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THE SCIENCE OF PLANT BIOLOGY

Inaugural Lecture
delivered at the College
on February 20th, 1968

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The Chair of Botany here at University College, Swansea was established over 30 years ago in 1936 although botany has been taught in the college for almost 50 years. The Department of Biology was set up in 1921 under the late Dr. Florence A. Mockeridge and it was she, who in 1936, became the first Professor of Botany. Some of you will remember her. I never met her but I have talked with several of her past students who remember her with affection. Professor Mockeridge's memorial is the Natural Sciences Building for she was, before her retirement in 1954, responsible for the initial planning of the biological laboratories there. The task, however, of really establishing Botany in its new accommodation fell to her successor Professor H. E. Street and many of you know how well he succeeded. Professor Street was responsible for laying out the Botanic Garden which makes such a valuable, and pleasant, adjunct to the college ; he was responsible for planning the extensions which Botany now occupies and for the establishment, within Botany, of a subdepartment of Microbiology which holds much hope for the future. Because of his personal distinction in research and because of the abundant energy which overflows from him, he has built up a department that ranks high in British botany. He has now moved on to the Chairmanship of the new School of Biology at the University of Leicester, regretting very much the move from Swansea but seeking, I think, fresh fields to conquer.

I am, therefore, the third occupant of the Chair of Botany and it is possible, though not probable, that I shall be the last. That sounds rather as if we in Botany are about to realise that dream of the old alchemist, and perhaps of the modern gerontologist, that is to discover the Elixir of Life. With that, and the Council's permission, I might stay on for ever. Let me allay your fears, that is not what I mean. The fact is that although since the war, many new Universities have been created in this country, in none of them have Departments of Botany with Professors been established. This is not because they have considered the study of plants unimportant. How could they when the life of everyone of us depends directly or indirectly on the food we get from plants and when plants contribute so much to make our surroundings enjoyable ? It is that the new Universities have preferred to set up Schools of Biology rather than separate departments of Botany and Zoology, and it is probable that, in time, the older Universities will follow their example. Some have already begun to do so but, as yet, none has liquidated its Professor of Botany.

I think a consideration of why this move towards Schools of Biology has come about will reveal much of the nature of present day biology and the place occupied by the study of plants. Botany is today often regarded as a academic subject but it is still at the basis of agriculture and, in the past, it was the basis of medicine. For a long period almost all known drugs were derived from plants. When Botany, like the other Sciences began to stir after the Renaissance a number of things contributed to its revival, amongst them the more realistic drawing and painting of plants initiated by Leonardo and Dürer, the discovery of new plants outside Europe by the early explorers and, most important, the demands of medicine for more accurate knowledge about plants and their properties. In Tudor times botanists were herbalists. The word botany itself is derived from a Greek word meaning herb and our first floras were herbals in which the medicinal properties of plants were stressed, sometimes with a little too much imagination. My slides show two illustrations from Porta's "Phytognomica", published in 1588, a book on the doctrine of signatures which proposes that each plant carries a sign of the malady it cures. So plants with crescent or moon-shaped fruits or leaves were supposed to cure lunacy and those with curved segmented fruits or inflorescences were remedies for scorpion bites.

The practice of medicine has always included a modicum, or more, of nonsense but this doesn't detract from the medicinal importance of plants at this time ; one of the oldest Botanic Gardens in Britain is that of the Society of Apothecaries in Chelsea founded in 1667. It was this usefulness of plants combined with a feeling that they were worthy of study in their own right which led to the establishment of the first British Chairs of Botany, at Oxford in 1669, followed by Edinburgh in 1695 and Cambridge in 1724. The Chairs accompanied Botanic Gardens and University Botany in this country remained almost entirely concerned with the naming and classification of plants for the next 200 years. It is interesting that although at the same time animals were being named and classified, Zoology lacked sufficient relevance to medicine for the Universities to establish chairs and they came only after another 100—150 years. So from the outset in the older Universities, Botany and Zoology grew up to a large extent as separated subjects and this separation has influenced the development of biology in the later Universities. The separation of animals from plants is understandable. Animals are active, mobile, usually searching for food, or other things. Plants are quiet, docile, static, well-behaved and it is not at all obvious that they feed at all. The differences between plants and animals at a macroscopic level are much more apparent than their similarities. Why should they be studied together ? Even the great embracing concept of evolution by natural selection did not change things very much although it reminds us that there were great naturalists like Darwin, largely outside the Universities, to whom all living things were an object of study.

