PLANT AND ANIMAL BIOLOGY

VOLUME 1

A E Vines & N Rees

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VOLUME I

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PREFACE TO THE FOURTH EDITION

WE have again endeavoured to give some account of important modern work in these topics considered necessary at the level of this textbook, and to include more recent interpretation of some older ideas. Most of the additions and amendments appear in Volume II; they concern physiology, cytochemistry, genetics and behaviour. In the more classical biology of Volume I, there has been less need for amendment; the most important changes occur in the endocrinology of vertebrates and the higher invertebrates, with somewhat more emphasis on neurosecretion.

S.I. units are used throughout both volumes; this has necessitated redrawing of certain figures bearing scale measurements. A number of minor errors, pointed out by perspicacious students, have been gratefully noted and corrected. Some of the older examination questions have been substituted by more recent examples, and a number of questions on current topics have been added. It is hoped that the volumes will continue to be of use to students of the biological subjects.

We take this opportunity of thanking our publishers, and particularly the Technical Editor, for continued whole-hearted co-operation and encouragement. For the typing of the new material in Volume I and some parts of Volume II, we are greatly indebted to Mrs Rees.

A.E.V.
N.R.

CAVENDISH,
SUFFOLK.
26 *November*, 1971

PREFACE TO THE FIRST EDITION

We hope that this and its companion volume, in scope and presentation, reflect the main purposes for which they were written. Our chief aims were to present to the Advanced Level student an approach to the biological subjects through an integration, and to bring within his reach a more modern outlook towards biological problems. There is at least one valid reason for the integration. There exists but one living world, and, although we may choose for convenience to recognize and study separately the two main classes of its inhabitants, we cannot escape from the fact that all exist under the same conditions afforded by this planet, are intermingled, have the same corresponding life processes and are largely interdependent. We feel that at this level of study it is still too early to make a completely rigid separation between Botany and Zoology. To do so, in some measure at least, defeats the object of trying to teach a proper understanding of the processes involved in the maintenance of life, surely the most important of all teaching aims. In the past there has been a sad lack of emphasis on other than very elementary physiology due undoubtedly for the most part to paucity of accurate, understandable information relating to this subject. But as chemists and physicists have increasingly provided biologists with better techniques of investigation, much of what was once obscure can now be explained in terms well within the comprehension of the sixteen- to eighteen-year-old student, providing that he studies physics and chemistry as parallel subjects. We foresee a radical change in the pattern of biology teaching and hope that our effort, if only to a small degree, may speed its coming. We do, however, recognize that there will always be the necessity for morphological study, particularly in a comparative way, and in the field as far as possible, since this is an essential background. We believe that a great deal more of this kind of work could be undertaken at the Ordinary Level if students commenced serious biological study at an early enough stage in their science career. There is presented first, therefore, a variety of type studies from which the student can select according to his needs. We recommend that all should be treated, if some only for interest rather than for examination purposes. These types have been described in a way which does not preclude the purely Botanical or Zoological study if that is desired.

It was our original intention to attempt a complete coverage in one volume, and our first scheme was prepared accordingly. As the work progressed, it became increasingly evident that, unless many important topics were to receive scanty treatment, the book would become far too cumbersome. To avoid pruning the content too heavily, our publisher generously allowed us to modify our original plan and the subject-matter has been divided into two sections. This first volume is mainly systematic, with the types presented as a series showing gradation in complexity, and transition from fully aquatic to fully terrestrial forms. The free-living organisms are treated first, and then

in their proper perspective, the parasitic, saprophytic and other modes of living are described. Our second volume consists chiefly of physiology but it includes also the topics of general biology with which it is necessary for the Advanced Level student to be familiar.

This division into two volumes necessitated some rearrangement of the sequence of topics from that which we considered to be best from both learning and teaching viewpoints. We had intended that the introductory chapters to the physiology should appear before the detailed studies of types. However, if the volumes are used in conjunction with one another, and this is borne in mind, it is still possible to follow the scheme as we first prepared it.

