

LOOK



Mechanical properties and design (Guildford)

Practical rheology in polymer processing (London)

SPRING 1969

REMEMBER !

BULLETIN



**BRITISH SOCIETY
OF RHEOLOGY**

Hon. Editor:

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FOREWORD

This edition marks one of the periodic changes which occur in the membership of the Council of the British Society of Rheology. The most notable of these changes is the assumption of the Presidency by Dr. L. Grunberg of the National Engineering Laboratory in succession to Professor A. Charlesby who has chaired many of the Society's meetings during the last two years with such efficiency and aplomb.

Many of the members of the Society will have become aware of the shift in emphasis of nationally funded research towards the more useful applications of science. This change in the climate of scientific opinion has been generally felt and at present most research organisations are eager to show how useful their work is, indeed commercial viability is the latter-day goal of most research management. Technology is now respectable as it never was before and the National Engineering Laboratory has contributed greatly to raising the standards of applied science and making it useful, the field of Rheology has also benefited by its existence.

Dr. Grunberg's background is one of leadership in Applied Science as the synopsis of his career, to be found elsewhere in this edition of the Bulletin, will testify. The changing climate of opinion about research in this country is reflected in a singular (though unconscious) way in the election of the new President and it would be a happy coincidence if his term covered the first award of the Society's Gold Medal which is to be awarded on the grounds of successful application of Rheology.

Another notable change in the Society's affairs is that Dr. Dennis Hadley has now relinquished the Editorship of this Bulletin. There is no more devoted worker for the welfare of the Society than Dr. Hadley and we are fortunate that the council continues to benefit from his services. All his council colleagues and members of the society would wish to acknowledge his contribution to the society.

Several new features have been introduced into this edition of the Bulletin which it is hoped Members will find both interesting and useful. The value of these items will depend to a large extent on obtaining a successful response from members, positive co-operation will be beneficial to everyone.

One of the important new features to be introduced on the cover of the next Bulletin is the allocation of a volume number. The next Bulletin will therefore be No. 1 of Volume 1, it will thereafter contain four editions per volume and can be referenced in the usual standard forms. As a complementary feature, future technical or scientific papers will be passed to two referees (one for a letter to the Editor) prior to acceptance for publication. It is hoped that these two features will encourage authors to submit scientific papers for consideration for the Bulletin, and we expect to offer an efficient service in the processing of papers. Non-scientific articles will however continue to be considered without refereeing.

THE EMERGENCE OF RHEOLOGY

From the days of Newton and Hooke, scientists from many fields have contributed to the study of the deformation of materials. But a lack of communication hindered developments until rheology emerged as a formal branch of mechanics.

by Hershel Markovitz

The definition of the newly coined "rheology" in the constitution of the Society of Rheology, when it was founded in 1929 under Eugene C. Bingham of Lafayette College, was "fundamental and practical knowledge concerning the deformation or flow of matter." As Markus Reiner recalled telling Bingham at the time, this word would appear to have the same meaning as the term *continuum mechanics*. An operational definition obtained by an examination of what most rheologists actually do would more likely lead to the conclusion that, as accurately as any scientific discipline can be defined, "rheology—a branch of mechanics—is the study of those properties of materials which determine their response to mechanical force," a statement that appears in a brochure recently issued by the Society of Rheology. This more restricted view, the one that I shall take in delineating the area covered in this historical review, removes from consideration the more complicated flow and deformation problems usually discussed in fluid mechanics, hydrodynamics and elasticity.

The material property that determines the response of a body subjected to force is usually expressed mathematically in terms of the dependence of the stress on the deformation. There are three classical models:

- *the Hookean (or linear elastic) solid characterised by stress that is a linear function of the strain.

- *the perfect (or inviscid) fluid characterised by a stress that is always isotropic.

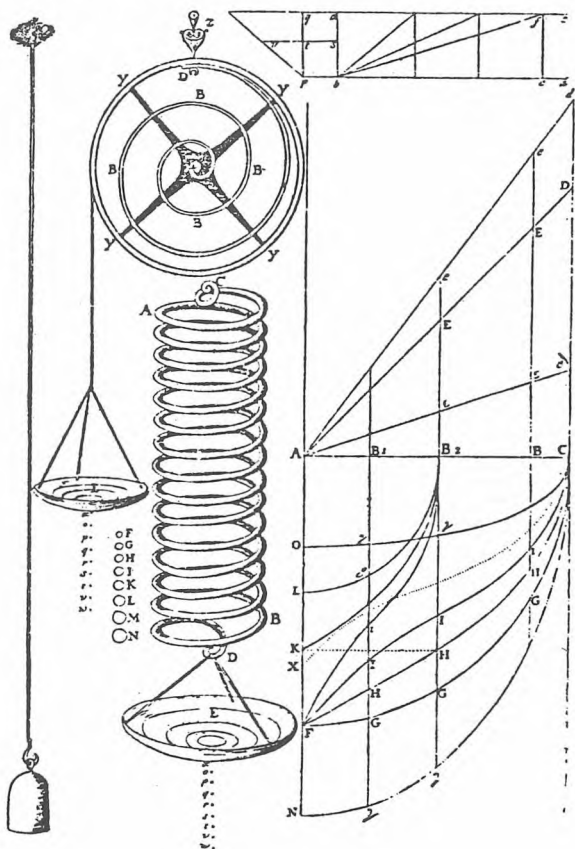
- *the Newtonian (or linear viscous) fluid characterised by a stress that is isotropic when the fluid is at rest but which is a linear function of the rate of deformation when it is being deformed.

By Bingham's time it was established that these classical models were not adequate to describe the mechanical behaviour of many materials. Among the experiments that were to have the greatest influence on the future of rheology were creep and related time-dependent phenomena in solids and fluids. A considerable amount of work had been done on the nonlinear relation between applied driving pressure and rate of flow through small tubes. These are the main developments that I will follow. To put them in their proper historical perspective, it is necessary to indicate how some of the classical theories developed and how confidence in their applicability to some materials was attained.

Hooke and Newton

The two classical model materials, the linear elastic solid and the linear viscous fluid, were introduced within a decade of one another in England towards the end of the seventeenth century.

In 1678 Robert Hooke announced his "true Theory of Elasticity or Springiness" . . . "The Power of any Spring is in the same proportion with the Tension thereof: That is, if one power stretch or bend it one space, two will bend it two, and three will bend it three, and so forward." (See figure 1.) His claim for his Law of Nature was quite



ELASTICITY EXPERIMENTS. Hooke investigated a great number of materials in various forms including: "the coyl or helix of Wire," "a Watch Spring coyled in a Spiral" and a "Wire string of twenty, or thirty, or forty foot long." His results indicated that the displacement of an elastic spring is proportional to the force applied to it.

—FIG. 1

general. It is true not only for any kind of deformation but “in all other springy bodies whatsoever, whether Metal, Wood, Stones, baked Earths, Hair, Horns, Silk, Bones, Sinews, Glass, and the like.”

In 1687 Sir Isaac Newton stated his hypothesis concerning non-perfect fluids in his *Principia*. The main purpose of this work was to discuss the motion of the heavenly bodies. The prevalent theory at the time was René Descartes’s theory of celestial vortices. It was Newton’s main purpose in discussing the motion of bodies in resisting mediums to devastate Descartes before he proceeded with his own theory of celestial motion.

To this end he discussed “The circular motion of fluids.” He began with the hypothesis: “The resistance arising from the want of lubricity in the parts of a fluid, is, other things being equal, proportional to the velocity with which the parts of the fluid are separated from one another.” It is this “want of lubricity” that we today call *viscosity*. Newton immediately proceeded to discuss the problem of the rotation of an infinitely long cylinder in an infinite medium that offers a “resistance arising from the want of lubricity.” At the conclusion of his discussion of this theorem he makes the statement: “All these things will be found true by making the experiment in deep standing water.”

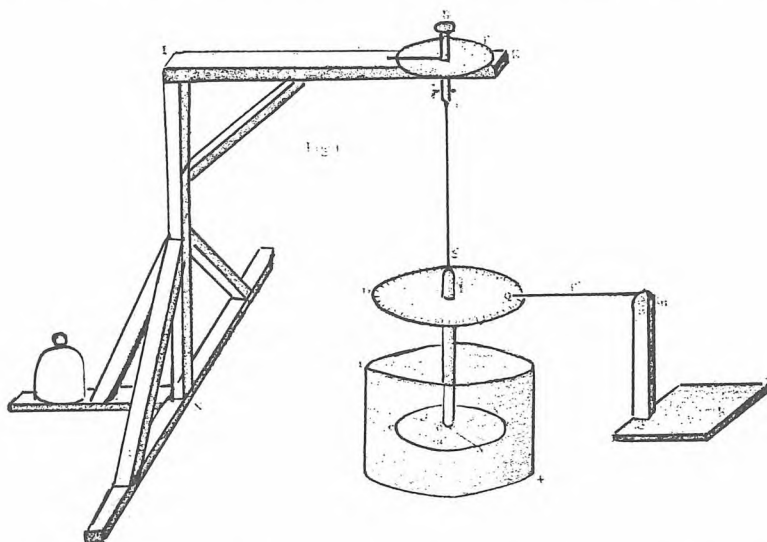
Some take this to mean that Newton had performed such experiments. But I doubt it. For one thing, Newton deduces that the angular velocity is inversely proportional to the distance from the axis of rotation—or that the linear velocity is independent of that distance. As George Gabriel Stokes was to point out, in 1845—more than a century and a half later—this answer is incorrect owing to an error in Newton’s derivation.

Indeed Newton himself did not take his hypothesis seriously: “And though, for the sake of demonstration, I proposed, at the beginning of this Section, an Hypothesis that the resistance is proportional to the velocity, nevertheless, it is in truth probable that the resistance is in a less ratio than that of the velocity.” It remains a puzzle to me why Newton invited the experiments in deep standing water.

However, even the idea that deviations from perfect-fluid behaviour are due to a property of the bulk fluid was an advance. For example 50 years after Newton, Daniel Bernoulli attributed such deviations to “adhesion of water to the sides of the tube, which adhesion can certainly exert an incredible effect in cases of this kind.”

