RHEOLOGICAL PROBLEMS IN BIOLOGY

INTERNATIONAL COLLOQUIUM

DURING July 26–28, a colloquium was held in Lund, attended by workers in a variety of fields of biological study, with the object of surveying problems relating to "the flow and deformation of matter". Such problems are essentially part of the subject-matter of physics; but physicists in the nineteenth and early twentieth centuries quite properly concentrated on the simplest types of rheological behaviour—the Newtonian fluid, with no relevant properties beyond a viscosity and a density, and the Hookean solid, of which examples are to be found in every text-book but in very few other places.

Biological science provides almost no examples of such simple types of behaviour, and scarcely any biological problems have proved to be amenable to treatment along lines suggested by nineteenth-century physical theory. Poiseuille, who wanted to study the flow of blood, had to give it up and study instead the behaviour of flowing water. He made thereby contributions of great value to physics, but left his original physiological problems as obscure as ever.

Developments in the present century—notably the introduction of plastics—directed attention forcibly to the flow and distortion characteristics of materials of high molecular or particle weight, leading to extensions of physical theory which seem likely in the near future to have application to biological problems. A survey of such problems as they exist today seemed desirable, and the meeting at Lund was accordingly arranged by the Joint Committee on Rheology of the International Unions of Physics and Biology.

The colloquium, attended by forty to fifty workers from several different biological sciences (and incidentally of ten nationalities), was opened at an informal reception by a short speech of welcome from Prof. Georg Kahlson, who had generously put his Physiological Institute at the disposal of the organisers both for the communication of papers and for the equally important informal discussion that went on during the subsequent three days in the gardens of the Institute.

At the first formal session, under the chairmanship of Prof. Hans Burström, dean of the Faculty of Natural Science at Lund, the meeting considered, appropriately, the rheological properties of protoplasm. Opening the session, Prof. W. Seifriz (Philadelphia), showed films of protoplasmic streaming in the slime mould, an astonishing demonstration of a circulatory mechanism with no permanent vessels and no discernible motive power, with the odd characteristic that the direction of flow is reversed every minute or so. This streaming can be reversibly inhibited by narcotic agents and stimulated to greater intensity by agents such as produce excitation in laboratory animals. The rheological properties of the cell nucleus were the subject of a communication from Prof. J. E. Harris (Bristol), who has measured the rate of fall of the nucleolus under gravity through the nucleus in the oocytes of several species of echinoderms, and revealed unmistakable evidence of thixotropy in the nuclear material. The session was concluded by an account from Prof. H. Pfeiffer (Bremen), of his work on the dichroism of flow in protoplasm streaming through capillary tubes.

A fascinating opportunity for the application of rheological considerations to biology lies in the locomotor activities of animals in relation to the properties of their environment. The mechanics of flight in air and of swimming in water are subjects that have been fairly extensively studied; but the communication of Dr. G. P. Wells (London), on the habits of the lugworm (*Arenicola marina*), dealt with an example of movement in a solid medium. The lugworm lives in a more or less permanent burrow in sandy beaches and feeds by passing sand through its body. The worm lives at a depth of 20–40 cm., yet it is only the surface sand that contains any particles of nutriment. This raises the problem of maintaining a permanent 'head shaft' in the muddy sand, a problem solved by the secretion of a cement substance on the part of the worm; this cement binds the sandy wall of the shaft to a thickness of several millimetres. Not only do the mechanical properties of the beach affect the worm, but also in the course of time a colony of worms may influence considerably the properties of the beach, for example by the formation of horizontal layers of coarse-grained material from which the finer components have been sucked away. These equip the beach with an irrigation system.

The flow of blood in the vascular system has been a subject of study since Poiseuille laid the foundations of the subject by his work on the flow of water in capillary tubes. The flow of blood plasma in tubes presents no phenomena of a puzzling kind; but whole blood is an example of a suspension, and the flow of suspensions is a subject only now beginning to take shape as a rheological topic. Physiologists have had to be content hitherto to collect data in the hope that ultimately these would fall into place in some theoretical scheme. The hope is not yet realized. Prof. R. Fåhraeus (Uppsala), himself a leading authority in this field, outlined the present condition of the problem in a paper beautifully illustrated by microprojection of blood flow in glass capillaries. Prof. Fåhraeus directed particular attention to the fact that in certain pathological states the rheological properties of blood are altered in such a manner that the distribution of flow in a capillary bed may be considerably changed. Dr. J. M. Potter (London), showed a film, prepared by Dr. D. A. McDonald and himself, of the flow of blood in the basilar artery of the rabbit. This artery is formed by the fusion of the two vertebral arteries, and the two streams of blood derived from these arteries remain astonishingly independent. This was shown beautifully in the film by the injection of dyes into either of the two vertebral arteries and by temporary occlusion of either. Some of the records were made at 1,500 frames per second, with a milli-second time-base recorded directly on the film.

Two of the papers presented to the meeting by W. Boothby and G. Lundin (Lund), and by P. Eggleton (Edinburgh), dealt with the elimination of nitrogen gas from the body resulting from the sudden reduction of atmospheric pressure. This physiological problem brings in rheological considerations in three ways: the diffusion of dissolved gas through the tissue cells to the nearest capillary, the transport of this gas by the circulating blood, and the tendency of the gas to separate as bubbles at certain sites within the body. Prof. Boothby spoke of the measurement of gaseous nitrogen elimination by means of the 'nitrogen meter' of Lilly and Anderson (a spectrophotometric technique of high specificity and accuracy), and of the

analysis of nitrogen-elimination curves into 'pulmonary' and 'tissue' components. Dr. Eggleton referred more particularly to the diffusion of nitrogen through fatty tissues and through fats and oils (in which nitrogen is five times more soluble than in water, and through which, on account of their viscosity, diffusion is slow).