In the treatment of some topics we may be accused of erring by giving too detailed an account, but our decision to do so was influenced by three main considerations. First, we have taken into account how much the student can be expected to learn and understand and at the same time be fitted for University study. We have assumed that he will already have gained some introduction at the Ordinary Level, and in most cases we have presented the facts without undue worry. On the other hand, there have been occasions when we were unable to find a suitable bridge between a very elementary approach and a much more complicated modern interpretation. In such cases, perhaps we have expanded beyond the bounds of what is necessary, but then we have always had in mind the greater requirements of the Scholarship student. Our second consideration has been the extent of the knowledge which it would appear that examiners expect of the student. We have studied many examination papers, and have concluded that a candidate can do well only if he possesses a real understanding of his subject-matter. A superficial knowledge of facts alone is not often sufficient. This is an excellent thing, but it invariably calls for a deeper than elementary study. The third influence was the extent to which a student might be expected to make use of the text as an aid to his work. Too frequently, it has been our experience that the textbook is used only to check classroom notes. We have tried to produce a text which will amplify these and not always be subsidiary to them.

During our own reading in preparation of the manuscript, we have found instances of confused terminology and some conflict of factual statements. It has been no part of our plan to attempt to "put the house in order," but we have tried always to make the best use of the terms customarily used and to employ authoritative sources for our facts. Here we must pay tribute to the originators of our information, having possession now of a much clearer comprehension of what tenacity of purpose their work must have entailed.

Of the figures to the text, we would say that neither of us lays claim to any special artistic qualifications, but, with few exceptions, we have managed to complete the illustrations without assistance. Some figures are, of course, purely diagrammatic representations, but wherever it was possible, these have been constructed from actual specimens. All illustrations are line drawings and almost invariably relate to matters in the text. We could have used photographs in many cases but felt that these would have detracted from rather than increased the clarity of meaning.

We gratefully acknowledge those to whom we are indebted for aid in the

completion of our work in preparing Volume I. Our wives must stand high in the list for their patience and ministrations during the many hours of toil, and special thanks must go to Mrs. Rees, who so competently and speedily completed all the typing. To the technical Editors of Sir Isaac Pitman & Sons, Ltd., we give our thanks for their ready advice and assistance in matters of preparation of which we started out with no knowledge. To Dr. V. Fretter, of Reading University, we are grateful for advice and criticism after reading some of the manuscript, and to Mr. R. C. Bullock, B.Sc., Biology Master, Sexey's Boys School, Bruton, for his encouragement and sympathy. Among others who made more material assistance we must acknowledge Prof. Gough, of the Department of Pathology, Cardiff University, for his gift of animal histology slides, Mr. C. B. Wyatt, of Southend-on-Sea High School for Boys, who prepared the originals for Figs. 4, 16, 17, 18, 19, 21, 22, 23, 24, of Chapter 29, all those who made loans of examination papers, and the various University Examination Boards who are listed in the heading to the Examination Questions, for their kind permission to use them.

A. E. V.
N. R.

SOUTHEND-ON-SEA.
22nd February, 1959

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CHAPTER 1

UNITS OF LIVING SUBSTANCE: CELLS

RECORDS of the study of plants and animals date from the time of the Greek philosophers Theophrastus, Aristotle and others, but prior to the invention of the compound microscope by Jensen in 1590 and its development and use by Leeuwenhoek in the period 1650 to 1700, no observers had recorded any comments on the nature of the substance to which the property of being alive is now attributed. It was not till well after Leeuwenhoek's time that the continued use of the instrument led more observant students to conclude that there did exist a definite substance, then described as a "living jelly," and that it could be associated with many of the animate objects under examination. No recordings of note concerning this substance were made until 1665, when Robert Hooke, in coining the term "cells" for the box-like structures he found in thin sections of plant material, dismissed their contents as "nourishing juices." One hundred and seventy years later, in 1835, Dujardin, a French student of microscopic animals, named their body substance "sarcode" and described it as "a substance, viscid, translucent, homogenous, elastic and contractile." In 1838, Schleiden and Schwann enlarged on a "cell-theory" previously conceived by Turpin in 1826. This was further extended by Naegeli (1854) and Virchow (1858) who stated that the bodies of living things were constructed of units each of which owed its origin to the pre-existence of another such unit, and indicated also that the plant "cells" previously described were merely the outer coverings of a substance of infinitely greater significance.

