Biology
A Functional Approach
Third edition

M. B. V. Roberts M.A. PH.D.

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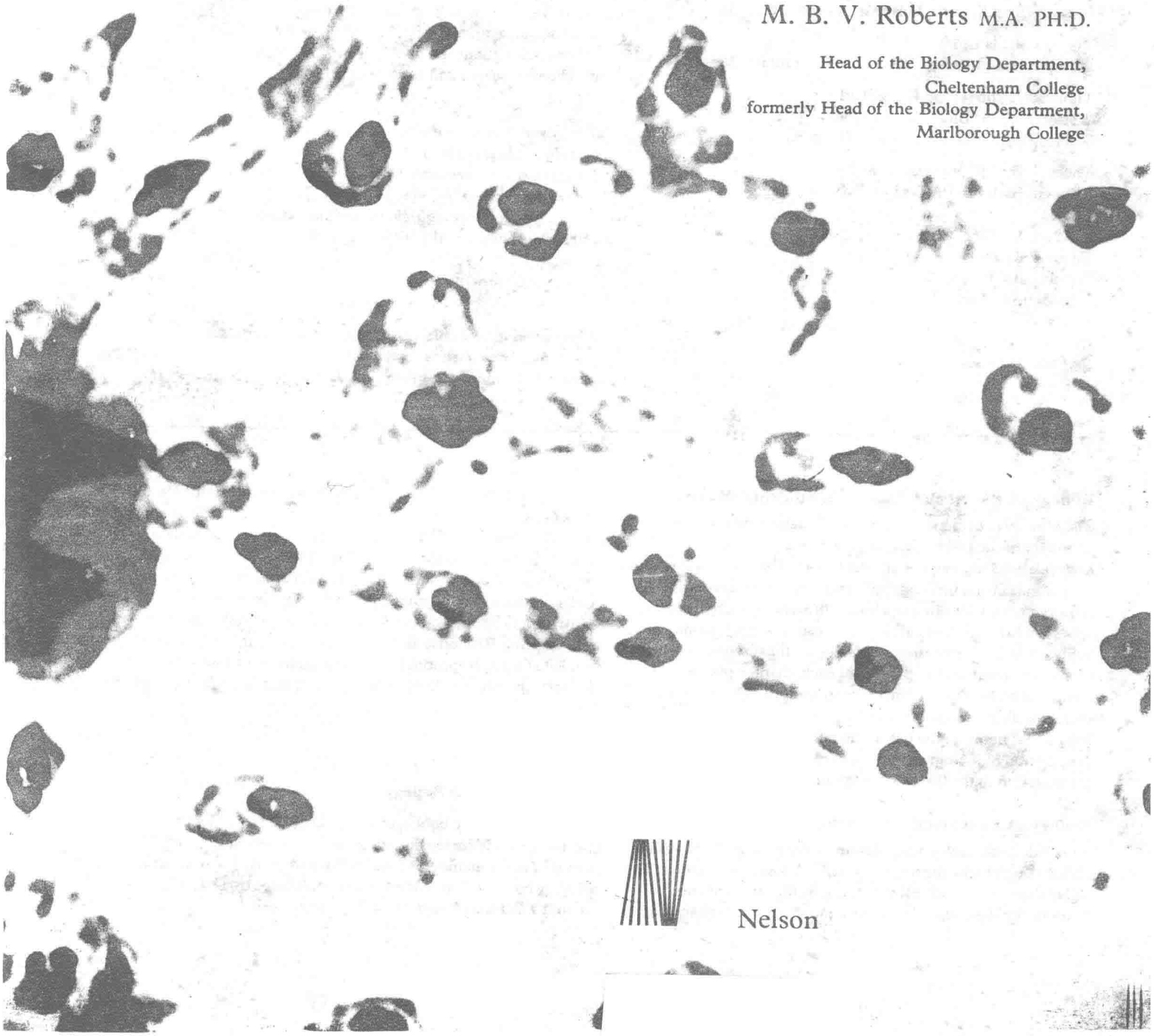

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The title page shows aggregation of amoeboid cells of the slime mould *Dictyostelium (photo by courtesy of Professor J. T. Bonner, Princeton University).*