Newton’s hypothesis was apparently ignored by contemporaries and successors for more than a century. The theoretical hydrodynamic investigations of this time continued to deal mainly with perfect fluids while experimental work concentrated on the flow of liquids through pipes and open channels where inertial effects dominated. For example shortly after the French Revolution in 1801 when Charles Augustine de Coulomb published his paper on the resistance of fluids in very slow motion, he refers to Newton’s experimental results and accompanying theory but not to the “want of lubricity”

hypothesis. Coulomb here introduced the widely used freely oscillating torsion pendulum shown in figure 2. (He had described experiments on the torsional oscillation of a wire in 1784, 17 years earlier.) Moreover in this paper he tried to resolve the question of the boundary condition at the surface, where the fluid is in contact with a solid.



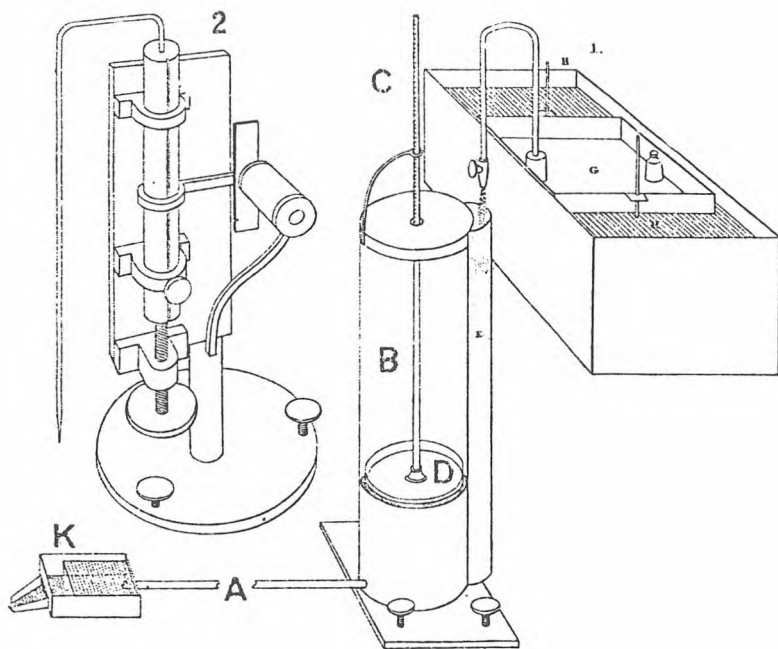
COULOMB'S APPARATUS to study the resistance of fluids in very slow motion. He measured the amplitude of a freely oscillating torsion pendulum: The disc is suspended from a torsion wire and submerged in a large cylinder of fluid. —FIG. 2

He noted that the addition of neither tallow nor sandstone affected the motion of the pendulum and concluded that the fluid moves with the solid surface.

Linear viscous fluid

The advance from the experimental side towards a basic law of viscous flow came from the study of flow through narrow tubes. The empirical determination of the law of slow flow through tubes was established about 1840 by the researches of G. H. L. Hagen and Jean Louis Poiseuille. Hagen's experiments led him to the conclusion that the rate of flow was proportional to the pressure gradient and to the fourth power of the radius (figure 3).

Poiseuille had been working simultaneously in France; his reports appeared between 1840 and 1846. He undertook this investigation because he was interested in the flow of blood in the body and had already published a prize-winning paper on that subject in 1835. His experiments on flow through small-diameter tubes were classical not



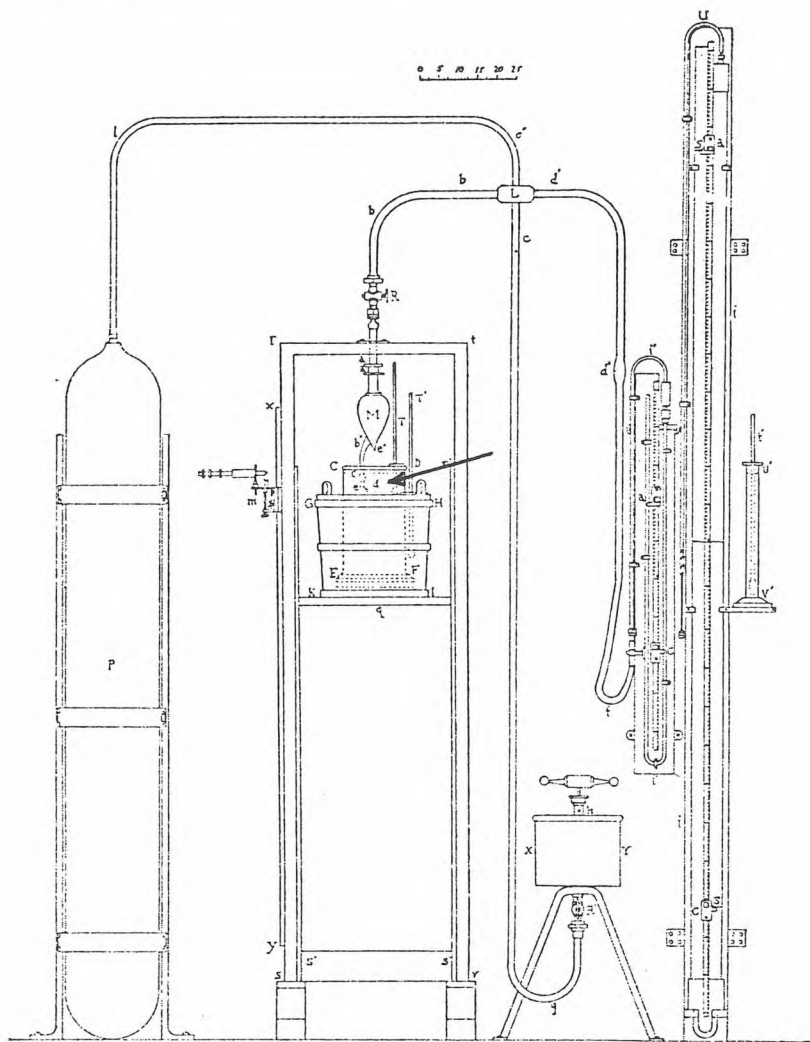
FLOW THROUGH NARROW TUBES. To study viscous flow Hagen caught and weighed the efflux from tube A. He determined the driving head from the difference between the height of fluid in efflux vessel K (measured with scale and pointer 2) and in cylinder B (indicated on scale C fixed to float D). —FIG. 3

only in their conception and execution but also in their reporting (figure 4). Poiseuille was able to achieve amazing precision—usually better than 0.1% and not infrequently greater than 0.01%.

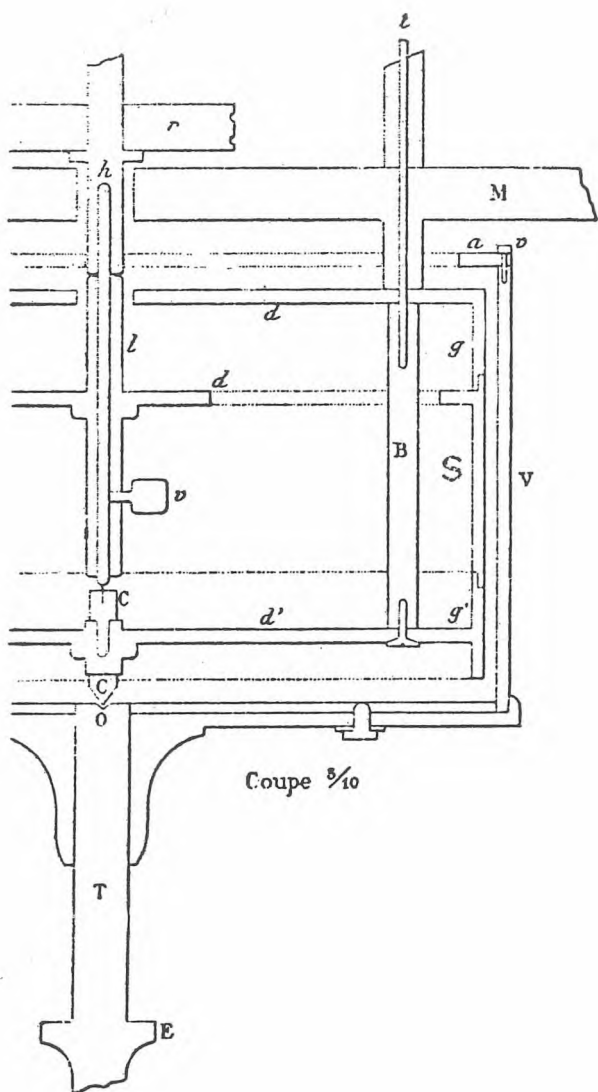
We note that the experiments of Hagen and Poiseuille were not performed to study Newton's, or any other, law. They were empirical investigations in narrow tubes.

The general theory for linear viscous flow owes its development to a number of investigators: Augustin Louis de Cauchy (1823), Simeon Denis Poisson (1831), L. M. H. Navier (1821), and Jean-Claude B. de St Venant (1843). The theory of Stokes (1845), which is quite modern in its approach, is based on the principle: "The difference between the pressure on a plane in a given direction passing through any point *P* of a fluid in motion and the pressure which would exist in all direction about *P* if the fluid in its neighbourhood were in a state of relative equilibrium depends only on the relative motion of the fluid immediately about *P*; and that the relative motion due to any motion of rotation may be eliminated without affecting the differences

of the pressures above mentioned." From this assumption, after a linearisation on the basis of a molecular argument, Stokes derived the Navier-Stokes equation. He then solved for the velocity distribution for flow between rotating coaxial cylinders and for flow through a cylindrical tube. He also derived the expression of the



PRECISE MEASUREMENTS on viscous flow were carried out (simultaneously with Hagen) by Poiseuille with apparatus that included an extensive pressure control and measuring system. Viscometer is at d (arrow). —FIG. 4



COAXIAL CYLINDER VISCOMETER. In studying flow between rotating coaxial cylinders, Couette avoided the end-effect difficulty with guard rings. The outer cylinder is driven at a fixed angular speed, and the torque is measured only in the central portion S of the inner cylinder by the twist of the torsion wire to which it was attached. —FIG. 5

discharge from the tube, but he did not record it: "But having . . . compared the resulting formulae with some of the experiment of Bossut and Dubuat, I found that the formula did not at all agree with experiment." Apparently in 1845 Stokes was not aware of the experimental results already published by Hagen and Poiseuille.

The first publication of the discharge equation for the rate of flow through a small tube was postponed another decade, when in 1856 G. Wiedemann published Edward Hagenbach's derivation. This derivation permitted the interpretation that Poiseuille's experiments verified a prediction drawn from the Navier-Stokes theory.