In 1859, Purkinje coined the word "protoplasm," to name this living jelly, which by that time was so frequently associated with animal bodies. Shortly afterwards, von Mohl applied the same term to the slime-like substance which he recorded as circulating inside some plant cells. Schulze (1861) reported on the similarity between the protoplasm of plants, of animals, and of the sarcode of protozoa and proposed that the same term should be applied to all these cases. Thus *protoplasm* became recognized as the physical basis of all life and the fundamental similarity between plants and animals was established. Except for convenience of study, there is no valid reason for treating them separately. Collectively they make up the living world and they all possess the special characters of living things, merely performing their functions in different ways and employing different structures for similar purposes.

Living things exist in a vast variety of forms, but in the majority of cases, it can be seen that their bodies are constructed of small, individual masses of protoplasm, to which the name *cells* has been given. Hooke's first use of the term was inept and can be confusing, but he must be forgiven, since he had no conception of the real nature of the living substance. Not all living things can be said to be composed of cells in the forms about to be described. Other protoplasmic units will be described later.

GENERALIZED CELL STRUCTURE

The term, *cell*, is now in general use to describe a protoplasmic unit or *protoplast*, whether plant or animal, together with any substance it may form in or around itself. Because of some inherent differences in the activities of plant and animal protoplasm the general appearance of plant and animal cells is strikingly different. Whereas plant protoplasts almost invariably construct around themselves rigid walls of dead material, animal cells are separated by an intercellular substance which varies greatly in thickness and consistency according to the type of cell producing it. This separating layer may easily be overlooked. Because of the constancy of the rigid wall, the term cell as applicable to plants, can be used to describe any one of several things—

An uncovered protoplast.

The more usual construction of the living protoplast surrounded by its dead wall.

The dead wall only, after the living contents have disappeared.

In animals, *cell* has a more definite application, almost always denoting the living protoplast alone.

Any protoplast whether of plant or animal origin has fundamentally three distinct parts. There is an outer protoplasmic membrane of submicroscopic dimensions, known as the *plasma-membrane* (*cell membrane* or *plasmalemma*), which encloses the mass of the protoplasm. Inside this surface layer, the protoplasm is differentiated into two distinct regions. There is an apparently more fluid and often granular *cytoplasm* in which will be seen a more dense and somewhat hyaline *nucleus*, consisting of *nucleoplasm*. It may be discoid or globular in shape.

There are protoplasts which may differ from this simplified pattern in several ways, but these are exceptions and will be referred to later.

The Living Cell of a Plant

Plant cell structure in a simple form may be elucidated by examining, with the aid of a microscope, convenient tissue prepared in a suitable way. Such preparations may include thin strips of cells such as may be torn from some outer covering of a plant, thin sections cut with a

razor by hand or on a microtome, or loose cells resulting from the maceration of bulky pieces. Any of these preparations may be suitably treated with dyes and other reagents to distinguish the main cellular parts more clearly, but will not truly represent the living condition.

If a preparation of mature epidermal cells of the fleshy leaf of an onion bulb is made by stripping it gently from the underlying cells, and examined in surface view under the microscope, it will appear as in

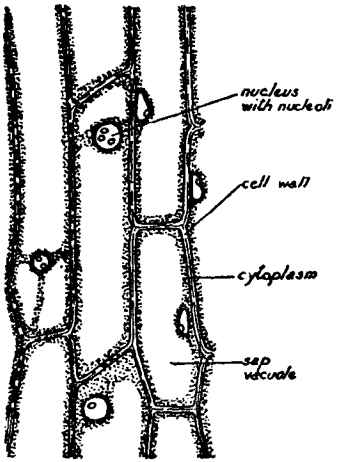

Fig. 1.1. Surface view of cells of epidermis stripped from the fleshy leaf base of an onion bulb. Diagram to show the main parts of the cells.

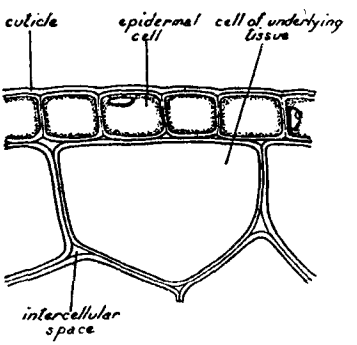

Fig. 1.2. Vertical section of cells of onion leaf epidermis with some underlying cells.

