

FLOW PROPERTIES OF BLOOD

AND OTHER BIOLOGICAL SYSTEMS

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PROCEEDINGS OF AN INFORMAL DISCUSSION
CONVENED JOINTLY BY THE FARADAY SOCIETY
(COLLOID AND BIOPHYSICS COMMITTEE) AND
THE BRITISH SOCIETY OF RHEOLOGY

Held at the University Laboratory of Physiology
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WITH A FOREWORD BY

G. W. SCOTT BLAIR

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FOREWORD

IT WAS my privilege to preside at one of the Sessions of the First Conference of the American Society of Rheology in Washington, D.C., in December, 1929, and to have been able to follow, in some detail, during the intervening thirty years, the progress of the organized study of the flow and deformation of matter, which we call Rheology. This definition might be taken to include the theory of elasticity, the whole of hydrodynamics and even aerodynamics. By convention, however, rheology is concerned only with the specific properties, in deformation and flow, of different materials. These properties are deliberately ignored in hydrodynamics and in classical elasticity theory. In practice, therefore, rheologists cover quite a different field from those studied in these other disciplines, and the organization of rheology is quite distinct from that of hydrodynamics or of elasticity theory.

From the beginning, there were rheologists whose prime interest lay in the study of living matter: indeed almost a century before the American Society was founded, the French physician, J. L. M. Poiseuille, whose portrait graces this book, discovered, independently of G. Hagen in Germany, the basic laws of flow of liquids through capillaries, as a direct result of his interest in the nature of the flow of blood.

The founding of modern rheology is generally ascribed to Professor Eugene C. Bingham and he too, towards the end of his life, was engaged in the study of the flow of blood.

In the early thirties Professor R. Fåhræus and his colleagues in Sweden laid the foundations of those studies into the complex radial distribution of blood corpuscles in capillary flow which form the subject of several papers in the present book and, at the same period, Prof. W. Seifriz published a number of papers on the rheology of protoplasm. During the Second World War, in 1944, the British Society of Rheology, at that time called the British Rheologists' Club, included in its annual Conference a Symposium on the application of rheology to medical science, at which several papers were read.

The term "Biorheology" was introduced in a General Lecture on Rheological Problems in Biology by Prof. A. L. Copley at the 1st International Congress on Rheology at Scheveningen, Holland, in 1948, at which there were also a number of biological papers; but it was some years before the term came into general use. In July, 1950, an International Colloquium on Rheological Problems in Biology was held at Lund in Sweden; and a short report on its proceedings was published in a classical book on biorheology, entitled "Deformation and Flow in Biological Systems", edited by Dr. A. Frey-Wyssling two years later.

At the 2nd International Congress at Oxford in 1953, one General Lecture (by Dr. P. Eggleton) and three Sectional Papers on biorheological subjects appeared on the programme; and at the 3rd Congress, in Bad Oeynhausen, Germany, in 1958, not only were there several biological contributions but a skeleton organization was set up to investigate the possibilities of developing further this branch of our science.

A few months before the 1958 Congress, on the initiative of Prof. A. L. Copley, a meeting was held in London to which about a hundred men and women came, in order to discuss the "Flow of Blood in Relation to the Vessel Wall". This occasion led to the general acceptance, not without protest, of yet another neologism: "haemorheology".

The success of this meeting indicated the need for further activities and, following discussions between Dr. R. G. Macfarlane, Prof. A. L. Copley and myself, Prof. F. J. W. Roughton drew the attention of the Colloid and Biophysics Committee of the Faraday Society to our project. It was agreed to extend the scope of the meeting to include biological systems other than blood and the British Society of Rheology joined the Faraday Society's Committee in sponsoring a meeting to be held in Oxford in September, 1959.

The choice of Oxford was a happy one, especially because of the presence there of Dr. R. G. Macfarlane and his colleagues, whose work on the coagulation of blood is outstanding. Dr. Macfarlane also not only undertook the Treasurership of the Organizing Committee but was responsible for all the local arrangements whose smooth functioning did much to add to the success of the Meeting.

Unavoidable circumstances, referred to in the Editors' Preface,

precluded any wide circulation of information about the meeting sufficiently in advance to attract a large gathering. There were, however, about eighty participants, who appeared to be unanimous in their appreciation of the programme and it was their resolve that further meetings on biorheology, both at national and international levels, should be arranged.

For the sake both of the participants and of those who were unable to attend, it was felt that the complete Proceedings should be placed on record in book form as quickly as possible and this has been done through the energy of the two editors and the enterprise of the publishers.

I personally feel that there is no field in which, in the near future, rheology is more likely to make really useful advances than in that concerned with medical problems; and, since I believe, with Epicurus, that "vain is the word of a philosopher which does not heal any suffering of man", I have most gladly agreed to contribute this short foreword in the earnest hope that the Meeting which this volume describes will lead, not only to many others of like kind, but will stimulate much further research into the nature of the flow and deformation of living matter which forms the subject of "Biorheology".