The acceptability of that theory was furthered by studies of flow between rotating coaxial cylinders. Stokes in 1845 had derived the velocity distribution and had suggested that experimental verification "would probably be best done by observing motes in the fluid." In 1881 Max Margules calculated the torque required to turn a cylinder at a given rate and concluded that for water, the torque would be very small. The first account of an experimental investigation was published in 1888 in England by A. Mallock. After making a correction for end effects he verified the viscosity values calculated from Poiseuille's experiments. M. Couette reported the results of his very painstaking experimentation in which he avoided the end-effect difficulty with the elegant guard-ring construction (figure 5). He compared these coaxial-cylinder results with those he obtained in tube flow and found good agreement.

Constant controversy

L. Euler, in 1727, was the first to introduce a property characterizing a material undergoing deformation when he defined the elastic constant,—now known as Young's modulus. In the succeeding decades the full three-dimensional theory for elasticity was produced by the same architects who developed hydrodynamics. On the basis of a molecular hypothesis, Navier (1827) arrived at a theory that involved only one elastic constant. Cauchy (1823), George Green (1839), Stokes (1845) and Gabriel Lamé (1852), using phenomenological approaches, produced theories that indicated the need for two constants. The controversy between the uniconstant and biconstant theories raged for some decades. Decision by experiment was not easily attained. Most elastic experiments were done on wires and these materials were known to be anisotropic. Furthermore the uniconstant Poisson-Navier theory corresponded to the biconstant theory with a Poisson ratio of 0.25, which is close to the value for many metals. Proponents of the biconstant theory offered evidence based on the properties of rubber and gels, but the uniconstant group rejected it because these materials were not accepted as isotropic. James Clerk Maxwell summarised the situation in 1853: "There are few parts of mechanics in which theory has differed more from experiment than in the theory of elastic solids." The final resolution of this controversy came as the result of the careful experiments of men such as G. Wertheim (1848), A. Kupffer (1853) and W. Voigt (1887). Thus, like

the theory of viscous fluids, the applicability of the biconstant theory for isotropic elastic solids was not generally accepted until almost the end of the 19th century.

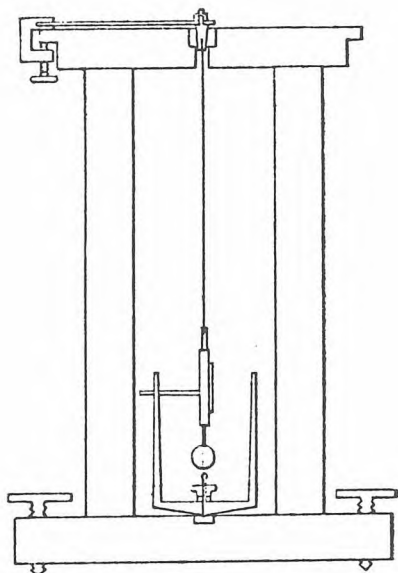
An experiment was described in 1808 that forms an important cornerstone of our understanding of rubber elasticity. The entropic nature is shown when suddenly a rubber band is stretched and the rise of temperature is observed by contact with the lip. The early revelation of this phenomenon can, I believe, be attributed to the blindness of its discoverer, John Gough. Despite the fact that he had been blinded by smallpox at age three, he decided on a scientific career. He developed his sense of touch to the point where he was able to identify plants by feeling them. I think that because he made full use of all his remaining faculties, he discovered that heat was liberated when rubber was stretched. Incidentally, his explanation of the phenomenon was that it "depends upon the mutual attraction of Caloric and Cautchouc, the former of which penetrates the latter, and pervades every part of it with the greatest ease and expedition." This explanation and experiment were not bettered for a half century when James P. Joule performed some quantitative experiments and Kelvin provided an explanation in terms of thermodynamics.

Linear viscoelasticity

Very early investigators reported time-dependent phenomena that could not be explained by either of the classical models, the Hookean solid or Newtonian fluid. The first serious study of this phenomenon was that of Wilhelm Weber in 1835 on silk threads. This fibre interested him since it was frequently used in electrical and magnetic instruments because of its small torsional rigidity. Employing an ingenious experimental technique suggested by Karl F. Gauss, Weber found that raw silk was not perfectly elastic. A longitudinal load produced an immediate extension that was followed by a further lengthening with time. On removal of the load, an immediate contraction equal to the initial immediate extension took place. This was followed by a gradual further decrease of length until the original length was reached. Thus Weber knew that he was not dealing with a permanent set. He summarises with the statement: "There is an extension which can be calculated by the law of proportionality from the modulus of elasticity, and in addition a further extension which takes place over a long period of time. This further extension is not defined in the law of elasticity and is to be regarded as an action or function of the *duration* of the loading." The author has denoted this extension by the term "Nachwirkung" (aftereffect). Furthermore, he deduced that the corresponding phenomenon of stress relaxation should exist and that the same phenomenon is responsible for the damping of vibrations in materials and for determining which materials produce sounds on being struck. There is no doubt that, qualitatively at least, Weber had captured the essence of viscoelasticity before Poiseuille had reported his results on flow through tubes and a

decade before Stokes wrote down his version of the laws of viscous fluids and elastic solids.

In 1847 during an investigation of the capabilities of an electrometer for quantitative measurements of charge, R. Kohlrausch investigated problems that arose from the aftereffect in the silk-fibre torsion element. Following his death these investigations were greatly extended by his son, Friedrich Kohlrausch, in Weber's laboratory in Göttingen (figure 6). In 1863 he established the linearity of the phenomenon.



DECAY OF TORQUE. F. Kohlrausch held a silk fiber in torsion for a fixed time, and observed its angular motion when it was released. —FIG. 6

The experiments of Weber and the two Kohlrausches led Ludwig Boltzmann in 1874 to present his principle of superposition. He arrived at his integral representation of linear viscoelasticity in its full three-dimensional generality and discussed a number of problems. The more limited representations (for example the differential operators, relaxation spectra, spring-dashpot combinations) were not introduced until after Boltzmann formulated his more encompassing approach.

The younger Kohlrausch immediately put Boltzmann's theory to the test by a number of superposition experiments on glass and

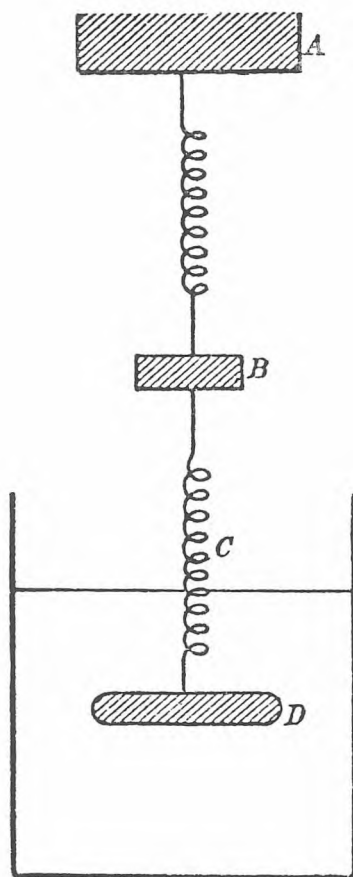
rubber. In perhaps the most dramatic of these he obtained reversals (sometimes a double reversal) of torsion direction in a rubber thread with a certain torque history. He measured the torque-history creep and recovery data for rubber, some of them over a 24-hour period. Thus he covered almost four decades of the time scale, a range rarely exceeded even today. He also demonstrated the large effect of temperature on creep.

Maxwell's influence

During these developments in Germany, an influential contribution to rheology came from a surprising direction. Maxwell in a paper "On the Dynamical Theory of Gases" (1867), an empirical explanation for the existence of shear stresses in flowing gases, introduced his famous first-order differential equation relating stress and deformation and the accompanying exponential stress relaxation. He furthermore proposed that this equation represents the phenomenon of viscosity in all bodies "independent of hypothesis". The simple exponential decay of stress does not explain the broad time scale frequently found in actual experiments. Maxwell knew about this from the work of Weber on silk fibres, Kohlrausch on glass and his own work on steel wires. He suggested that an explanation of these results could be found in the relaxation time was a function of the stress. However, he abandoned this explanation as soon as he heard of Boltzmann's work. In his 1878 article on the "Constitution of Bodies" he quoted Boltzmann's integral representation and ignored his own. Perhaps because the article was published in the famous 9th edition of the *Encyclopedia Britannica*, Maxwell's first-order differential equation continued to exert a much greater influence on the future development of rheology than did Boltzmann's more encompassing theory.

The gap between the approaches of Maxwell and Boltzmann was partially spanned in 1888 by E. Wiechert and by Joseph J. Thomson who independently introduced the concept of the distribution of relaxation times. The most commonly used representation of viscoelastic behaviour did not make its appearance until the turn of the century; in 1903 John H. Poynting and Thomson introduced the "spring-and-damper" analogy to illustrate the elastic aftereffect (figure 7).

Maxwell's differential equation inspired Theodore Schwedoff, a professor and rector of the University of Odessa, to seek direct evidence for elasticity in fluids. In 1889 he performed stress-relaxation experiments on gelatin solutions with a coaxial-cylinder instrument and found that the stress did not relax to zero in this material; it was a gel and not really a fluid. Thus its behaviour could not be represented by Maxwell's equation. He was able to fit his data with a modified equation in which he assumed the existence of a yield value. On the basis of this equation, in the following year he published his conclusion that in steady-state flow, the viscosity depends on the rate of the deformation. He had in fact, arrived at the equation



SPRING AND DAMPER of Thomson and Poynting. This model demonstrates the elastic aftereffect and damping of oscillations in metals. —FIG. 7

for plastic flow—an equation more usually associated with Bingham. For his experimental work, he constructed a copy of Couette's viscometer that had just been described (1888), and he obtained data that confirmed his theory. Despite the fact that he reported this work at the 1900 International Congress on Physics in Paris and a summary appeared in *Physikalische Zeitschrift*, it apparently remained unnoticed for several decades.

In his writings on states of matter, Maxwell drew a careful distinction between solids and fluids and, in many of his publications, pointed out that materials such as pitch are fluids: "If, therefore, we define a fluid as a substance which cannot remain *in permanent equilibrium* under a stress not equal in all directions, we must call these substance (cold pitch and asphalt) fluids, though they are so viscous that we can walk on them without leaving any footprints. What is required to alter the form of a soft solid is a sufficient force, and this, when applied, produces its effect at once. In the case of a viscous fluid it is *time* which is required, and if enough time is given the very smallest force will produce a sensible effect".