Fig. 1.1. If a preparation of the same material is made by sectioning the leaf base with a razor at right angles to the surface, and examined, it will appear as in Fig. 1.2. In either case, it will be seen that this layer of cells is composed of a very large number of more or less similar units clearly marked from one another by an intervening wall. Each wall delimits a cell and is known as the *cell wall.* If the student can now combine the picture in the one plane with the picture in the other plane at right angles to it, it must become obvious that each of these cells has three dimensions and is in fact a comparatively long (300–600μm), narrow (about 60μm) and shallow (about 50μm) box-like structure somewhat as in Fig. 1.3.

The student should remember that all cells have three dimensions and that it is always useful to make preparations of material in at least two suitably chosen planes at right angles to one another, in order to

appreciate fully the dimensions and shape of any cell. Careful focusing of the microscope at different levels in a preparation can also assist greatly in giving a better understanding of cell shape and contents.

The examination will also reveal that within the boundary of each cell wall, a living protoplast is contained. This appears as a lining to the wall and closely adheres to it at all points, leaving a clear central space or *vacuole*. For the most part this living substance appears colourless but slightly granular. This is the *cytoplasm*. Frequently, the granules can be seen in Brownian movement (*see* Vol. II, Appendix). Located either against one wall or suspended in the vacuole by cytoplasmic threads is the *nucleus*. Its shape will depend upon the direction from which it is viewed. It is generally a biconvex disc but the exact size and shape may vary slightly from cell to cell. Within its outline may be seen one or more (up to three usually) very much more refractive bodies of small dimensions. These are nuclear components known as *nucleoli*. No clear limiting membrane as such can be seen around either the cytoplasm or the nucleus, but there is no doubt that the cytoplasm is distinct from the cell wall and that the nuclear substance is clearly definable from the cytoplasm. As will be seen later, there is considerable evidence for supposing that the cytoplasm is surrounded by a surface plasma membrane where it is contiguous with the cell wall, and there is reason to believe that a similar membrane exists on its inner face delimiting it from the central vacuole. This membrane is called the *tonoplast*. Similar evidence exists to substantiate the presence of a superficial layer, called the *nuclear membrane*, separating the *nucleoplasm* from the cytoplasm.

A closer examination of the intervening wall between two cells will show that it is not a single thickness but a double one. This may not be very evident in the epidermal cells themselves since the walls are extremely thin and very great magnification is required to show this detail. But when the epidermal cells are examined in the vertical section in relation to the larger cells underneath, and when these are examined in relationship to one another, the double thickness becomes evident at once. This is due to the fact that every protoplast has secreted its own cell wall independently of the surrounding protoplasts. Adjacent cell walls are cemented to one another by an intervening substance common to both cells. This is known as the *middle lamella*. Where cell walls do not touch one another, and this can be seen very clearly at points where the epidermal cells are in contact with the underlying cells, are spaces devoid of any plant substance. They are *intercellular spaces* and in most cases will be air filled. The substance of which the cell wall is made can be shown to be *cellulose*. It can be demonstrated in younger cells that the cell wall is perforated by very fine channels or

pits through which adjacent protoplasts are in continuity with one another by means of cytoplasmic connexions called *plasmodesmata* (*see* Fig. 2.6 (*b*)). These will not be revealed in untreated living cells of the onion but such connexions can more easily be shown in other plant material.

In the case of onion leaf epidermal cells, as in fact with the outermost layer of the majority of plants, it will be seen that the whole of the outer face of the tissue is covered by a common overlying substance which gives the outer walls of the cells a thickness much greater than the inner walls. This outer layer is composed of a substance, different from the cell wall itself, and known as a *cuticle* (*see* p. 250). It is composed of a waxy material known as *cutin* but such an extra layer is not produced by all types of plant cells.

If an epidermal strip is lightly stained with methylene blue the important parts of the cell can be picked out more clearly. A phase-contrast attachment for the microscope can be put to good use in studying live, unstained cells. Cell parts with different refractive indices will stand out clearly from one another.