And yet, of course, the seeds of change were already sown. The microscope had been invented and even before 1700 Grew and Malpighi had used it to lay the foundations of plant anatomy. Malpighi indeed made distinguished contributions to the anatomy of both plants and animals but it was too soon for fundamental similarities to be recognised. In the next 100 years, microscopal studies progressed slowly, in truth microscopes were not yet very much good. Linnaeus, who perhaps did more than any other one individual in naming plants was contemptuous and dismissed such studies as not botany, that is not concerned with floral structure and classification. This has been the cry of reaction ever since. All my colleagues will have heard of some new development in the study of plants, using perhaps some novel chemical or physical technique, described as not botany. So science progresses.

Along with these studies went improvements in microscope design and in the 19th century came the fundamental recognition of the cell nucleus and protoplasm, by botanists, and the observations of chromosomes in the 1870's by both botanists and zoologists. It was a botanist, Strasburger, who first described the behaviour of the chromosomes in cell division but it was a zoologist, Waldeyer, who coined the name chromosome. And this is significant for it had by this time been realised that fundamentally both plants and animals are built up of cells containing protoplasm and a nucleus. Cells are easier to see in plants than in animals because plants make cell walls which remain when the plant dies and indeed, it was these that Robert Hooke saw when he first used the name cell many years earlier. So by the end of the 19th century it was clear that plants and animals were basically composed of cells with rather similar structures. Recent work with the electron microscope which enables one to magnify greatly sections of cells amply confirms this conclusion. If, for example, we look at a highly magnified part of a mouse heart cell we can see the mitochondria which produce energy for the cell by respiration. If we now look at a highly magnified part of a plant parenchyma cell showing mitochondria we are hard put to it to tell the difference even though at the lower magnification in the light microscope the difference would be clear. That is to say, the more deeply we probe

into the mechanisms and structures of plants and animals the more similar they become.

We can see this too in other ways. In 1900, Mendel's papers that have laid the foundations of genetics were rediscovered. Mendel's work was concerned with inheritance in pea plants. Ten years later, genetics was already a flourishing branch of biology ; flourishing perhaps most in California where Morgan was studying the genetics of fruit flies which Professor Beardmore now uses. In other words, the basic rules of genetics which Mendel discovered in pea plants were quickly shown to apply to fruit flies and indeed to you and me.

Again around 1900 the modern science of biochemistry was born. In 1897 the brothers Buchner discovered, by accident, that one can prepare a juice from broken yeast cells that ferments sugar to alcohol. This discovery made possible the study, in the test-tube, of the chemical processes that go on inside living cells. The first 40 years of this century saw an intensive attack on the mechanism of alcoholic fermentation by biochemists. At the same time others were studying the mechanism of the conversion of glycogen to lactic acid which occurs in mammalian muscle—when I flex my arm, for example. Soon it became clear that the biochemistry of these two processes in such widely different organisms as yeast, a microscopic fungus, and mammalian muscle was almost identical and serves the same purpose, the generation of chemical energy in a biological useful form. This process of glycolysis, as it is called, is common to almost all living cells whether of plant or animal origin. It is now a cardinal principle of biochemistry that while, of course, difference organisms will have their own metabolic patterns, on the whole the cells of plants and animals carry out biochemistry in the same fundamental way—they use energy in the same chemical forms, they make protein in the same way and they almost certainly share the same genetic code.

At the microscopic or cellular level then, we have three great unifying concepts that straddle the plant and animal kingdoms, similarity in cell-structure, a common mechanism of inheritance and a common pattern of basic biochemistry.

Other factors too, have also brought Botany and Zoology closer together over the past fifty years. Microbiology stems largely from the work of Pasteur and Koch during the last half of the 19th century ; it developed along two main lines, the medical and the non-medical. Non-medical microbiology has largely been carried on in departments of Botany because the chief organisms studied, the bacteria, are undoubtedly more like plants than animals in their method of nutrition. But bacteria have interrelationships with higher plants and animals. They may cause disease or they may live symbiotically and beneficially with higher organisms like the nitrogen-fixing bacteria in the roots of leguminous plants or the bacteria that decompose cellulose in a cow's stomach and so enable the cow to live on grass. At the unicellular level, the distinction between plants and animals that is so obvious to our naked eyes disappears and we find minute swimming organisms which are studied in both Botany and Zoology courses because neither kingdom can make a clear claim to them. If we probe deeper we find ourselves studying the viruses, many of which cause diseases of plants and others diseases of animals like measles, mumps and the common cold. The study of viruses opens up at once the question of "What is life ?" for here we are at the boundary of the living and the non-living worlds.