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Biology, A Functional Approach: Students' Manual

The Manual provides students with a chapter-by-chapter summary of the textbook, together with a series of investigations to complement the theory. Detailed instructions are given for each investigation, and a list of apparatus and requirements. Clear line drawings illustrate the experimental set-up and the anatomical detail as seen in a microscopic study, or step-by-step dissection. Topics for discussion follow each experiment and at the end of each chapter is a comprehensive list of examination questions. The appendix includes: an illustrated classification of the animal and plant kingdoms; notes on the use of the microscope, and on the preparation of biological slides and reagents; and an introduction to the use of statistics in biology.

Biology, A Functional Approach: Slide Sets

Ten Slide Sets, each one containing twenty-four 35mm colour slides, supplement the textbook and the *Students' Manual*. The slides show microscopical preparations that students need to examine for themselves in the laboratory, and illustrate and relate structures discussed in the textbook and described with interpretive diagrams in the *Students' Manual*. In addition they provide a range of full-colour materials that give a stimulating and exciting view of modern biology. Each *Slide Set* contains notes by Dr Roberts, and the ten subject areas covered are: Cells; Tissues and Organizations; Gaseous Exchange and Nutrition in Animals; Nutrition and Transport; Adjustment and Control; Response and Co-ordination; Cell Division and the Life Cycle; Reproduction of Mammals and Flowering Plants; Animal and Plant Development; and Associations and Evolution.

Selected Topics in Biology

This series of topic books, of which Dr Roberts is General Editor, provides extension material for biology students at A Level. Topics include: *Animal Behaviour* by A. J. Brookfield, *Ecology* by T. J. King, *Mathematics in Biology* by D. C. Carter *et al.* and *The Plant Kingdom* by T. J. King.

Preface

Until recently sixth form biology courses centred on the structure and physiology of a series of animal and plant types. For the most part modern biology was given a raw deal. There was virtually no cell biology, no functional genetics, no experimental embryology, very little biochemistry and no molecular biology.

In the last five years things have changed. Influenced by the Nuffield programme and the American BSCS curricula, and encouraged by some of the examining boards, schools have been swinging away from the descriptive approach and placing greater emphasis on investigation. Six of the examining boards have already rewritten their Advanced level syllabuses to take into account modern developments, and there has been a general shift from the memorization of facts to the understanding of principles.

Most teachers and students have welcomed these changes but they have brought problems. How far should one take the modern discoveries? What should one do about the traditional topics?

This book attempts to strike the right balance between the two. I have tried to reassess traditional topics such as anatomy and organ physiology in the light of recent advances and to combine both into a modern functional framework. Modern work in biology, particularly cell structure and function, is making it possible to draw together seemingly disconnected threads into a series of unifying principles, and it is these that I try to emphasize. I have kept the burden of descriptive facts to the minimum consistent with an understanding of these principles.

Within limits the chapters can be taken in any order. The grouping of the various topics and the overall sequence gives a thematic development that I personally favour, but I have intentionally made each chapter as self-contained as possible so as to give teachers and students maximum freedom and flexibility in using the book.

I have not included laboratory schedules or examination questions. To have done so would have made the book unwieldy, and I feel that such material is best dealt with separately. But biology is an experimental science and I have taken pains to give evidence for stated facts wherever possible, particularly where it would be difficult or impossible for the student to verify them for himself. This has obviously taken up space, but I have allowed room for it by omitting any systematic treatment of the animal and plant kingdoms. I decided at the outset that to include a superficial survey of the animal and plant kingdoms would be of little value and indeed would run contrary to the philosophy behind the book. Nevertheless I firmly believe that the 'whole organism' should occupy a central position in any basic biology text. I have therefore drawn examples from a wide range of organisms, describing each in sufficient detail to illustrate the basic principle under discussion.

This book is intended to be a pre-university text for prospective biologists, medical students and agriculturalists. At the same time I hope it may provide a useful introduction for the increasing number of students who choose to read biological science at university having done no formal biology at school. I have assumed an elementary knowledge of physics and chemistry, but I have tried to write the book in such a way that it is intelligible to a student who has not done biology before. I have not stuck rigidly to any particular syllabus but the content and approach should make the book suitable for those following any Advanced level biology syllabus or overseas equivalent.

