face a petroleum shortage does not now appear to be predictable. The distance to that day in the future lies not alone in the supply of oil remaining in the ground. It rests also with the geologist to continue to aid in the increasingly difficult problem of discovery, with the engineer to improve drilling technique and increase recoveries and with the chemist to continue improvements in refining practice. In part, it rests on the price that the public can pay in the future for oil products; the ability of the public to pay future prices in turn depends in part on increased efficiency in their use. In a large measure the distance to the day of petroleum shortage rests on conservation and efficiency in the discovery, development and production of our future oil fields.

Advances in science and technology affecting the discovery, recovery, refining and utilization of petroleum will undoubtedly continue. Thus far, such advances have enabled us to keep and augment supplies ahead of needs, but they afford us no assurance that the same record can be maintained indefinitely.

When a shortage of domestic crude petroleum arrives and there is a consequent rise in prices of petroleum products, substitute oil products from coal and oil shale, alcohol from farm products and gases from wood will be utilized, just as they are now used to some extent in certain countries that possess little or no oil resources. The cost of making gasoline from coal in British and German plants is probably three or four times the present cost of producing gasoline from petroleum in the United States. Concerning this subject Dr. Fieldner, of the Bureau of Mines, remarks: "These costs will be reduced by further research, but no other liquid motor fuel, whether it be from coal, oil shale, or vegetable matter, can hope to be as cheap as our present petroleum fuels." Should coal be called upon to supply the demands now met by oil and gas the coal deposits of the United States would, according to independent estimates by Dr. Fieldner and T. A. Hendricks, last about 2,000 years. These estimates are based on the assumptions that coal will be called upon to supply energy at the rate of the peak energy consumption of 1929 and also that there will be a 30 per cent. loss of coal in mining.

THE CASE AGAINST THE CELL THEORY[1]

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MODERN biologists, in general, resent listening to theories; they are interested, they say, in facts only. But the organization of the present gathering and of many similar ones, all over the world, to commemorate the formulation of a *theory,* proves, on the other hand, that there is still some consideration for this form of intellectual activity. Why, then, do the biologists condemn theorization at times and honor it at other times? Is such an attitude mere inconsistency on their part? It seems, rather, that it is due to a state of mind which resulted from an apparent conflict between two evident facts: one is that theories have often been dangerous because they were held as doctrines; the other is that the elaboration of theories, at least in an implicit form, is a necessary and unavoidable procedure in any thinking. To reconcile ourselves with the situation we need only to recognize the necessity of theories but to remember also that they are dangerous tools which should be put in the hands of those only who know enough never to believe in them. The science of thinking consists in knowing how to use these tools, that is, in never admitting any theory except as a possibility. Since faith in theories has done much harm to human thought, the dangerous aspect of any theory, namely, to inspire belief, will be emphasized in the following discussion.

A theory is often considered acceptable if it is useful and if it allows one to foresee unknown facts. It is clear, however, that, in the last analysis, we require more than that from a theory; we want it to represent the truth. We are not satisfied in knowing what a thing might be, as proposed by any theory, we want to know what it actually is, and this is proposed by only one theory. When it becomes evident that a theory does not represent the truth, even if it has been useful and is still useful in the discovery of new facts, we abandon it and try a new theory which might have more chance of being the true one. In general, a theory is useful in proportion to its nearness to the truth, but there are examples of theories which have been useful for centuries and finally had to be abandoned as inadequate to explain newly discovered facts; such is the case of the old classical theory of the corpuscular nature of light. In the last analysis, then, the decision as to the acceptance or maintenance of a theory depends only on the answer to the question: Has this theory a chance of being true or not?

Let us come now to the definition of the cell theory. The statement of the fact that most living beings

[1] Address delivered to the Sigma Xi Club of Saint Louis University on April 18, 1939, at a meeting organized to commemorate the centenary of the formulation of the cell theory.

possess a cellular structure is often confused with the cell theory; and the discovery of the cell is assimilated to the formulation of the cell theory.

That most plants and animals are made of cells is a well-established fact based on innumerable observations, the first of which is generally attributed to Robert Hooke in 1665. As to the cell theory, it is only 173 years later, in 1838 and 1839, that it was clearly formulated by Schleiden and Schwann.

How does the theory differ from the fact? Essentially in this: the fact is that *most* living beings are cellular, and the theory is that *all* living matter should be cellular; in other words, the fact is that a cellular structure has been observed, and the theory is that such a cellular structure is a necessary condition for the existence of life.