The Origin and Development of the Mature Cell

The structure just described is that of a mature cell. It must be clearly understood that whilst it had the same fundamental components all its

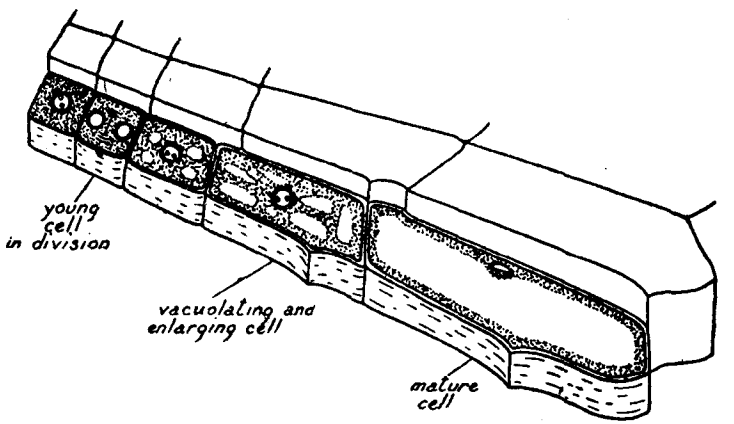

Fig. 1.3. Diagram of the origin and differentiation of the cells of the onion leaf epidermis.

life, it did not appear thus in the early stages of its development. Fig. 1.3 illustrates the development of the mature cell from its young stages

which appear at the base of the leaf where the cells are in constant division to form a meristematic region. It will be seen that the young cell, produced by division of an already existing one, has much smaller dimensions. It is roughly cubical in shape, a property common to most young plant cells, and the cavity within the wall is completely filled by the richly granular protoplast in which the nucleus appears to be large in relation to the size of the cell. Such a cell proceeds to grow in size and develops a shape peculiar to its own type. It is said to *differentiate*. As will be seen, the characteristic shapes of plant cells are many and varied. Both the cell wall and the protoplast are affected by the developmental changes. The protoplast, being the active part of the cell, is responsible for the changes and the wall is modified by the changing protoplast. During these changes, the wall is easily moulded, physically and chemically, and only after cell maturity is attained is a fully-developed and permanent wall present. Details of cell division, separation and wall formation will be found in Chap. 2.

In the maturing of the protoplast, many changes occur. They may be summarized briefly, as follows. The nucleus appears to be reduced in proportion to the size of the cell, whilst the cytoplasm develops as a much less richly granular substance. At various places within the cytoplasm fluid-filled cavities appear. They are the vacuoles, which ultimately run together to form one large central vacuole which restricts the cytoplasm to a peripheral position adjacent to the wall. The formation of vacuoles seems to be due to the secretion of watery droplets, which increase in volume as the cell enlarges and finally run together. In some cells, the cytoplasm may traverse the vacuole as strands and in these the nucleus may be suspended in a central position.

In the maturing of the wall, there occurs increase in area and thickness accompanied by changes in chemical and physical structure. In most cells, the rate of growth of the wall is not uniform for all areas. If it were, the mature cell would have roughly equal dimensions in all directions, i.e. be isodiametric. In the case of the onion leaf epiderm cell, it is obvious that greatest growth occurs in length of the walls parallel to the longitudinal axis of the leaf, so that the mature cell is usually six to ten times as long as broad. Its depth and width, whilst increasing slightly, never reach the same proportions. Since all the neighbouring cells are increasing in size at the same time, they must exert pressure on one another and adjacent walls must adjust themselves to their surroundings. Growth brings about changes in the relative positions of the walls. This is clearly demonstrated by the onion epidermal cells where the elongation tends to force the ends of one cell between the two cells on either side of these extremities. When all the cells are developing together in this way, the result is, that the end faces of cells

are set obliquely to the longitudinal axis, giving a very characteristic zig-zag effect. In order to achieve their final positions, the adjacent walls must have slipped alongside one another; such a phenomenon may be referred to as *sliding growth* of the cells. This simple conception cannot be used to explain all such peculiarities and no satisfactory comprehensive explanation has yet been made.