Acknowledgements

It is a pleasure to acknowledge the debt I owe to the many friends and colleagues who have helped me in producing this book. Various parts of the manuscript have been read by Dr H. W. Lissmann, F.R.S., Professor R. A. Hinde, F.R.S., Professor J. A. Ramsay, F.R.S., Dr Richard Bainbridge, Dr P. K. Tubbs, Dr A. V. Grimstone, Professor R. R. A. Coombs, F.R.S., Dr B. L. Gupta, Dr C. B. Goodhart, Dr Sydney Smith, Dr T. ap Rees, Dr P. J. Grubb and Dr Rufus Clarke, all of the University of Cambridge; Dr B. E. Juniper and Dr J. B. Land of the University of Oxford; Professor Bernard John of the University of Southampton; and my former colleagues in the University of California, Dr Garrett Hardin and Dr J. L. Walters. To all of them I owe my thanks for giving me the benefit of their expertise. Dr R. Gliddon of Clifton College kindly undertook the formidable task of reading the whole of the manuscript and I am most grateful to him for his frank and helpful comments. I also owe a debt of gratitude to my colleagues at Marlborough College, Mr Malcolm Hardstaff, Mr J. H. Halliday, and Mr John Emmerson for reading parts of the manuscript and assisting me in sundry other ways; working closely with them over the years has done much to shape my own ideas. I am also grateful to my colleagues Dr T. E. Rogers and Dr F. R. McKim for assistance on matters pertaining to chemistry and physics, and Mr S. W. Hockey for advice on units. In thanking all these people I must emphasize that I am fully responsible for any shortcomings that remain.

A substantial proportion of the text was written during tenure of a Fellow Commonership at Corpus Christi College, Cambridge, and I owe grateful thanks to the Master and Fellows for their hospitality, and to Professor T. Weis-Fogh for laying the facilities of the University Zoology Department at my disposal.

The names of the many people who have so kindly supplied photographs are given in the captions, but I would specially like to mention Mr J. F. Crane of the Cambridge University Anatomy School who prepared many of the photomicrographs, and my colleague Mr Beverley Heath whose skill as a photographer speaks for itself.

Many of my pupils have had a hand in the production of the book, particularly in the preparation of the illustrations and the checking of the typescript. I owe particular thanks to my former pupil Mr Peter Saugman for his sterling editorial work on an earlier draft, and to my technicians Mr C. R. Hughes and Mr Michael Ward for assistance with apparatus. The latter also prepared some of the more difficult drawings and assisted with the reading of proofs, as did my pupil Mr Guy Northridge. I also owe grateful thanks to the good ladies who typed the manuscript, particularly Mrs Berenice Loney, Miss Hermione Budge, and Mrs Jeanette Radford. The last not only typed much of the book but managed to maintain a semblance of order in my office during the final stages of its preparation.

Finally I am indebted to my publishers, Thomas Nelson and Sons Ltd., particularly Mr W. T. Cunningham and Mr D. R. Worlock, for their patience and encouragement. No author could have wished for a more sympathetic treatment of his manuscript.

M. B. V. Roberts
Marlborough, February 1971

Preface to the Second Edition

Since the first edition of *Biology, A Functional Approach* appeared in 1971, a number of examining boards in addition to those listed in the preface to the first edition, both in the United Kingdom and overseas, have changed their Advanced level biology syllabuses from a study of animal and plant types to a more unified functional approach.

In preparing the second edition I have tried to bear in mind the diverse needs and requirements of the various students who use the book. The perceptive reader who is already familiar with the first edition will find that very little material has been removed, but certain topics that were given scant treatment in the first edition are now discussed in more depth. This particularly applies to ecology, especially its human implications. No one would doubt the increasing importance that the environment is playing in our lives, and I need make no apology for the additional pages which are now devoted to this important topic.

Having said this, I remain convinced that an Advanced level course should present a balanced view of the whole subject, and I hope that, whilst recognizing current trends in biological ideas, I have achieved an appropriate balance.