In a condensed form, the cell theory can thus be formulated in the statement: "The cell is the fundamental structural and functional unit of any living matter." Schwann expressed it as follows: ". . . *all* organized bodies are composed . . . of cells" and ". . . there is one *universal* principle of development . . . the formation of cells."[2]

After these introductory definitions and remarks we come to the essential point of this discussion, which is the contention that the more we learn about life, the more the cell theory loses its chances of being true. The discovery, or the more complete observation of a number of facts during the 100 years which have elapsed since the formulation of the cell theory, as well as a more synthetic comprehension of these facts, make it now highly probable that the cell is not the necessary structural unit of any living matter. Like for many old theories, as those on the nature of light, on the nature of electricity, on the structure of matter, etc., the time seems to have come also for the cell theory to pass into the realm of the past. To abandon a theory which no longer agrees with newly studied facts is the only way by which matter-of-fact modern biologists can honor the pioneers who formulated it.

We shall discuss here briefly a few of the cases in which the inadequacy of the cell theory is more evident.

I. Coenocytes, Large Organisms not Divided into Cells

(1) *The Mycetozoa.* These animals (or plants) consist of large masses of living matter, sometimes as much as a pound, spread in a thin layer over an area of several square feet; the mass has usually an arborescent structure through the branches of which one observes an intensely active protoplasmic streaming. There is no trace of any division of the organism into cells (at least in the plasmodium stage). Yet all the vital functions—nutrition, respiration, secretion, locomotion and reproduction—are performed. A complete vital activity in an organism not divided into cells indicates that the cellular structure is certainly not necessary for the carrying on of the living processes.

Some consider the mycetozoa as monocellular organisms of giant size. Others assume that the structure of the mycetozoa is, in the last analysis, cellular, because of the presence of numerous nuclei, the membranes of the cells having been resorbed in the evolution of these organisms. But either of these views is suggested by the cell theory itself, and to judge the adequacy of the theory one must confront it with uninterpreted facts.

(2) *The Phycomycetes.* Almost the entire class of fungi to which the common moulds belong, the phycomycetes, consist of a mycelium, that is, of a system of tubes, sometimes several centimeters long and about one fourth of a millimeter thick in which the protoplasm circulates back and forth as in the mycetozoa and in which there is no cell division at all. Only the reproductive cells separate off by cell walls. Two classes of fungi, which have much similarity otherwise with the phycomycetes, the ascomycetes and basidiomycetes, possess a mycelium divided into cells by transversal walls. We have therefore here, among closely related forms, cellular and non-cellular organisms, both performing their vital functions apparently with the same efficiency. The cellular structure is not, therefore, necessary for life.

(3) *The Siphonales.* What has just been said of the Phycomycetes applies also to an order of green algae, the Siphonales. Let us mention *Udotea,* which has the shape of a leaf 2 to 3 cm across; *Bryopsis,* which presents a finely branched arborescent habit and measures as much as 5 cm in height, and *Caulerpa,* which consists of leaf-like organs some 10 cm long carried on a rhizome provided with rhizoids. All these plants consist of a protoplasmic mass not divided into cells. In a closely related order, the Siphonocladiales, there are a few septa which are sometimes considered as cell walls separating giant multinucleated cells. It is clear that these latter plants represent an intermediate stage between the completely coenocytic and the definitely cellular green algae. As far as the vital functions are concerned, it would be difficult to state if they are enhanced, impaired or unaffected by the cellular structure.

II. Intracellular Differentiation

(1) *The Ciliates.* The ciliates are puzzling creatures on account of the highly differentiated characters which they present, despite their monocellular nature. Let us consider *Diplodinium,*[3] a ciliate which is par-

[2] Quoted by Sharp, in "An Introduction to Cytology," p. 7. Van Nostrand, 1921.

