confirmed Gough's results, and found that the heat of extension was almost exactly equal to the work done by the stretching force, i.e. that the energy expended in stretching the rubber was converted into heat. The effect is reversible; if stretched rubber is allowed to retract, doing work, there is an approximately equal cooling effect. Joule correctly inferred, from these experiments, that the origin of the elastic force of rubber is to be ascribed to the *motion of its constituent particles*.

This fundamental conclusion, that the elasticity of rubber is an effect of the kinetic energy of its molecules, and not the result of static force fields or potential energy effects, apparently fell on stony ground, for it was more than sixty years before the next phase of development occurred. The growth of the plantation rubber industry and the development of German synthetic rubber during the first world war had greatly stimulated technical and scientific interest in the study of high-molecular compounds. When, therefore, the kinetic theory of rubber elasticity was re-introduced, *on the basis of a specific structural model of the rubber molecule*, by Meyer, von Susich and Valko⁴ in 1932, the field was ripe for development, and further advances quickly followed. On the new theory, the elasticity was shown to be an inherent property of any linear molecule which possesses sufficient length and flexibility to take up a variety of random configurations by virtue of the thermal agitation of the atoms of which it is composed. However, for rubberlike elasticity to be exhibited by a material in bulk, it is not sufficient that its constituent molecules should conform to this type; it is also necessary, as Busse⁵ pointed out in 1932, that the intermolecular forces should be of a rather special character.

Briefly, all the requirements for high elasticity can only be satisfied by postulating a loose net-like structure, which permits the necessary freedom of movement of the individual chain segments. The junction points of the network are normally provided by the process known as vulcanisation; the number of such junction points or intermolecular linkages is relatively very small, e.g. about one for every few hundred atoms.

The swelling of rubber by organic liquids becomes readily intelligible on this model of the rubber structure, as the recent work of Gee⁶ has demonstrated. In

most of its properties rubber closely resembles a liquid, and the absorption of a liquid (e.g. benzene) by rubber is essentially a process of diffusion, like the mixing of two liquid hydrocarbons. There is, contrary to one's immediate expectation, no specific attraction between the solvent and rubber molecules; the diffusion occurs simple because the mixed state is *more probable* (i.e. has a greater entropy) than the unmixed. Swelling will be prevented only if there is a strong *repulsion* between the rubber and liquid molecules. There is thus a fundamental difficulty involved in conferring oil-resistance on natural rubber or other hydrocarbon rubbers.

From the standpoint of the rheologist the chief interest of the kinetic theory of rubber arises from the quantitative derivation of the laws of deformation of the idealized molecular network. Wall⁷ (1942) was the first to show, from the application of statistical thermodynamic theory to this model, that a rubber should obey Hooke's law in a large shear deformation, but not in an elongation or unidirectional compression, for which the theoretical relation between force and extension (or compression) ratio is non-linear. Thus it was shown that a material, though perfectly elastic, might nevertheless have a non-linear stress-strain curve. This result had, however, been partly anticipated by Mooney⁸ (1940) who, taking the experimental fact of Hooke's law in shear as a starting point, developed a general theory of large elastic deformation. This theory proved that with a linear shear relation, the stress-strain relations for any other type of strain (such as elongation or compression) must be non-linear. Of still greater interest are the stress-strain relations for a rubber in the most general type of homogeneous strain defined by three principal extension ratios in three mutually perpendicular directions (the principal axes of the strain ellipsoid). The result derived by the author⁹ (1943) from the statistical theory may be stated thus: the difference between any two of the principal stresses is proportional to the difference of the *squares* of the corresponding extension ratios.

This general law provides a reliable basis for the interpretation of the stress-strain relations for rubber under any type of homogeneous strain, and represents a distinct step forward in the understanding of large elastic deformations. The significance of the statistical theory may be appreciated when it is recalled that the general laws of elastic deformation had not previously been discovered from experimental studies on the properties of rubber. Since their theoretical derivation, however, a number of experimental studies have shown them to be generally true, though not necessarily accurate in detail. Curiously, perhaps, a study of the general homogeneous strain in vulcanised rubber recently carried out,¹⁰ revealed significant small deviations from the statistical theory, which could be partly accounted for in terms of Mooney's more general theory. Independently, Rivlin, from an experimental study of the stresses in a rubber cylinder under torsion, has concluded that Mooney's formula gives a better representation of the facts than the statistical theory. This does not imply, of course, that the statistical theory is superseded as an *explanation* of the phenomenon of rubber elasticity; it merely means that the idealized model on which it is based is not strictly accurate in detail, which is to be expected in view of the simplifications introduced. If one wants a more accurate representation of the detailed behaviour of a rubber, it is necessary to patch up or modify slightly the resultant equations. Mooney's theory provides instructions on the possible ways in which this patching up can be performed; it tells us nothing of the mechanism responsible for the observed discrepancies.

REFERENCES

- ¹GOUGH. *Mem. Proc. Manchester Lit. Phil. Soc.*, 1805, **1**, 288.
- ²KELVIN (LORD). *Quart. J. Math.*, 1855.
- ³JOULE. *Phil. Trans.*, 1859, **149**, 91.
- ⁴MEYER, V. SUSICH and VALKO. *Koll. Z.*, 1932, **59**, 208.
- ⁵BUSSE. *J. Phys. Chem.*, 1932, **36**, 2862.
- ⁶GEE. *Trans. Faraday Soc.*, 1942, **38**, 418.
- ⁷WALL. *J. Chem. Phys.*, 1942, **10**, 485.
- ⁸MOONEY. *J. Appl. Phys.*, 1940, **11**, 582.
- ⁹TRELOAR. *Trans. Faraday Soc.*, 1943, **39**, 241.
- ¹⁰TRELOAR. *Nature*, 1947, **159**, 231.
- ¹¹RIVLIN. *J. Appl. Phys.*, 1947, **18**, 444.