Once again I have pleasure in thanking the many friends who have assisted me. Many teachers and students have made valuable suggestions, most of which I have heeded. I owe particular thanks to Mr Peter Holway of St Dunstan's College, Professor Ralph I. Smith of the University of California, and Mr David Pinney of Trent College for their advice; and also to my colleague, Dr James Parkyn, and my father, Dr Llywelyn Roberts, for help with medical matters. My former pupils Mr Chin Joo Lim, Mr James Otter and Mr Jonathan Cooper kindly read through drafts of the new material with critical eyes characteristic of one's more astute sixth formers, and I am grateful to them for their comments. I am also grateful to Mrs Elspeth Waddilove and Mrs Edna Halliday for typing the manuscript of the new sections, and to my wife for assisting me in many ways.

Producing a new edition of a book of this kind is a complex business and I would like to thank my publishers, Thomas Nelson and Sons Ltd, for steering it so efficiently through the press.

M. B. V. Roberts
Marlborough, October 1975

Preface to the Third Edition

The last ten years have seen the consolidation and refinement of a number of theories which were relatively new and speculative when this book was first published. At the same time some of the more traditional and seemingly established parts of the subject have been questioned. I hope this third edition reflects these trends.

I have introduced several new topics and amended others. The fluid–mosaic model is included in the section on the structure of the cell membrane and there are new sections on allosteric enzymes and genetic engineering. The osmotic terminology has been revised and the section on water uptake in plants brought into line with this. The sections on active transport and membrane carriers have been brought up to date, and I have added new material on such topics as C_4 plants, plant hormones and food chains. I have also tightened up the terminology in the chapters on heredity. By judiciously repositioning certain illustrations and making fuller use of the wide margin, it has been possible to make all these changes without altering the overall page numbering, an achievement for which my publisher must share the credit.

As always it is a pleasure to thank the many friends who have helped me. I am particularly grateful to Dr Tim King of Magdalen College School, Oxford, Mr Geoffrey Harper, lately of the Centre for Science Education at Chelsea College, and Dr Barbara Banks of University College, London, all of whom have kindly perused the second edition and made many useful suggestions as to how it might be improved. The last two have been at the centre of major controversies, the former for his criticism of the theory of evolution, the latter for her views on the rôle of adenosine triphosphate in metabolism. They are only too well aware of the tightrope which the author of a general textbook has to walk, and if I appear to have adopted a position of compromise I know they will understand. I am also indebted to Professor David Cove and his colleagues at the University of Leeds for their helpful advice on the genetics sections, to Professor James Sutcliffe of the University of Sussex for commenting extremely helpfully on the revised section on osmosis, to Mr Gordon Woods of Monmouth School for advice on new chemical nomenclature, to Dr Peter Kohn of the University of Sheffield for his help with the neurophysiological section, and to Mr Peter Holway, lately of St Dunstan's College, for his characteristically perceptive comments on various parts of the text. Finally I must thank Dr James Parkyn and my father, Dr Llywelyn Roberts, for continuing to advise me on medical matters. Needless to say, any mistakes that remain are entirely my own.

Ever since its inception the aim of this book has been to give students a balanced view of the whole subject and to stimulate them into delving more deeply into those areas which they find particularly exciting. Some indication that this aim is being achieved has been provided by the many students and teachers who have written to tell me how useful they have found the book. I would like to take this opportunity to thank them all for taking the trouble to write. Perhaps the most encouraging letter came from a student who, stimulated by the section on fish locomotion, had derived his own formula for calculating the propulsive thrust exerted by the tail of a teleost fish. There could be no better illustration of what *Biology: A Functional Approach* aims to achieve.

M. B. V. Roberts
Cheltenham, January 1981

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1 Introducing Biology

Biology, the study of life and living organisms, is a branch of natural science. It is an enormous subject, involving many other disciplines such as chemistry, physics, mathematics, geology and psychology. Medicine and agriculture are really applied biology. It is only necessary to glance through the current issues of the British scientific journal *Nature*, or its American equivalent *Science*, to appreciate the extensiveness and ramifications of biology, both pure and applied. Over one million original papers are published in the biological sciences each year, ranging from descriptions of new species to analyses of complex chemical reactions in organisms. Moreover the volume of information grows at a rate that makes it impossible for any one person to keep up with it all. Of course this great burst of scientific activity is by no means peculiar to biology: it is happening in other sciences as well. In fact the explosion in scientific knowledge prompted a former President of the Royal Society to remark that nowadays the only item on the agenda which all Fellows of the Society can be guaranteed to understand is the statement that tea will be served in the lounge at 4 p.m. With such a wealth of information pouring out of research laboratories it is sometimes difficult for a beginner to see the wood for the trees.