And then we must mention Ecology, that is the study of the distribution of plants and animals and the factors that control this. As the work of naming and classifying plant and animals approached its end, at least in Europe, ecology developed. At first it too was, perforce, descriptive but it quickly became analytical in that many chemical and physical parameters of the environment had to be measured, and then it became experimental. Our

knowledge of the factors controlling the distribution of plants and animals is far from complete but it is obvious that plants and animals, and among the animals we must certainly include ourselves, interact in many ways. The dramatic change in the natural vegetation of parts of the country that occurred a few years ago as a result of the decimation of the rabbit population by myxomatosis is an example. As another, we may mention the sea, where the food for fish consists of smaller animals which in turn feed on phytoplankton, minute floating plants which by photosynthesis obtain their food from dissolved substances in sea-water. Thus, in the sea, as on land, plants are the starting point of the food-chain that may end with food for ourselves ; if we are to farm the sea these relationships are fundamental.

I have developed these arguments at some length because I wanted to show clearly why it is that instead of the distinct subjects of Botany and Zoology which developed in the past for historical reasons and which were largely concerned with the classification of plants on the one hand and animals on the other, we now have new, or at least not so very old, fields of biology that cut across this division. We now have to train new types of biologists. Of course, there is still need to train botanists interested mainly in algae, or fungi or plant physiology or some other aspect of botany and the same is true for zoology but we need also to create the opportunity to train biologists who specialise not in plants or in animals but who understand particularly well something common to both. You may object that this is not the function of an undergraduate course in biology but should be dealt with at post-graduate level. I think this view is wrong for two main reasons. Firstly, it is uneconomic ; if people with such training are required, that is jobs for them exist, then we should train them for such positions. There is no evidence that a training in microbiology or ecology at an under-graduate level is any less rigorous intellectually or less satisfying than a more traditional biological training provided that a proper regard is paid to fundamentals. But secondly, and more important, to teach those aspects of biology that straddle the plant and animal kingdoms is in many respects better academically because of the broad, basic, principles that can be taught. The fact that at a cellular level the structures and mechanisms in plants and animals are similar is a good illustration of Sir Peter Medawar's argument that as a science progresses the body of factual knowledge that has to be remembered and taught grows less, not more, for it is replaced by general statements of wide applicability. Just as the periodic classification of the chemical elements and its interpretation in terms of the electronic structure of atoms makes sense of a great mass of data in inorganic chemistry so, too, do these new concepts in biology allow an understanding of the mechanisms in widely different organisms.

There is nothing very original in the arguments I have been putting before you and indeed I have probably been boring my biological colleagues by stating the obvious. But I wanted to explain to you the reasons why no new departments of Botany and Zoology have been created in our new Universities. Rather they have, from the outset, founded schools of biological sciences in which the new aspects of biology can develop unfettered—these developments we have seen particularly at East Anglia, Sussex, Lancaster and most recently at Coleraine. In the older Universities with established departments of Botany and Zoology and often of other biological sciences, change is also taking place and moves towards integration are happening. Sometimes a formal School of Biology has been created encompassing the old departments as at Leicester and Aberystwyth. Sometimes the association is less formal and takes the shape of common biological courses particularly in the first year. Liverpool, Birmingham, Cambridge and the London colleges are moving in this direction and we at Swansea are developing in this way too. At Swansea we shall retain the old degree structure but within it allow students of biology a wide

choice among courses in all years so that students can specialise across the old subject divisions.

It should not be thought, however, that there is any very general agreement about the exact way in which biology should be taught, particularly to first-year students. I think it is generally agreed that change was necessary but just what change is disputable. We are in an experimental period. The Schools of Biology at the new Universities are only just producing their first graduates ; the changes in teaching at the older Universities are just as recent and we do not know what will work best. Let me develop this theme a little.

Alongside the development of new fields of biology has come a change in the nature of biological study. It has become experimental rather than descriptive. Of course there have always been experimental aspects of botany like plant physiology but today not only physiology but taxonomy, ecology, genetics and even the study of plant shape and structure are experimental sciences.

Indeed, within the Universities, botanists are perhaps unique in that they alone are dissatisfied with the name of their subject. The public image of botany is not good. We are still supposed to be concerned with looking at flowers. We have not lived down our image in the early nineteenth century when an author could write :

> "By forming an early attachment to the study of plants, many a youth might be saved from the gaming table, and not a few modern young ladies would hasten from contemplating their own persons in the mirror, to admire the lasting beauty of divine nature".
>
> (From *Young Botanists in Thirteen Dialogues*, 1810).