G. W. SCOTT BLAIR

Reading

PREFACE

IN arranging the Proceedings of this Informal Discussion for publication we have divided the book into five parts. First there is the General Introductory Lecture (Part I) defining many terms in common usage in rheology and describing some of the complex behaviour which is shown by solutions containing large but, biologically speaking, simple molecules. This is followed (Parts II and III) by the twenty-one papers, and the discussions on these, which formed the main section of the Conference. Here, in order to follow the title more closely, we have inverted the order of the proceedings: the papers on blood were in fact presented on the second day but now appear first. Exhibits and films, accounts of which appear in the order of the proceedings of the Conference, were shown also on the second day. From the very beginning, the Organizing Committee decided that an important aspect of the Discussion should be the showing of apparatus and demonstrations, both "live" and with films. A record of this has been made in Parts IV and V, beginning with an account of Professor Weissenberg's lecture-demonstration of unusual properties in simple systems. All in all, this volume contains forty contributions by forty-eight authors.

The Discussion was held on an informal basis, and that tone has been preserved in this volume. Needless to say we, as Editors, accept no responsibility for the opinions recorded herein. As Organizing Secretaries we are acutely aware that this Discussion does not completely survey the present status of biorheology. Such a survey could not be considered for the period available, and our selection of topics is, therefore, an arbitrary one, exposing the paucity of rheological study in some systems and the wealth of information in others. We hope that the diversity and treatments of the topics selected will be a stimulus to biologist and non-biologist alike, provoking thought and much new experimental work.

Although there were at least eighty participants, it had been hoped that there would have been a still larger attendance.

Unfortunately, just at the time when notices should have been widely circulated, a dispute in the printing industry in the United Kingdom made this extremely difficult.

This volume is addressed to a wide scientific audience including physiologists, haematologists, physicians and surgeons, as well as physicists, chemists, mathematicians and engineers, thereby reflecting the interests of the participants themselves. Mutual assistance in biorheological problems will ultimately lead to significant advances in the diagnosis, treatment and prevention of disease and disorders in man and animals.

The editing and organizing has, not unnaturally, been assisted in many various ways and we wish to express our appreciation here to: our colleagues on the Organizing Committee, particularly Dr. G. W. Scott Blair and Dr. R. G. Macfarlane, F.R.S.; to the authors of papers and other contributors, and here we are especially grateful to Professor P. A. Allison, F.R.C.S., F.R.A.S., for Opening our Conference and allowing us to publish his opening address; to Professor E. G. T. Liddell, F.R.S. for kindly granting us permission to hold our meeting in the University Laboratory of Physiology at Oxford; to the Chairmen of the eight sessions—Prof. I. de Burgh Daly, F.R.S., Prof. M. H. Knisely, Dr. R. G. Macfarlane, F.R.S., Prof. M. Reiner, Prof. F. J. W. Roughton, F.R.S., Dr. G. W. Scott Blair, Prof. J. Scudder, and Prof. K. Weissenberg—who willingly and extremely ably conducted the discussions; to the President and Fellows of Trinity College and to the Master and Fellows of St. Peter's Hall for accommodating many participants; to the President and Fellows of St. John's College for allowing us to hold the Conference Dinner in Hall; to the Wellcome Trust for generous financial assistance to overseas participants and to the inevitable running costs of the meeting; to the National Science Foundation, Washington, D.C. for the award of travel grants to enable two of the distinguished speakers from the U.S.A. to come over and take part in the Conference; to Dr. E. Neumark, of St. Mary's Hospital, London, who, as Secretary of the 7th European Congress of Haematology (London, Sept. 7th–12th, 1959), made our Conference known to a wide scientific public by kindly making our programme available to some thousand members of that Congress; finally, to our publishers for encouraging and assisting with the speedy production of this book.

A. L. COPLEY and G. STAINSBY

London and Leeds

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OPENING ADDRESS

PROFESSOR P. R. ALLISON

TO GREET a Joint Meeting of the British Society of Rheology and the Faraday Society here in Oxford is a great pleasure. Welcome to you all, members of the Societies and guests.

A symposium of this sort is an attractive occasion on which to invite guest speakers but the uninvited guest is equally honoured and we hope that you will all enjoy the diverse and stimulating papers which you are going to hear and discuss.

It occurred to me as I read the excellent summaries that have been provided that perhaps not all of us would understand all of the papers all of the time, but this is an intellectual challenge that must be given and taken if we are to remain intellectually alive.

The scientist, like the artist, is reputed to be unfettered by thoughts of the practical application of his work, but if we take the hurdles more slowly and one at a time we find that the man who studies the amoeba must have a lot in common with one who works on the rheological properties of concentrated polymer solutions. The movement of a lot of amoebae in a fluid medium in a rigid tube is a step towards the blood in an elastic branching tube. It's a hell of a big step as the duchess said but a step all the same. We don't go far before we find the clinician at the receiving end whose training should be such as will allow him to watch your research and make what use of it he can, and, if utility be not the end but a side product of your work, there must be few scientists who would be ungracious enough not to be pleased.

The surgeon has to use and often abuse the most intricate and intimate processes of nature without ever understanding them. The function of the respiratory mucus in relation to electrolyte balance and infection, what happens to blood when you take it out and put it back through mechanical pumps, or even how a torn blood vessel is plugged and why the plug sometimes comes

out—these are problems about which we know so little. We have to use empirical data and wait for you to explain them.

When we became interested in blood pumps we had much help from an engineer whose main job in life was to pump tons of raspberries along a tube without crushing them. Until recently most of my knowledge of the rheology of the circulation was learnt, not in medical school, but whilst out fishing with a water works engineer. This was somewhat simplified by the river banks being inelastic. But now I know that the exact way in which two arteries are joined together or how a heart valve is repaired will be governed by the results of such studies that we are to hear about. The more detailed we become the more wonderful it all seems.