Remarks such as these apparently were the inspiration for a number of experimenters. Around the turn of the century they undertook the study of very viscous fluids that could readily be mistaken for elastic, even brittle solids. Carl Barus of the U.S. Geological Survey Physics Laboratory, A. Pochettino in Italy and Wilhelm C. Röntgen, Rudolf Reiger and others in Germany studied similar materials.

Experimental advances

The most remarkable study of such materials was done in England. F. T. Trouton and E. S. Andrews in 1905 reported on their studies on hot glass, pitch and shoemaker's wax. In their apparatus they mounted a cylindrical sample of the material and performed torsional experiments. On applying a load they were surprised to note first that the coefficient of viscosity of bodies such as pitch is a function of the time and "second, that on removing the stress there is a flow back in the opposite direction". Thus, for the first time, we have a creep and recovery experiment on a fluid. They noted further that when they plotted the applied torque against the steady-state angular velocity they did not obtain a straight line through the origin; this was the first evidence of a shear-dependent viscosity in a fluid. Then they proceeded to perform a stress-relaxation experiment by removing weights to keep the angular deformation constant. Even now few rheological investigations are that thorough.

In this same year (1905) Poynting presented an extension of his work on pressure of electromagnetic waves by applying it to the calculation of the pressure of elastic waves in a solid. For this application he had to introduce terms in the square of the strain. This conclusion led him, in 1909, to perform careful experiments in which he determined the lengthening of a steel wire when it is twisted. He found that loaded wires increased in length by a small amount that was proportional to the square of the twist. In a still more elegant experiment, three years later, he actually measured the change in volume during a torsion experiment; for steel wires there was a contraction that was proportional to the square of the angle of twist. These experiments in nonlinear elasticity have not been improved as far as I know.

Shear dependence

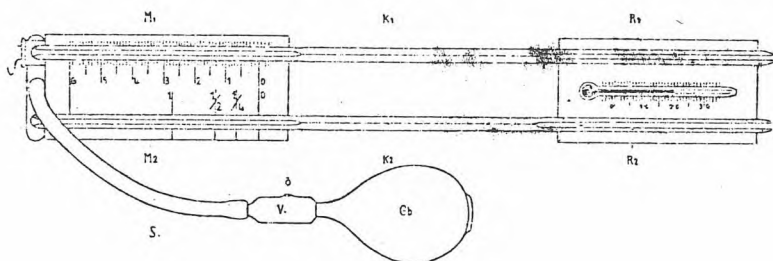
The phenomenon of a shear-dependent, steady-flow viscosity was discovered independently by several researchers with quite different motivations.

About 1900, at the University of Heidelberg, experiments were being performed that, although of limited value, apparently did have considerable influence. To test his "foam-cell" theory of colloids, G. Quincke experimented on the decay of oscillations of a disc in various colloidal suspensions. In their doctoral researches in this laboratory, Henry Garrett, with solutions of gelatin, silicic acid and albumin, and A. du Pré Denning with colloidal iron hydrate, found that the logarithmic decrement depended on, among other things, the amplitude of the oscillation. Although these were quite complex experiments, both in the nature of the material and the type of measurement, these results were interpreted by others as indicating non-linearities in steady-flow behaviour and apparently led them to study simpler flows.

Denning returned to England and there he performed experiments on the flow of blood through tubes. From the effect of the bore size he and John H. Watson concluded that blood containing a large number of corpuscles does not obey Poiseuille's law if the tube diameter is less than 3 mm; that is, the viscosity is apparently a function of the radius for smaller capillaries. Furthermore it also depends on the driving pressure for these small tubes.

In the second decade of the twentieth century there were already a number of laboratories investigating deviations from Navier-Stokes behaviour in steady-flow situations.

The physiologist Walter R. Hess, first at Rapperswill and continuing at Zürich, studied the flow of blood and gelatin solutions in tubes. He noted (1910, 1912) that the measured viscosity depended on the apparatus and convinced himself that he was not dealing with turbulence. He concluded that Poiseuille's law was not valid for these



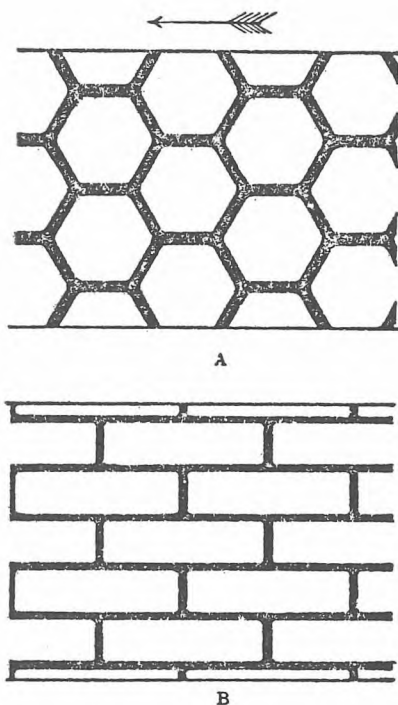
VARIATION OF APPARENT VISCOSITY with the nature of test apparatus was discovered by Hess with this viscometer. The same suction pressure could be applied simultaneously to a test fluid and a standard fluid in the two separate tubes. Driving pressure could be varied by changing applied suction. —FIG. 8

materials in laminar flow. Furthermore he showed that, contrary to the contention of Denning and Watson, it was not simply the diameter of the tube that was the cause of the deviation. Hess apparently made his discovery because he was using a viscometer that he had designed much earlier for other considerations (figure 8). In this apparatus the same pressure could be applied simultaneously to force fluids through two parallel tubes. He attributed the failure of Poiseuille's law to the existence of *cohesive forces*, which should lead to elastic behaviour. He demonstrated the latter (in 1915) by performing free-oscillation experiments in a Couette configuration. In his work on gelatin solutions he was careful to note that, not only were they not gels, but also that they did not solidify even on standing. Thus this appears to be the first demonstration of memory effects in fluids of ordinary viscosity. Apparently because Hess published in medical journals, for a few years his discovery lay unnoticed by another group who were about to be involved in this problem.

Rate of shear

Colloid chemists had been using viscometers ever since the father of that field, Thomas Graham, had pointed out in 1864 that "The flow of liquid colloids through a capillary tube is always slow compared with the flow of crystalloid solution, so that a liquid-transpiration tube may be employed as a colloidoscope".

On 12 March, 1913, the Faraday Society conducted a General Discussion on colloids and their viscosity. Wolfgang Ostwald, in his opening statement, listed ten factors that could influence the viscosity of colloidal systems. Rate of shear was not one of them. Famous colloid chemists such as Herbert Freundlich and Emil Hatschek spoke, but no mention of either Schwedoff or Hess is recorded. Hatschek mentioned Garrett's dissertation in the discussion of his theory of emulsions. He pictured a dispersed phase, represented as polyhedra, separated by a film of continuous phase (figure 9). On shearing, these polyhedra are distorted. Hatschek then concluded that for every system there must exist a critical value of the rate of shear at which a significant change in the system's viscosity begins. He stated, without giving data, that gum arabic and gelatin sols possess different viscosities at different rates of shear. Only two months after the Faraday Society discussion, Hatschek reported his first experimental results, obtained with a Couette viscometer at the Sir John Cass Institute in London. Unlike Hess and many later workers, but like Schwedoff, Hatschek thought that he was dealing with a viscosity that was a function of the *rate of shear*. He is probably entitled to credit for an independent discovery. Despite this work, there were still many papers to come where analogous data were viewed simply as deviations from Poiseuille's law rather than as reflecting nonlinear relation between shear stress and rate of shear.



SHEARING PHENOMENA. Hatscheck pictured the continuous phase of emulsions as polyhedric films A that on shearing would assume an altered shape B. He concluded that below a critical value the viscosity would depend on the rate of shear. —FIG. 9

One-dimensional approach

In the 1920's a number of laboratories were engaged in work related to studies of deviations from Poiseuille's law. Among the most active were those of Freundlich at the Kaiser-Wilhelm Institute for Physical Chemistry and Electrochemistry in Berlin, Ostwald at Leipzig and H. R. Kruyt in Holland. A number of capillary instruments were developed, particularly in Ostwald's laboratory, to cover a wide range of shear rate, and a great number of materials were investigated.

The method of handling these steady-flow data developed by stages. A one-dimensional approach was adequate to describe the results of the experiments: It was assumed that the shear stress was not simply proportional to the rate of shearing but rather a more

complicated function. This approach allowed the data to be processed without touching on the basic problem, which was the failure of the Navier-Stokes equation to describe the flow behaviour of these materials. Therefore the consequent three-dimensional stress-deformation relation was not sought. At first various functional forms were assumed for the one-dimensional relation and then expressions were obtained for measured quantities in steady-flow experiments in terms of the parameters in these functional forms. For the plastic material, E. Buckingham (1921) derived the equations for flow through tubes while Markus Reiner and Rassa Rivlin obtained the corresponding expression for Couette flow in 1927. For the power-law relation between shear stress and rate of shearing, H. L. Dryden (1926) exhibited the first deviation for capillary flow and F. O. Farrow, G. M. Lowe and S. M. Neale (1928) for Couette flow. The treatment of tube-flow data reached its culmination with the derivation by K. Weissenberg of an expression that made it possible to deduce the shear-stress-rate-of-shear relation from the experimental data without a priori assuming any functional form.

The above-mentioned paper by Farrow, Lowe and Neale is also noteworthy because they reported measurements made on their materials (a number of starch pastes) in Poiseuille flow with five different capillary tubes as well as in Couette flow and showed that the results were concordant. Thus they established that a shear-dependent viscosity is a useful concept. They also pointed out that, when they plotted their data linearly, the Couette data could hardly be seen since they were so close to the origin. In order to give them their due weight, they plotted the data logarithmically and thus set the mode widely followed thereafter.

This presentation lays no claim to being scholarly. My intention is to remind us of the debt we owe to some of our scientific progenitors. While some of our creditors are well known, their fame frequently rests on their contributions to other fields rather than on those to rheology. On the other hand, important innovations were made by men whose names are no longer mentioned. The development of rheology has not followed a monotonic, single-valued path in time—nor the road we would think most logical.

* * *

I would like to express my appreciation to the Mellon Institute and the National Science Foundation for their support of the research that the Bingham Award recognised.