Wholly admirable, no doubt, but that is not quite the image we want to present to the youth of today ! Some years ago a rather half-hearted attempt was made by the Professors of Botany in this country to change the name of the subject to "Plant Science". But they were too late, the term "Plant Science" had already been usurped.

I remember that about that time we had a research student who wanted a job in the U.S.A. She had relatives there and asked them to send her any advertisements they saw. A fine crop arrived, all for "Plant Scientists" but alas it was clear that there are two sorts of plants, our sort that grow naturally and the sort that men make. Indeed we have been reading quite recently about something called "University plants" which we are apparently not using as efficiently as we should. I'm not quite sure what a plant scientist does but he isn't a botanist. No doubt it will all become clear when we listen to the inaugural lecture of our first Professor of University Plant Utilisation as we may well do at some time in the future.

Anyway, we have lost plant science as a possible alternative name for the subject ; I prefer plant biology. The fact is that, to-day, the use of apparatus like spectrometers, electron microscopes, high-speed centrifuges and scintillation counters for estimating radioisotopes is common-place in botany and biology departments. A research student may well use half-a-dozen different fairly complicated physical techniques on his problem. An undergraduate should at least be familiar with these techniques and preferably should use them. Thus biology relies increasingly on the physical sciences. We see this too at an interpretative level. Some organic chemistry is basic for the understanding of cellular biochemistry ; an elementary treatment of biological growth gains from a little differential calculus and it is nice if students knew what a logarithm is. Genetics and ecology need statistics to analyse their data and already have entered the computer age. One could multiply the examples. Modern biology sits on top of a pyramid of the other pure sciences and increasingly some knowledge of them is necessary for its effective study. This knowledge was not as essential when biology was more concerned with description and classification. A number of difficulties, then, are met when one considers what sort of biology course to teach first year students. In many ways it is

satisfying to base this course on the unifying principles of cell biology—structure, inheritance and cell physiology. But such a course often demands more physical science, particularly chemistry, than the students possess. And it has to be remembered that sometimes students are taking biology as escape from what they consider to be the more difficult disciplines of mathematics, physics and chemistry. For this reason, some schools of biology base their first year courses on the unifying ideas of function in whole organisms and their relationship to their environment. This avoids to some extent the requirement for chemistry in first-year students but means that consideration of the fundamentals of cell biology has to be postponed. Many of us are agreed, I think, that it is advantageous for our students to have a considerable background in the physical sciences and not the least of our problems is to try to ensure that they receive it both at school and in the University. The teaching of biology in the University is thus itself in somewhat of an experimental state. This must be good for the subject. In the long run it probably doesn't matter too much just *what* we teach our students. What does matter is *how* we teach it. To be forced to rethink one's courses often gives them the vitality that more settled courses lack. Of course it is uneconomic and unsettling to change one's courses too frequently but a reasonable amount of change stimulates the teacher and this should react on the students. There *is* something to be said for change for its own sake.

The need to rethink one's courses in view of the change of emphasis in biology is not restricted to the University. I should like to show you two pairs of slides :

Slide 1—Some rather poor drawings of bacteria ;
Slide 2—Drawing of demonstration of oxygen production in photosynthesis by *Elodea.*

Both these pictures are taken from an O-level text-book in biology, the first edition of which was published in 1957 only a decade ago, though it is fair to say that they could have been taken from any number of text-books published in the past 60 years. There is no suggestion in the text that the pupils should see bacteria for themselves and the experiment on photosynthesis is essentially a class demonstration experiment. Contrast these with the next pair of slides :

Slide 3—Diagram of procedure to be followed in aseptic cultural technique.

Here students are expected to transfer a micro-organism from a stock culture to a petri dish of agar on which it will grow. The experiment to be set up is one to illustrate the genetics of yeast.

Slide 4—Diagram showing extraction of an iris leaf after a period of photosynthesis and the quantative estimation of sugar formed.

Again students are expected to do this themselves.

We are still dealing with O-level biology but this time from the Nuffield O-level Biology texts. I don't think I have been unfair in my selection except that one could find better books than the 1967 O-level text. But the Nuffield approach of having students do things themselves and, as far as possible, find things out for themselves is really a new one at school level. Moreover, the approach is quantitative whenever possible. The Nuffield approach too, emphasises the relationship of biology to important human problems. My slides didn't show this but for example, one finds in the texts a quantative treatment of the relationship between lung cancer and smoking, a discussion of the merits of fluoridisation, a discussion of the food value of a large number of articles of diet and what is different about the chromosomes of Mongoloid children and so on. To my mind the publication of these books is a most important event in British Biology.