The Living Cell of an Animal

Many types of animal cells may be examined under the microscope while still in the living condition. Protozoa are normally studied in this way; the developing eggs of many animals may be inspected periodically. Cells of the blood, and small pieces of many tissues may be kept alive long enough for thorough examination. Such living specimens are best mounted in saline solutions which are similar to their cell contents.

By the technique of tissue culture, pieces of animal tissue can be kept alive for long periods, provided that due attention is paid to aseptic precautions, nutrient materials and oxygenation. Thus the growth of cells, their division and many particular processes such as those of ossification and tooth formation, have been carefully observed.

The standard method of study of animal cells, as with plants, is that of fixation, staining, permanent mounting and then examination, but this involves death of the cells. For animal tissues there are four principal types of permanent preparation. Smears are used for concentrations of small animals such as *Monocystis*, and for separate cells such as are found in blood and saliva. Thin sections are cut of softer tissues, and ground sections of material such as bone. Fibrillar structures such as striated muscle and nerve are finely teased with needles. Thin extensible sheets, as are found in bladder and mesentery, are examined as stretch preparations.

As with plant cells, so with animal cells there are often very great differences in the shape, size, structure and functions of mature cells. Here will be described a cell from the inside of the human cheek, mainly because of its availability, and because of its relatively simple nature. Such cells may easily be scraped from the inside of the cheek and examined alive. They are regularly shed into the mouth and may thus be found in smears of saliva.

There is some variation in the size and shape of these cells, but they are often irregularly oval in surface view, and their size averages 110μm $\times$ 80μm. Viewed under the light microscope, the living cell appears perfectly transparent, and apart from an obvious and highly refractive nucleus near the centre, there is no apparent differentiation (*see* Fig. 1.4).

A single nucleolus may sometimes be seen within the nucleus.

Vertical sections of fixed material, when stained and mounted, show the thickness of these cells in various planes. The greatest thickness is in the region of the nucleus and is approximately 15μm. At the edges, the cytoplasm tapers to a point.

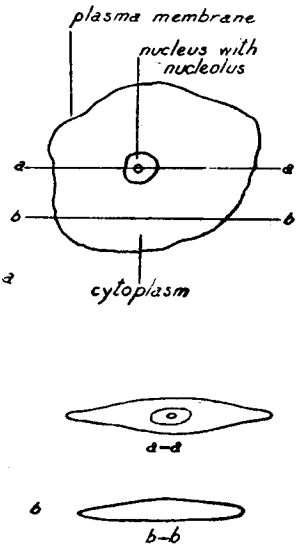

Fig. 1.4. (*a*) Surface view of untreated epidermal cell of the human cheek (inside mouth). (*b*) Sectional views of the same cell in the planes indicated.

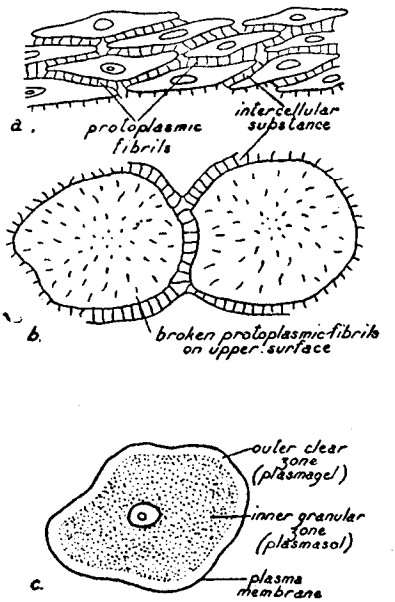

Fig. 1.5. Diagram of human cheek cells to show (*a*) and (*b*), inter-cellular substance, protoplasmic fibrils and (*c*), granular and non-granular cytoplasm.

If the upper few layers of cells in a vertical section are carefully examined, it will be seen that the cells are separated by narrow zones of intercellular material. Across these zones there are fine protoplasmic connexions. Their main function in this tissue is probably to afford some mechanical strength by binding the cells together. Sections cut in other planes will show that these protoplasmic connexions run in all directions (*see* Fig. 1.5). In a well-stained smear preparation, some differentiation of the cytoplasm into an outer clear zone, and an inner granular zone may be seen. There are no vacuoles present.