Herschel Markovitz is professor of mechanics and polymer science at Carnegie-Mellon University. As a senior fellow at Mellon Institute, he has helped to make it a leading centre of rheological research. His experimental work on viscoelastic properties tests many of the theoretical concepts of nonlinear continuum mechanics. This article, an adaptation of the acceptance speech given by Markovitz when he received the Bingham Medal for 1967, is reprinted from *Physics Today*, April 1968, by kind permission of author and publisher.

COMPUTER PROGRAMME CATALOGUE

The use of digital computers in performing routine tasks in rheology is now of common occurrence and there must be relatively few members of the British Society of Rheology who are without access to a machine with coded computing facility. Equally, there must be few members who are not faced either with the need to process experimental data or generate theoretical numerical data, and in both these classes of operation a suitable efficient machine programme is a valuable aid to research productivity.

The production of a fault-free machine programme can be fairly expensive in terms of time and money, depending upon the fluency of the writer, and few programmes would cost less than £5 if costed on a realistic basis, whilst a high efficiency complex programme might cost £50 to £10,000 at least.

During the past five years or so there has been a relatively large increase in scale of research effort in the field of rheology and a by-product of this has been the generation of computer programmes which are unknown outside the establishment where they were written. These programmes represent a valuable scientific resource and it would be much to the advantage of members if a catalogue of such programmes was compiled.

It is proposed to allocate a special section in future editions of the Bulletin in which programme abstracts can be published and which will ultimately be the source of material for a programme catalogue. A separate tear-out page is available in this edition of the Bulletin for the notification of programmes and members of the Society are urged to send in a notice of the machine programmes which they now have. Additional copies of the abstract form are freely available.

The use of a computer programme by others for published work could reasonably be expected to be accompanied by an acknowledgment of the programme source if it was not of the same as the written work. Also the cost of reproduction, handling and postage at least could be expected to be recovered by organisations supplying programme copies; but this would often be a favourable investment on the part of the purchaser.

BRITISH SOCIETY OF RHEOLOGY

Computer Programme Catalogue

Publication Abstract

1. Author
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2. Establishment
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3. Programme Abstract
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4. Programme date
.....
5. Language
.....
6. Computer and store requirements
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7. Type of Input/Output
.....
8. References
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.....
9. Related programmes
.....
.....
10. Available for copy/data processing
.....
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Return to: Dr. J. Harris,
Postgraduate School of Chemical
Engineering,
University of Bradford,
Bradford 7, U.K.

Additional blank abstract sheets are available as required from the above address.

LETTER TO THE EDITOR

September 3, 1968.

Dear Sir,

The swelling of an extrudate is often referred to in the literature of rheology as the Barus effect, and where it is so called, the authors cite a paper by C. Barus in the American Journal of Science, Third Series, 45, No. 226, February 1893.

Friends at Cabot Corporation, Boston, have been kind enough to obtain a copy of this paper, and I have studied this interesting piece of rheological research for an explanation by Barus of the Barus effect. Unfortunately, the effect we know by this name is *not* the one described by the gentleman in question, although probably very closely associated with it. The phenomenon described is one which occurs when an extrudate of circular cross section is cut along a plane normal to its axis. The section gradually changes shape, until it becomes a surface which Barus described as conoid.

The correct name for the swelling effect on emergence should be called the Merrington effect, as noted by Truesdell on p. 458 of Vol. III of the Encyclopedia of Physics.

It is of interest to add that the experimental work appears to have been carried out in connection with the design of a manometer for the measurement of extremely high pressures, possibly for use in geological work.

Z. RIGBI, Assoc. Professor
Head, Department of Mechanics,
Technion—Israel Institute of Technology,
Haifa.

PROJECT REPORTS

The bulk of the work in the published scientific literature is concerned with reporting investigations which have been drawn to a more or less definite conclusion, even on the date of publication the work reported is history and allowing for writing-up time, refereeing and printing, the time-lapse between termination of a project and publication of results may typically be of the order of eighteen months. (Authors submitting work to the Bulletin can, however, expect a significantly reduced lapse.)

Most people with an interest in rheology are as keen to learn not only what *has* been done but also about work currently *in progress*. This is helpful in forward planning of research and also in knowing where to seek discussion and information.

It is intended to set aside space in future editions of the Bulletin in which summaries of *current* projects can be published without authors feeling that any special commitment arises out of the publication. It

is fully understood that the emphasis, or indeed the general theme, of a project may not remain constant and revised summaries could be published as the occasion arises.

A brief summary of about 100 words describing the project should be sufficient to acquaint readers with the salient features and overall give an indication of work presently in progress in the field of rheology.

PERSONAL NOTES

Dr. Leander Grunberg is the new President of the Society. He joined the Society in 1950 and was a member of the Society's Committee which organised the highly successful Second International Congress at Oxford in 1954. His interest and active involvement in rheology started in 1943 and continues to the present day. He leads a team of some 100 scientists and engineers in Fluids Group, National Engineering Laboratory, which contains a strong rheology section and contributes much to rheological research and to the activities of the Society. It publishes the biennial Survey of Rheological Research in Britain.

GRUNBERG, LEANDER, Superintendent, Fluids Group, National Engineering Laboratory, East Kilbridge, Glasgow. M.Pharm., 1933, (Prague); B.Sc., 1942 (Oil Engng) (Birm.); M.Sc., 1946 (Oil Engng) (Birm.); D.Sc., 1957 (Chem. Engng) (Birm.); F.R.I.C.; F.I.Mech.E.; M.I.Chem.E.; F.Inst.Pet., Faraday Society. Dr. Rosin Industrial Research Company (1942-1951). Lubrication Division, NEL, (1951-1961), P.S.O. (1951), Special Merit S.P.S.O. (1958), Head of Division (1959), Superintendent, Fluids Group, NEL, since 1961. Some forty-five scientific papers in Proc.Roy.Soc., Trans.Far.Soc., J.Inst.Pet., Phil.Mag., Proc.Phys.Soc., Brit.J.Appl.Phys. etc. dealing with viscometry, viscosity temperature relationships, viscosity and molecular structure, electron emission from deformed metal surfaces, boundary lubrication, pitting failure of rolling bearings, radioactive techniques for wear measurement, surface chemistry, etc. Non-scientific interests: bridge, motoring, serious music. His wide scientific interests and experience and his recognised organising ability will be of great assistance to the Society during the next two years.

CONFERENCE ON "RHEOLOGICAL EFFECTS IN MATERIALS UNDER ALTERNATING STRESS"

held at the Royal Military College of Science, Shrivenham
9th-12th September, 1968

This meeting of the Society attracted a registration of 90 participants, of whom 14 were from overseas. This substantial support given to meetings by members and friends from overseas continues to be a source of gratification to the Society. On this occasion, the pleasure was heightened by the fact that among them was Mr. K. R. Hall of C.S.I.R.O., Melbourne, who, at the Annual General Meeting held during the Conference, brought us the fraternal (or is it filial?) greetings from the members of our Australian branches; Mr. Hall carries with him our reciprocal greetings and good wishes when he returns to Australia.

From a technical point of view, the conference stands out as one in which the presentation, content and time keeping of individual papers was universally excellent. Professor A. Charlesby took the chair for the first session on Monday morning, and had the distressing task of announcing that the first paper, by Mr. K. Bogie on the "Dynamic Response of greases" could not be given because the author was in hospital, suffering, so we understood, from ulcers. We hope that he will have fully recovered long before this "Bulletin" appears in print. The first offering, then, was given by Mr. R. Zangger, of Contraves AG, Zurich, who described and demonstrated a rheometer invented by Dr. A. Kepes, of the Société Éthylène Plastique. One shortcoming of most rheometers which subject the sample to sinusoidal strain is that the motion derives originally from some reciprocating device, which can suffer from backlash. The Kepes design avoids this by shearing the sample between two spherical surfaces, whose axes of rotation are inclined to each other and which are both driven in continuous rotation. The instrument is intended for use with polymer melts. This paper was followed by "Analysis of the linear viscoelastic relaxation of a liquid hydrocarbon" by J. F. Hutton and M. C. Phillips, which was read by the latter author. He described measurements made on 2,2,4,4,6,8,8-heptamethylnonane at frequencies of 6, 18, 30 and 78 MHz, over a temperature range of from 200 to 150 deg K, using a new version of the Mason-McSkimin apparatus. The results show that the principle of time-temperature superposition is valid at these temperatures and that the data fit the Barlow, Erginsav and Lamb (B.E.L.) model of viscoelastic relaxation. The third paper of this session, "Dynamic viscoelasticity of polymer melts" by J. C. Weeks and S. Raha, was presented by Mr. Weeks, who gave results of dynamic parameters for polyethylene melts at temperatures of up to 350 deg. C and over a frequency range of 10^{-2} to 10^3 Hz.

Mr. J. F. Hutton took the chair for the second session of the morning. Dr. G. Harrison presented a paper by himself and Prof. J. Lamb on "Viscoelastic relaxation in supercooled liquids and polymer melts". In this, a new model is proposed from which the viscoelastic relaxa-

tion of supercooled liquids in alternating shear can be predicted. From this model an equation is derived relating complex compliance to limiting shear compliance, frequency and relaxation time, and this is confirmed by experimental results obtained for a number of widely different liquids. Incorporation of a single additional parameter into the equation enables it to be used for binary mixtures of pure supercooled liquids. This paper was followed by "Flow behaviour of elastic liquids under a varying pressure gradient" by H. A. Barnes, P. Townsend and K. Walters. The chairman remarked that this paper was a preview of work to be given to the International Congress at Kyoto, by Dr. Walters, and he didn't know if we would hear it today in Welsh or Japanese. One member of the conference was heard to comment sotto voce—"If it's one of his theoretical papers, then it doesn't much matter what language it's in". Be that as it may, the mathematicians among us were guided steadily through a sea of tensors, partial differentials and Bessel functions to the final equations. From these, Dr. Walters drew the appropriate conclusions and made the relevant predictions; these were explained tersely but clearly to the non-mathematicians, and were compared with the results of experiments which showed to what extent these conclusions and predictions were borne out. This taking the "meat" out of a highly theoretical paper and putting in a way which can be understood by those whose interests are almost wholly practical is much appreciated by the latter.

Fortified by an excellent lunch, the conference resumed with Professor Raffle in the chair. The keynote of the afternoon's session was the behaviour of solids under alternating stress. Firstly, Dr. C. J. Beevers spoke on the "Role of twinning in the fatigue behaviour of α -titanium", and described from the microscopic point of view the fatigue mechanism operating in samples of this material subjected to tension/compression cycles about zero mean load at a frequency of about 100 c/s. This was followed by a paper by Dr. N. J. I. Adams on "Fatigue crack growth studies on constant compliance specimens". Fatigue crack growth in metallic materials due to cyclic stress reversal is normally studied using wide test plates and high load testing machines. The constant compliance specimen is small, and compact, and can be tested on a low load machine. Additionally, the stress intensity remains constant for crack growth, from approximately one quarter to one half the specimen width. Results are given for mild steel, brass, aluminium and 18 per cent. nickel maraging steel.