The purpose of this book is to present the broad sweep of the subject in a reasonably integrated manner. Throughout the book fundamental concepts are stressed: concepts such as how life is maintained, how organisms adjust to changes in the environment, and so on. But one cannot really appreciate such concepts without first being familiar with the facts on which they are based. However, not all facts are necessary, or even desirable. It is a matter of separating the important from the less important ones. In this book we shall look at a large number of specific biological facts within a framework of concepts and basic principles. The specific facts must come first, just as the parts of a jigsaw come before the completed picture.

THE DIFFERENT BRANCHES OF BIOLOGY

Biology means the science of life (Greek: *bios* – life, *logos* – knowledge). Traditionally the subject has been divided into **zoology**, the study of animals, and **botany**, the study of plants. A third subdivision, **microbiology**, embraces that vast assembly of microscopical organisms many of which do not fit neatly into either the animal or plant kingdoms. Within this no-man's land come such subjects as **bacteriology** and **virology**, the study of bacteria and viruses respectively.

Fifty years ago biologists were mainly preoccupied with describing the

structure and general form of animals and plants – **anatomy** and **morphology.** But in more recent times there has been a shift of interest towards the way organisms function, resulting in the development of animal and plant **physiology.** During the last thirty years or so such functional studies have become more and more chemical, resulting in the growth of **biochemistry,** now a subject in its own right.

Biochemical studies are showing us that in many respects the traditional division of biology into botany and zoology is an unnatural one. At the chemical level animal and plant cells are remarkably similar. The **cell** is the fundamental structural unit of which organisms are made. Research on cells, the study of **cytology,** has shown that in their structure as well as their functioning, animal and plant cells have much in common. This similarity is also seen in the way an organism's characteristics are transmitted to its offpsring, the study of **heredity** or **genetics**. Genetics is associated with the word **gene,** the term used to describe the particles that are transmitted from parents to offspring. Recent studies on the structure and properties of molecules found in cells have helped us to understand how genes exert their action. This new field, in which spectacular advances have been made in recent years, is known as **molecular biology** and, like biochemistry, is now an established subject in its own right.

So, looking back over the last fifty years, there has been a gradual shift of interest from anatomical description of the whole organism to functional studies at the cellular and molecular levels. This does not of course mean that all biologists are engaged in cellular or molecular research, or even that all modern biologists work in these fields. The older, more traditional studies are still pursued and have a very important part to play in the building of an integrated conceptual biology.

From the earliest times men have been interested in observing the ways and habits of animals and plants: **natural history** as one would call it. Today the naturalist, still enthusiastic in the pursuit of his hobby, is adopting a more analytical and experimental approach, studying **animal behaviour** and organisms in relation to their environment.

Behaviour itself is becoming a more experimental science, involving increasingly the techniques of **neurophysiology.** Environmental studies constitute **ecology** and are important if only because they affect the future wellbeing of man. Man's hopes of solving the world food problem and of making better use of his environment and natural resources will depend in large measure on advances in this field. Man is beginning to realize the importance of not destroying his natural environment. Ecological studies are demonstrating how man can derive material benefits from the environment without destroying it: **conservation** as opposed to exploitation.[1]

WHAT IS LIFE?

The honest answer is that we cannot say categorically what life is. The best we can do is to list those attributes of a living organism that distinguish it from non-living matter. These are as follows:

(1) Movement. It is characteristic of organisms that they, or some part of them, are capable of moving themselves. Even plants, which at first sight appear to be an exception, display movements within their cells. For example, if you examine the hairs on the stamens of *Tradescantia* under a

[1]Conservation is not the same as preservation. Can you explain the difference?