There will obviously be some resistance to the development of this type of teaching in schools. Firstly, because it can be argued that the authors have been over-ambitious and included, too much ; the texts do total over 1,000

pages. Secondly because this method of teaching, compared to the old, requires much more preparation on the part of the teacher together with apparatus and help by technical assistants which, while common in the Universities, is still too rare in schools. But thirdly, and perhaps most important, because teachers at present in the schools have not been trained, while at University, to think about biology in the way required. This seems to me one of our tasks for the future. If we agree, and I hope we do, that this approach to biology is the right one, then we must play our part in ensuring that our students leaving here to enter teaching are able to teach successfully in the new way. Some argue that the Nuffield project is only old cloth made into a new coat. I don't accept this. Indeed, I would argue that, at the moment, many of our first year students coming up to read Biology after taking A-level Courses in Botany and Zoology are ignorant of much of the material in the Nuffield O-level course and almost entirely unaware of this type of approach to biological problems. We should see that they don't leave in the same state of mind.

In conclusion, I would like to touch on the effect the unification of biology is having on biological research. I mentioned the unifying ideas of cell structure, genetics, biochemistry and microbiology. As one analyses each of these further one finds that they tend to merge into what is now loosely called molecular biology. In other words the resolution of the electron microscope is now such that we are speculating about the arrangement of individual molecules in the structures we see in cells. Similarly the function of genes is now interpreted in terms of the detailed chemistry of molecules of DNA. Biochemistry, of course, has always been concerned with the chemistry of molecules ; it is becoming increasingly concerned with structure and organisation in cells. Microbiology, especially from studies of the genetics of bacteria and viruses has produced concepts, at the molecular level, of the greatest fundamental importance. Let me give you one example. There is a common, and generally, harmless bacterium that lives in our intestines and which grows very happily in pure culture and has been for years a favourite object of study by laboratory microbiologists, chiefly because it grows fast and readily. This organism, *Escherichia coli*, ferments sugars like glucose quite readily. If, however, one gives it milk-sugar (lactose) it cannot ferment it immediately but after some minutes it develops the capacity to do so. This is because it doesn't normally have within itself the necessary catalyst, or enzyme, that allows it to attack lactose but when given lactose, the bacterium can make the enzyme that attacks the sugar. There are many other examples among micro-organisms of this phenomenon of enzyme induction, as it is called, and for some years its mechanism was obscure. The work of a number of people, particularly the Frenchmen, Jacob and Monod, has revealed this mechanism. In simple terms it is that the gene that controls the production of the enzyme that attacks milk sugar is normally switched off in *Escherichia coli* cells but when lactose is given, it becomes switched on and the appropriate enzyme is made. Jacob and Monod, from genetic studies, proposed a clear hypothesis for the mechanism of this switch and very recent biochemical work by Gilbert and Müller-Hill shows that this is right. Jacob and Monod were awarded a Nobel prize for medicine in 1965 because of the fundamental importance of their work to biology. Why should this be ? Why is the way in which an insignificant and harmless microbe adapts to ferment milk-sugar important to us ? It is because one of the outstanding unsolved problems in biology to-day is the problem of differentiation. How is it that in our bodies, one set of cells develops into a kidney, and another into a bone ? How is it that hormones control the growth and differentiation of both animals and plants ? What goes wrong with our cellular processes when a cancerous tumor starts to develop ? The work of Jacob and Monod goes to the heart of these problems for the evidence is that these

changes come about by different genes being switched on and off at different times in a controlled manner. Hence the chemical reactions that can occur are controlled and the course of development is determined. There is, for example, good evidence now that the thyroid hormone, thyroxine operates a switch of this kind and evidence too that the plant hormones may work in a similar fashion.

Botanists too are much concerned with problems of differentiation. Let me finish by showing you some slides that illustrate a simple example. They also remind us that plants are an object of pleasure to us all, even to a modern botanist ! They are pictures of some of Miss John's fine collection of Fuchsias in the Botanic Garden. In several varieties like *Marinka* the petals and the calyx are both pink. But in the variety *Mrs. Marshall*, while the petals are pink the calyx is white ; that is to say the genes controlling the pink pigment production, although almost certainly still present in the calyx are completely inoperative or switched off. In the variety *Springtime* this situation is reversed, the calyx is pink but the petals, multiplied in this variety, are white. While in *Wood Violet* a new pigment is produced, but only in the petals which are blue. Here then are clear cut problems of differentiation but their solution will be difficult. When we have finally solved them the science of plant biology will be much further forward.

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