From metals we moved to plastic clay, and in the unavoidable absence of Dr. N. Astbury, Mr. F. Moore read the former's paper on "Torsional hysteresis of plastic clay" in which hysteresis loops obtained when plastic clay and ceramic bodies are subjected to alternating torsional stress are accounted for in terms of viscosity and elasticity parameters. Finally, Mr. E. A. Vaughn read a paper by himself and J. W. S. Hearle on "Fatigue testing of textile fibres" in which results of cumulative extension cycling and tension/compression by means of biaxial rotation were given for a variety of fibres.

Numerical data were coupled with scanning electron micrographs of specimens ruptured in both types of test.

Dinner, a violent thunderstorm and a vociferous Annual General Meeting at which the new President, Dr. L. Grunberg, was introduced to office by the retiring President, Prof. A. Charlesby, concluded the day.

With the new President in the chair, the Wednesday morning session opened with a paper by Mr. M. Bily and Dr. T. R. G. Williams on "Plastic yielding and the discontinuities in the S/N fatigue curve of mild steel". This was followed by a paper by Dr. A. Payne entitled "Dynamic properties of filler loaded polymers". The author explained the behaviour of three dimensional carbon black networks in rubber from model experiments on carbon black oil materials and model vulcanisates containing phenyl- β -naphtalamine crystals. Results suggest that hysteresis phenomena in reinforced rubber result from the cyclic breakdown and re-formation of the three dimensional aggregate structure of the filler. The morning session concluded with a symposium on "Information retrieval with the help of computers"; this will be reported more fully elsewhere in this Bulletin.

In the afternoon, some of the members of the conference took advantage of a coach tour of ancient ecclesiastical monuments such as Avebury and Stonehenge, and the day's proceedings terminated with a successful and most enjoyable Conference Dinner. The gastronomic reputation of Shrivenham must by this time be well known to readers. Suffice it to say that this conference served to reinforce that reputation. It is a genuine pleasure to be fed at a table where the philosophy of providing sound English cooking is still strictly adhered to, instead of taking one's input of carbohydrates and protein in those commercial enterprises presided over by a Cordon Bleu tin opener, as some of us have to.

The first lecture on Thursday morning could well have been one on "Pianoforte transfer functions" but was, in fact, on "Behaviour of non-Newtonian under combined simple and oscillatory shear" by T. E. R. Jones and K. Walters; Dr. R. Roscoe was in the chair. Using general equations of state, Dr. Walters analysed the behaviour of non-Newtonian liquids when sheared in this manner and compared the theoretical predictions when the steady part of the motion is "sufficiently slow" with experimental results obtained on a rheogoniometer. The influence of harmonics on rheogoniometer oscillatory work was also described. This paper was followed by "Relations between dynamic and steady shearing experiments" by J. L. den Otter and J. L. S. Wales, which was read by the latter. Using a concentric cylinder viscometer, the dynamic loss and shear moduli were measured for several polymer melts, while the shear stress was measured in steady flow. From flow birefringence measurements estimates of $p_{11} - p_{22}$ and $p_{11} - p_{33}$ were obtained. Using these results the authors commented on the validity of certain well known

expressions which relate the dynamic parameters with the corresponding steady state ones.

The next paper by Ir. R. Jongepier dealt with "The dynamic shear modulus of bitumens as a function of frequency and temperature". Measurements were made (on bitumens) of shear rate independent viscosity and complex shear moduli at frequencies between 50 and 0.005 c/s, at various temperatures. The results could be plotted as master curves of reduced modulus versus frequency; these curves corresponded fairly well with Gaussian distributions of log (relaxation time). Finally, we had a paper by Z. H. Stachurski and I. Ward on "Viscoelastic relaxations and mechanical anisotropy", given by Mr. Stachurski. Specially oriented sheets of high and low density polyethylene were "sampled" in various directions, and anisotropy investigated by measuring dynamic mechanical properties on the various specimens. Results were presented both graphically and by some very helpful 3-dimensional models determined by values of mechanical variables, frequency and temperature. Mechanisms of the various relaxation processes were discussed.

After lunch the participants dispersed to their various destinations and so ended yet another successful conference. Our particular thanks are due to Dr. M. F. Culpin who, as Conference Secretary, organised the event, and to the authorities of the Royal Military College of Science who provided the venue, and who fed and accommodated us so well. We understand that it may well be possible to hold future conferences at R.M.C.S., which is comforting news. On the other hand, it was suggested that for a future conference we might hire some large sea-going vessel for a day or two and hold a conference afloat. Any offers for the "Queen Elizabeth"?

K. M. BEAZLEY.

COMPUTERS IN INFORMATION RETRIEVAL

Shrivenham, September 1968

by

D. W. Hadley (University of Reading)

The Information Retrieval issue of B.S.R. Bulletin has been well received, with requests for copies coming from abroad as well as Great Britain. One information scientist has described it as the most comprehensive state-of-the-art review that he has seen devoted to a single field of study, whilst other experts have expressed surprise at the high quality of the articles.

Such praise, however, is not enough; the Bulletin was meant to provide an introduction for the working rheologist, and not be yet another specialist publication for the information scientist. To further the aims of the Society in bringing to its members an awareness of recent developments in coping with the information explosion, rather more than two hours of the Shrivenham conference were devoted to a session entitled "Computers in Information Retrieval; a Symposium for Users". Four short introductory talks were given by invited speakers "skilled in the art", with the remainder of the session being left free for general discussion. By interpolating the symposium within a general conference (at a time when the bar was closed and there were few alternative attractions) the organisers ensured that the audience was more representative than that generally found at meetings on information retrieval.

Mr. H. East (ASLIB) began the session with what he described as a superficial survey of current practice, which would introduce nothing new to those members who read their Bulletin. He warned that the devices of technology would not work miracles, but they would alleviate the problems caused by coping with 8,000,000 abstracts per year, increasing at a rate which would cause the number to double within 10 to 15 years. Mr. East did not agree with the Business Manager of "Chemical Abstracts", who had described the publication "Chemical Titles", which is produced with the aid of a computer, as "the greatest thing in chemistry since the test tube".

The scientist required information in two distinct forms: current awareness was necessary for keeping abreast of recent developments; whilst comprehensive information was needed to undertake retrospective searching. Both these aspects would be considered later in the symposium. The use of computers was leading towards the provision of integrated information services, providing a current awareness publication, formal abstracts, and a personal information service making use of a "profile" supplied by the individual user.

After discussing the use of computers in the preparation of conventional abstracts journals and citation indexes (Computerisation has permitted "Chemical Abstracts" to reduce the delay between publication of the original and publication of the abstract from more than a year to less than three months, despite an almost doubling in the size

of the publication) Mr. East concluded by describing the fully integrated information systems now being developed at MIT and by the Systems Development Corporation. In both of these systems the user has his own computer output, which enables him to retrieve directly either titles or abstracts held in the computer store.

The next speaker Mr. J. R. Smith (INSPEC) described the way in which use of a computer in compiling and publishing stages would enable "Science Abstracts" to appear in an enlarged and improved form in 1969. Intellectual effort was still required to prepare the abstracts, but thereafter the computer largely took over the operation. This system, the only complete one being developed in Great Britain, had so far cost £150,000 of national funds. It was expected that initially the cost of production would be about 7% more than by conventional methods—but in a few years' time the size of the publication would be such that conventional methods could not cope. A further major advantage of the new system was that all the basic data would be on computer tapes, which were then available for a host of ancillary information retrieval purposes.

The longest established computer oriented retrieval system is MEDLARS, based on tapes produced for "Index Medicus". Sets of tapes are flown to Britain and the system is organised here by the National Lending Library in conjunction with Newcastle University. Mr. A. G. Myatt (NLL) described the preparation of the input tapes, and the operation of the retrieval system, which has been available free of charge since 1963. Each paper mentioned in "Index Medicus" is indexed by up to 10 subject headings, and at present the Medlars index refers to approximately 750,000 papers from 2,300 journals, increasing at the current rate of 12,000 entries per month.

Users, who cannot have direct access to the tapes because of the difficulties associated with an ever-changing subject classification, receive titles of all papers referring to subject combinations requested. If the computer is asked a stupid question it gives a stupid answer, and so a built in test programme is included to prevent a user receiving a list of tens of thousands of papers. A particular use of the system is in tracing papers mentioning the concurrence of two distinct entities, e.g., the simultaneity of two different medical conditions, where it is necessary to scan a large volume of literature with only a small probability of finding a relevant reference (picturesquely described as needing a large amount of eyeballing).

The formal part of the symposium ended with a partial description by Dr. A. Kabi (Chem.Soc) of the profiles provided by the Chemical Society Research Unit at Nottingham University. The system operates using tapes produced for "Chemical Titles" and "Chemical and Biological Activities"; tapes from "Polymer Science and Technology" will be added in 1969.

Users of this system describe their general field of interest, and identify three or four concepts from an available list. Each concept is then expanded, using the guide to the system, and the user's stipulations are then coded. All papers keyworded according to an

individual profile can then be extracted. The retrieval can be refined using Boolean algebra; for instance it is possible to retrieve all papers mentioning A and B, except those mentioning C as well. Rather complicated weighting functions are also employed.

An experimental free service had been run until June 1968. This experiment had now been evaluated, and the results would be announced before the end of 1968. A service aimed at recovering its costs was now in operation, a typical profile costing £40 per year. Unfortunately there was no time available for Dr. Kabi to discuss the results of the system. It would have been interesting to hear whether the papers retrieved contained as high a proportion of non-relevant material, or whether as many relevant papers were not retrieved, as in the apparently less sophisticated profile scheme run in conjunction with "Science Citation Index". A large amount of "noise" would not, however, be too discouraging a feature. It is much simpler to select the six relevant papers from a list of twenty than from a list of 2,000.

Each speaker had deliberately described different systems, but would several bodies each producing several different systems lead to a modern Tower of Babel? It was encouraging to hear that an international committee was considering a feasibility study for a world information service. Let us hope that this is one international committee that does come to a unanimous decision.