The formal programme of the colloquium contained, in all, sixteen communications. This is a very small sample of rheological topics to draw from the whole of biological science, and there is no knowing whether it was representative. The fact that three of the sixteen papers (A. V. Hill, London; F. Buchtal, Copenhagen; and O. Sten-Knudsen, Copenhagen), were concerned with the mechanical properties of muscle, was probably a fair indication, however, of the great interest aroused by this rheological problem, and the substance of these communications illustrated the degree to which this subject has passed beyond the purely descriptive exploratory phase of research into the phase of exact measurement under controlled conditions. Prof. Hill's communication has been printed in *Nature* of September 9 (p. 415), and it is sufficient here to note the interest aroused by his recent results indicating that the stretching of a muscle in the excited state may bring about some endothermic chemical reaction. If a muscle can derive chemical potential energy from mechanical work done upon it, we are far indeed from the simple rheological picture of muscle mechanics—an assemblage of springs and dash-pots—that seemed sufficient twenty years ago.

The two communications referred to above, from the Neurophysiology Department at Copenhagen, illustrated the attempt to simplify the nature of the problem by study of the mechanical properties of single muscle fibres. Buchtal and Kaiser have applied longitudinal vibrations to such individual fibres, and by electrical recording have obtained Lissajou figures on a cathode-ray oscillograph in which the x-component records the alternating applied tension and the y-component the resulting alternating changes of length. The shape of the ellipse produced is affected by the physiological conditions of the fibre and the frequency of the vibration. These authors distinguish between 'elastic stiffness' and 'viscous stiffness'. The former is determined by the resonance frequency of the vibrating system, and the latter by the ratio of load to amplitude of movement at this resonant frequency. The changes in these two dynamic properties induced by electrical stimulation, by loading conditions, by temperature, etc., were the subject of this communication.

Dr. Sten-Knudsen's paper dealt with experiments of similar nature, in which the applied force consisted of an oscillating twist instead of a tension. The response of the fibre to such torsion enables conclusions to be drawn as to the structural forces operating normally to the fibre axis.

Even the stress – strain relations of non-living natural fibres are too complicated to describe in terms of simple viscous-elastic models: Dr. F. Anderson (Copenhagen), described the phenomena of after-stretch or relaxation observable in cellulose fibres subjected to sudden strain. Such relaxation, if attributed (following Eyring and his associates) to 'flow' of cellulose molecules or aggregates, can be used to provide a description of the rheological properties in terms of molecular structure—to determine, for example, the size of the aggregates between which slip is occurring.

Perhaps the most fundamental topic discussed at the meeting was that raised by Dr. M. Joly (Paris). It concerned the structures—transient and microscopic structures—present even in many relatively simple colloidal solutions. The flow characteristics of certain colloids point to the conclusion that reversible dissociation or aggregation of particles can occur as a direct consequence of the shear in the flowing liquid. Extreme examples of such effects are displayed in the phenomena of thixotropy and of rheopexy.

In addition to the communications just described, papers were read by Dr. R. D. Preston (Leeds), on the ascent of sap in trees, Prof. A. Frey-Wyssling (Zurich), on Poiseuille flow in latex tubes, Dr. T. D. Day (Leeds), on the flow of water in connective tissue, and Dr. F. A. Glover (Reading), on the rheology of human uterine secretions; all provoked warm—occasionally heated—discussion, both in and out of the lecture hall.

The success of this colloquium—and those who had attended it appeared all to rate it highly successful—was no chance result, but directly due to the care and forethought of Prof. H. Burström and Dr. A. Deutsch, who acted as local organisers. It was an agreed policy that informal discussion should be an important part of the proceedings; but discussion cannot be brought about by decree. That discussion took place freely and fully was the result of two things. The restricted size of the colloquium made it possible for each member quickly to make the acquaintance of all others; and the provision of a buffet for meals and refreshments in the grounds of the Institute made it unnecessary for members to scatter at intervals in search of sustenance. The generosity of the Swedish Government, which placed a sum of money unreservedly at the disposal of the organisers for hospitality, made it possible to provide this refreshment free of charge, and no better way could have been found to make this hospitality effective.

The proceedings of the colloquium will be published as part of a monograph on "Rheological Problems in Biology" now being prepared by Prof. A. Frey-Wyssling (Pflanzenphysiol. Inst. d. Eidg. Tech. Hochschule, Zürich). The cost of publishing the proceedings is borne by a grant from the United Nations Educational Scientific and Cultural Organisation, to which body the organisers of the colloquium are also indebted for a grant of money towards the expenses of the meeting.

OBITUARIES

Prof. A. W. Conway, F.R.S.

Arthur William Conway, by general consent the most distinguished Irish Catholic man of science of his generation, was born at Wexford on October 2, 1875, and died in Dublin on July 11, 1950. He was educated at University College, Dublin, and Corpus Christi College, Oxford, and was elected a junior fellow of the Royal University of Ireland in 1900 and a senior fellow in 1901. In the latter year he was appointed professor of mathematical physics in the old University College, being continued in a similar office when the new University College was created in 1909.

Conway's earliest papers, which appeared from 1902 onwards, were concerned with problems in the electromagnetic theory of light—the reflexion of