It was encouraging also to hear that consumer research is being carried out, so that in certain circumstances it may be possible to fit the system to the scientist rather than vice versa. But the scientist also had responsibilities; he ought to express his title in a form suitable for retrieval systems, and not give a title that is either meaningless or only partially descriptive.

Overall the symposium was informative, and quite interesting, and those present were grateful that such authoritative speakers were prepared to spend time in addressing the meeting. Nevertheless there was a certain disappointment; although one sensed the problems it proved difficult to get an integrated picture, and the discussion never quite caught alight. Probably it was too much to expect attempting to discuss a complete technology in a couple of hours—but additionally, as one of the speakers commented later, "scientists like to experiment, want to publish, but hate having to read".

REPORT OF THE HONORARY SECRETARY, 1966-67

I am pleased to be able to report on a year of growth and much activity in the Society. The activity was mainly in the scientific field and consisted of organising meetings, editing publications and supplying experts for various committees; we have also dealt with numerous financial and administrative matters, as is inevitable in the running of a fair sized organisation which we can now claim to be.

This was the second year of office of our President, Professor A. Charlesby, who is due to retire today and we are very grateful to him for sparing some of his valuable time to lead our society. We shall be asking you to elect a new President today, along with the Executive Officers and Ordinary Members of the Council.

I shall describe the year's activities under the same headings as used in the previous years.

Finance

As usual, the Treasurer is submitting a separate report which will show you in detail that our financial position, which was quite good last year, has further improved. The main reason why the Society is making a profit is that we keep our administrative expenses negligible, since at present all our officers are voluntary and we run the Society without permanent staff or premises. With our increasing membership and range of activities, this is becoming more and more difficult and the Council may have to consider recommending a change in this direction.

Membership

The number of members has risen during the year from approximately 550 to about 600 including overseas members. We find that new applications come in waves, usually after a successful conference, such as the one we held here last year which brought in about 20 applications from attending non-members. We take this as a compliment on our meetings and a sure sign that our members join us for what we provide in the form of scientific meetings and discussions.

Last year we published a survey of our members' interests and employment. This was based largely on information provided by our members when they joined the Society and, of course, in many cases it was many years out of date. This year we shall ask our members to give us fresh information on their interests in a manner which is amenable to easy classification and forms have been sent out to all of you. Please co-operate by filling up these forms and return them as soon as possible.

In accordance with the new addition to Rule 3 (d) of our Constitution passed last year, we have elected four honorary members. They are: Mr. E. B. Babler, Dr. G. W. Scott Blair, Mr. A. L. Deadman and Mr. W. F. O. Pollett.

Research Committee

The Secretary of the Research Committee is reporting separately on the year's activities. All I want to say is that they have completed a task which the Society considers very important and fulfilling a long felt need, the classification scheme for rheological information on non-Newtonian fluids. They have now started working on a similar scheme for solids. The Gold Medal competition is also on again with slightly modified rules, as you will be informed.

Change in Council Membership

Mr. A. Graham who was elected as an Ordinary Member of the Council last year felt obliged to resign in December owing to pressure of other work. At the 166th Council Meeting held on January 17th 1968, Dr. M. F. Culpin was co-opted to fill the vacancy until the next A.G.M.

Meetings Held

We organised three meetings during the year, including one jointly with another Society:

(a) *Haemorheology and the Microcirculation*

Joint meeting with the British Microcirculation Society. One day meeting in London on February 10th, 1967. Although this was held on a Saturday, 74 members and non-members attended. Twelve papers were given.

(b) *Experimental Rheology*

Three day meeting at Bradford University, April 17th-19th, 1968. An exhibition of rheological instruments was also arranged in connection with this conference. There were over 100 attendances and 28 papers were given, including short research notes, as introduced at our Annual Conference last year.

(c) *Rheological Effects in Materials under Alternating Stress. Information Retrieval*

Three day meeting, Shrivenham, September 10th-12th, 1968, i.e. the present conference.

Meetings Projected

We have planned a number of meetings for 1969 and even 1970. Most of these are joint meetings with other societies and it is worth pointing out that in all cases the initial proposal came from the other societies concerned, which is, I think, a good sign, indicating that we are held in fairly high esteem by these societies.

The provisional arrangements are as follows:—

(a) *Practical Rheology in Polymer Processing*

Joint meeting with the Plastics Institute, London, April 17th-18th, 1969.

(b) *Mechanical Properties and Design*

Joint meeting with the Materials Science Club, Guildford, March 31st–April 2nd, 1969.

(c) *Annual Conference Autumn 1969*

Our plans are not yet crystallised but we are considering “Rheological Measurements in Process Control” as our central theme.

(d) *Yield, Deformation and Fracture of Polymers*

This is planned as an international meeting, to be held in the spring of 1970. The suggestion came from the Materials and Testing Group of the I.P.P.S. and our Society will be one of the seven participating bodies.

(e) *Non-Newtonian Fluid Technology—Industrial Practice and Problems*

Joint meeting with the Institute of Chemical Engineers, to be held in the autumn or winter of 1969.

Our most urgent concern is, of course, to make a decision on the Annual Conference to be held next autumn, and the Council would be interested to hear your suggestions.

Publications

The Bulletin and the Abstracts continued to appear regularly. Both have introduced small changes. The cover of the Bulletin now displays the Society emblem, and it is planned to get a completely new cover professionally designed in the near future. A few more feature articles appeared and we are planning to commission review articles for future issues. We particularly want to draw your attention to our last “Special issue” which is entirely devoted to information retrieval. We hope that you find this both useful and interesting—all the comments received on it so far have been highly complimentary. The Abstracts are now using the new classification system to the complete satisfaction of most of the abstractors and, we hope, the readers too. As usual, we wish to express our thanks to our faithful abstractors without whose devoted and unpaid work the publication would be impossible.

The papers given at the Symposium on Rheology and Texture of Foodstuffs (London 1967) have been published by the S.C.I. in a Monograph form.

The papers given at the Conference on Polymer Systems: Deformation and Flow (Loughborough 1966) have been published by MacMillan in a book form.

B.S.I.–B.S.R. Joint Committee on Rheological Terms and Symbols

A committee has been set up to consider and define the terms and symbols used in rheology. All members of the Committee, with the

exception of the administrative secretary, have been nominated by the British Society of Rheology. Dr. Scott Blair has been elected as Chairman. We think that this is a very important project.

Overseas Liaison

We have maintained good contact with our Australian Branches and publicised the meetings of several foreign societies.

Our Society will be represented by one of our Executive Officers, Dr. K. Walters, at the International Congress on Rheology to be held in Kyoto next month.

We have also had particularly good relations with the U.S.A. Society of Rheology and also with the Groupe Français de Rhéologie. The officers of both these societies supplied complimentary copies of their publications, kept us informed of future meetings and even persuaded experts in their own countries to write articles for the special issue of the Bulletin.

HONORARY TREASURERS REPORT

BALANCE SHEET as at 30th JUNE, 1968

	£	s.	d.	£	s.	d.
GENERAL FUND						
As at 1st July, 1967				1,240	17	2
Add: Excess of Income over expenditure for the year to date ...				1,627	2	5
				<u>£2,867</u>	<u>19</u>	<u>7</u>
<i>Represented by:</i>						
ASSETS						
Leatherhead UDC 6½ Bonds	1,500	0	0			
Debtors	720	2	2			
Cash at Lloyds Bank Ltd.						
Deposit Account ... 564 13 10						
Current Account ... 95 17 6						
				<u>660</u>	<u>11</u>	<u>4</u>
Cash in hand	60	0	0			
				<u>2,940</u>	<u>13</u>	<u>6</u>
<i>Less</i> CURRENT LIABILITIES						
Sundry Creditors				72	13	11
				<u>£2,867</u>	<u>19</u>	<u>7</u>
NET ASSETS						

Note. The amount due from the Publishers in respect of Abstracts for the year ended 31 December 1967 is not yet known. £700 was received on account in July 1968, and this amount has been included in the accounts to 30th June 1968 and shown as a debtor.

R. J. COLE, *Hon. Treasurer*

We have examined the above Balance Sheet and annexed Revenue Account together with the books and vouchers of the Society, and certify them to be in accordance therewith. We have not inspected the membership records.

The Market Hall,
Redhill, Surrey.
12th August, 1968.

ALFRED SIMMONS & Co.
Chartered Accountants

REVENUE ACCOUNT for the year ended 30th JUNE, 1968

INCOME

	£	s.	d.	£	s.	d.
<i>Annual Subscriptions</i>				470	12	8
<i>Entrance Fees</i>				59	0	0
<i>Rheology Abstracts and Bulletins</i>						
Publisher (Abstracts)	1,292	12	6			
Bulletin Subscriptions	2	0	0			
	1,294	12	6			
Less Production & Distribution costs	424	12	4			
				870	0	2
<i>Conferences</i> —net income per schedule				393	14	10
<i>Investment Income</i>						
Bank Deposit Interest	35	5	6			
Leatherhead 6½% Bonds	66	12	11			
				101	18	5
<i>Sale of Membership List</i>				3	3	0
				£1,898	9	1

EXPENDITURE

	£	s.	d.	£	s.	d.	£	s.	d.
<i>Administration</i>									
Clerical Services	33	17	9						
Printing and Stationery	27	14	3						
Postage	16	16	7						
				78	8	7			
<i>General Expenses</i>									
Travelling									
Officers and Council	112	11	7						
Research Committee									
& BSI Committee	42	12	1						
	155	3	8						
Professional Services	21	0	0						
Sundries	8	7	0						
				184	10	8			
<i>Intermittent Items</i>									
Awards	7	9	5						
Publications	18	0							
				8	7	5			
							271	6	8
EXCESS OF INCOME OVER EXPENDITURE							£1,627	2	5

SUMMARY OF CONFERENCES

for the year ended 30th June, 1968

Net Income

					£	s.	d.	£	s.	d.
Joint Food 1967	...	...	...	...	14	12	5			
Sheffield 1967	...	...	...	...	6	0	0			
Shrivenham 1967	...	...	...	...	132	19	5			
Bradford 1968	...	...	...	...	241	8	0			
								394	19	10

Net Expenditure

Joint Haemorheology 1968	...	...						1	5	0
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Overall Net Income

£393 14 10

RESEARCH COMMITTEE

Annual Report June 1967—June 1968

1. *Membership*

At the beginning of this period the composition of the Committee was as follows:

Prof. J. F. Raffle (Chairman)
Dr. J. P. Berry
Dr. M. F. Culpin
Dr. P. Feltham
Mr. P. Lamb
Dr. J. R. A. Pearson
Mr. A. T. J. Hayward (Secretary)

Dr. Feltham retired from the Committee in March 1968. Mr. A. Evans and Mr. B. Warburton were appointed to the Committee in October 1967.

Mr. Hayward's four-year term of office as Secretary was due to expire in September 1968, and to preserve continuity during the period of the next Gold Medal Competition Dr. Berry took over the duties of Secretary in an acting capacity in March 1968, with a view to taking office in September 1968.

The Committee met three times during the year, in October 1967, and in February and June 1968.

2. *Gold Medal Competition*

The rules for the Competition have been revised, and a press release based upon them was prepared and sent to a large number of trade periodicals and other interested organisations. It was also distributed to the contributors to the new edition of the survey "Rheological Research in Britain".

3. *Classification scheme for solids*

A working party has been formed to undertake this task, and a method of procedure was agreed upon at the first meeting. It is expected that the work of the group will be greatly facilitated by the experience gained in the working party on the classification of fluids.

4. *Computerised information services*

Further consideration of this topic during the year led to the recommendation that it be included in one of the meetings of the Society. Provision has been made to hold a Symposium on Information Retrieval at the meeting in Shrivenham in September 1968.

5. Cooperation among experimental rheologists

Discussion in the Research Committee indicated that considerable benefit could result from a cooperative effort among members of the Society directed to experimental techniques in rheology. The attempt to obtain support for this idea at the Bradford meeting proved ineffectual, and the matter is to be reconsidered by the Committee with a view to clarifying its proposals.

6. Survey of Research in Progress

The survey "Rheological Research in Britain", sponsored jointly by the Society and the National Engineering Laboratory, has been revised and brought up to date. It will shortly be ready for distribution.

7. Enquiries from members

Since only two enquiries have been received this year, the enquiry service is to be brought to the attention of the members of the Society through the forthcoming survey "Rheological Research in Britain".



BRITISH SOCIETY OF RHEOLOGY

RECLASSIFICATION OF INTERESTS OF MEMBERS

As mentioned in the previous Bulletin interests are to be regrouped in the Membership List to be published during 1969.

Will members who have not already returned the similar form sent earlier in 1968 please detach the present insert and return it as soon as possible to: Dr. D. W. Hadley, J. J. Thomson, Physical Laboratory, Whiteknights, Reading. RG6 2AF.

BRITISH SOCIETY OF RHEOLOGY

CLASSIFICATION OF RHEOLOGICAL ACTIVITIES

It would be helpful to the Society for organising its meetings and publications so that they are of maximum benefit to members if you would complete the questionnaire below. Your replies will be entered in the published Membership List.

Place ticks in appropriate boxes.

1. Is most of your work of rheological concern? (f); or ☐
Does rheology enter into your work only occasionally? (p) ☐
2. Are your rheological interests mainly
(t) Theoretical ☐
or
(e) Experimental ☐
or
(et) Theory and experiment ☐
3. Are your rheological interests mainly
(s) Pure science ☐
or
(a) Technology ☐
or
(sa) Pure and applied science ☐
4. Do you have a secondary interest in branches of rheology which you have not indicated in the list of major interests below? Yes ☐
No ☐
5. Which materials in the list below are of major concern to you?
 - A Metals, alloys ☐
 - B Composites (e.g. fibre-reinforced resins) ☐
 - C Solid polymers ☐
 - D Molten or dissolved polymers ☐
 - E Natural fibrous materials (e.g. cotton, paper, wood, wool) ☐
 - F Liquid—liquid systems (e.g. emulsions) ☐
 - G Liquid—solid systems (e.g. suspensions, slurries) ☐
 - H Particulate solids (e.g. granules, powders, fluidised beds) ☐
 - I Glasses, ceramics ☐
 - J Oils, greases ☐

Continued overleaf

- | | | |
|----------|---|--------------------------|
| K | Building and road materials | ☐ |
| L | Foodstuffs | ☐ |
| M | Biological materials (e.g. blood, tissue) | ☐ |
| N | Theoretical materials | ☐ |
| O | Other materials (<i>please specify</i>) | |

Name

Degrees, etc.

Private Address

.....

.....

Business Address

.....

.....

.....

DIARY

Meetings

- 6-10 January 1969 Symposium—Polymer Physics. At University of Manchester Institute of Science and Technology. The Meetings Officer, 47 Belgrave Square, London, S.W.1.
- 15 January 1969 Discussion—Recent Techniques in Strain Measurement (London). Applied Mechanics Group and Joint British Committee for Stress Analysis. Institute of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.
- 15 and 16 January 1969 Symposium—Lubrication in Hostile Environments (Risley). Tribology and Process Engineering Groups. Institute of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.
- 21 January, 1969 Discussion—Future Pattern of Supervisory Management. Thermodynamics and Fluid Mechanics Group. Institute of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.
- 5 and 6 February, 1969 Discussion—Project Management. Manufacture and Management Group. Institute of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.
- 19 and 20 February, 1969 Symposium—Tribology in Railways. Tribology and Railway Engineers Groups. Institute of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.
- 31 March-2 April 1969** Joint B.S.R.—Materials Science Club Meeting (To be held in Guildford).
- 1 April 1969 4th International Conference on Experimental Stress Analysis. (Camb. Univ.) R. J. Millson (4th International Conference E.S.A.). Institute of Mechanical Engineers, 1 Birdcage Walk, London, S.W.1.
- 13-18 April 1969 2nd International Conference on Fracture (Brighton). Dr. A. H. S. Matterson, Secretary, Fracture Conference office, B 77 AERE, Harwell, Didcot, Berks.
- 17 and 18 April 1969** Conference—Practical Rheology in Polymer Processing. Joint B.S.R.—Plastics Institute Meeting. (To be held in London).
- 2-6 September 1969 Conference—International Convention on Education and Training at Grosvenor House, London. The Secretariat, The Institute of Electrical Engineers, Savoy Place, London, W.C.2.
- 15 December, 1969 Conference—Physics of Liquids (University of East Anglia). Meetings Officer, 47 Belgrave Square, London, S.W.1.

Autumn 1969

(Date to be arranged) Joint meeting with Institution of Chemical Engineers.

Spring 1967

(Date to be notified) Symposium—"Grease". Tribology Group. Institute of Mechanical Engineers. 1 Birdcage Walk, London, S.W.1.

Exhibitions

- 6-11 January 1969 London International Inventions and New Products Exhibition. Business Conference and Exhibitions Ltd., Mercury House, Waterloo Road, London, S.E.1.
- 30 January-4 February, 1969 International Trade Fair for High Precision Techniques, Dimensional Measurement and Control. "Zuspa" Exhibition Halls, Zurich. Agifa, G.m.b.H. Universitatr, 120 Zurich, Postbox 257, CH—8033 Zurich.
- 10-13 March 1969 Physics Exhibition. Institute of Physics and Physical Society, Great Hall, Alexandra Palace, London, N.22. Meeting officer, Institute of Physics and Physical Society, 47 Belgrave Square, London.
- 10-14 March 1969 Second International Medical Engineering and Automation Exhibition. MEDEA Earls Court, Industrial Exhibitions Ltd., 9 Argyll Street, London, W.1.

25-29 August 1969 Data Fair 69 Manchester. The British Computer Society,
23 Dorset Square, London, N.W.1.

Late additions

March 1969 Measurement of Rheological Properties. Ceramics, dough, pastes, powders etc. Metals and Testing Group of Institute of Physics and Physical Society. Still in formative stage.

April 1969 Short Course on Non-Newtonian Fluids. Schools of Chemical Engineering, Bradford University.

April 1969 On-line rheological measurement. Measurement and control Group. British Scientific Instruments Research Association, South Hill, Chislehurst, Kent.

2-11 April 1969 Symposium on Inorganic Polymers, at Northern Polytechnic, London, Head of Chemical Department, Holloway, London, N.7

LIBRARY NEWS

Deformation of Solids, Published Nelson & Sons Ltd.

by I. H. Hall, Manchester Institute of Science and Technology.

Bds. 70s. Paper 35s.

This book attempts a more comprehensive and rigorous treatment of the properties of matter than that which is commonly presented to physics students.

The first part deals with methods of specifying stress and strain, leading to those assumptions which must be made about the behaviour of materials if these quantities are to be simply related. The second part is concerned with the experimental behaviour of real materials and their deviation from the assumptions made in the first part, and gives methods of describing this deviation. A final chapter qualitatively relates the observed behaviour to the molecular structure. Worked examples and problems are provided throughout. Although this book has been written primarily for physics students, it should also be of value to engineering and materials science students. It is suitable for undergraduates nearing the end of their first year, or beginning their second.

“On The Rheology of Concentrated Solutions of Macromolecular Carbohydrates.”

Dissertation by Y. Nedonchelle, University of Strasbourg, France

This work may be borrowed on application to Dr. D. W. Hadley, J. J. Thomson Physical Laboratory, Whiteknights, Reading, Berks. RG6 2AF.

OBITUARY

Professor W. R. A. D. Moore, M.B.E., B.Sc., Ph.D., F.R.I.C., F.P.I., died in the Duke of York Nursing Home on Saturday, 7th September, at the age of 58. Professor Moore joined the staff of the Bradford Technical College on 1st August, 1946. Professor Moore first worked as a chemist with the firm of Savory & Moore Ltd., London. After gaining his first class honours degree in Chemistry at the University of London, he joined Electronics Laboratories, London as a research chemist, in 1939. During the war he was an experimental officer with the Armaments Research Dept. of the Ministry of Supply.

Professor Moore was appointed Reader in High Polymer Chemistry at the Bradford Institute of Technology in July, 1958, and in 1966 he became Professor of Polymer Science at the University of Bradford. He was a member of the Senate of the University, Chairman of the Board of Studies in Physical Sciences, and also Chairman of the Post-Graduate School of Studies in Polymer Science. Professor Moore was well known nationally and internationally for his research and teaching in the field of Polymer Science, and has published many papers in this field. He was the author of the well known text book "An Introduction to Polymer Chemistry", and has contributed to other text books.

Amongst his many activities he was Chairman of the Plastics and Polymer Group of the Society of Chemical Industry; he was a consultant to Esso Ltd. He was also active in the Royal Institute of Chemistry, the Society of Dyers and Colourists, The Plastics Institute, The British Society of Rheology, the British Association for the Advancement of Science and the Bradford Chemical Society.