[3] See description by R. G. Sharp, in *Univ. Cal. Pub. Zool.,* Vol. 13, 1914.

ticularly remarkable in this respect. This animal has a rudimentary digestive *system,* including an esophagus and a tubular rectum. It possesses a nervous *system* which is endowed with several of the morphological features observed in metazoa, in particular, with a brain and a circumesophagal ring. The excretory system (the contractile vacuoles) is also a remarkably elaborate one. The presence, in a monocellular, of tubular rectum, an organ which in metozoa is always made of cells, the existence of a circumesophagal ring developed according to the same plan as in metozoa, where the cells are the building units, and the formation of other systems which have their cell-made equivalent in pluricellulars, all this shows that such systems do not require cells as structural units. In the three preceding sections it was concluded that the vital functions are possible without cellular structure, here we find that the systems which perform these functions develop without the intervention of cells.[4]

III. The Structure of Bacteria and Bacterioids

Whether or not bacteria are cells is, at present, an unsolved question. This fundamental point being unsettled, it can evidently not be raised as an argument against the cell theory. It should be noticed, however, that it is from the field of bacteriology that the cell theory has been most often frowned at. In other words, the inadequacy of the theory is felt throughout, although no definite argument can be formulated against it.

IV. The Infracellulars

(1) *The Chloroplastids.* It is a well-established fact that the chloroplastids metabolize, that they grow and that they multiply. Consequently, it would seem logical to consider them as living units. In fact, they are, in many respects, comparable to bacterioids. The bacteria, it is true, can be cultivated on various media, while the chloroplastids live only in protoplasm; this difference has probably had an important influence on the fact that the chloroplastids, unlike the bacteria, were never classified as biological species. The possibility that they are necessary parasites or symbiotic living beings did not receive the consideration that it deserves. Besides the general acceptance of the cell theory itself contributed to establish the view that they are mere cell constituents and can not be biological species. Our contention here is that the cell theory does not do justice to the biological properties of such units.

It might be of interest to notice, although this has no bearing on the present subject, the enormous quantity of living matter represented by the chloroplastids. If one could put them all together and compare this mass to that of the other forms of living matter, one would probably obtain the highest percentage of all. To have an idea of the rapidity of their growth and reproduction one has only to look at the grass and foliage-trees in the spring.

(2) *The Viruses.* Among the so-called viruses some have been identified as small bacteria; what has just been said of bacteria and bacterioids applies to them. The others are so much a puzzle that even their vital character is a subject of controversy. Since the nature of these latter is unknown, it can not be brought to testify against the cell theory. But, though formal testimony is lacking, circumstantial evidence is accumulating, mostly in the new findings on viruses. When it was reported, for example, that some viruses were obtained in the crystalline form, there was a movement of surprise among biologists and it was remarked that such a discovery, if confirmed, might require that we change our definitions of life and of a living being. It seems that the surprise is attributable mostly to the state of mind created by the cell theory and that abandoning the theory might suffice to remedy the trouble. It is clear that a body which has the dimension of a molecule or assumes the crystalline structure can not be a cell, but why should it be a cell?

V. The Nucleo-Cytoplasmic Constitution of the Cell

Since the cells of higher animals and plants consist almost always of cytoplasm and nucleus it was soon admitted that this structure is as universal as the existence of the cells. Though not essentially a part of the cell theory, this conception is often considered as such. Its influence on biological thought is intimately related with that of the cell theory. We shall mention here two sets of observations which speak against the theory of a necessary nucleo-cytoplasmic association for the performance of vital processes.

(1) *The enucleation of cells by the method of centrifugalization.* During the last century, numerous investigations which consisted in separating by some method of dissection (merotomy) the cytoplasm and the nucleus of a cell, resulted in the general conclusion that life is possible only when these two constituents are present in a certain state of organization. But during the last ten years, several of these experiments have been remade with a method which did not require the insertion of dissecting instruments into the cell, the method of centrifugalization. It has been possible by this method to separate the nucleus from the cytoplasm, to expel the nucleus[5] out

[4] C. O. Whitman, in his paper on the "Inadequacy of the Cell-Theory of Development," (*J. Morph.*, 8: 651, 1893), mentions another example (quoted from Gruber) of similarity in cellular and in intracellular differentiation. The membranellae formed on the monocellular organism *Stentor* have their morphological and functional equivalents in *Cyclas,* where they are made of cells.

[5] E. B. Harvey, *Biol. Bull.*, 71: 101, 1936.

of the cell and to stratify the cytoplasmic and the nuclear contents.[6] The results were that the cells so mutilated or disturbed were capable of further growth, division and differentiation.

(2) *The cells without nuclei of the Cyanophyceae.* According to modern plant cytologists there is a large number of Cyanophyceae (blue-green algae) of which the cells are without nuclei. This conclusion, it is true, has been reached only after a long period of hesitation, but the reason of the hesitation is to be found in the influence of the cell theory. The adventures of some investigators who wanted to find a nucleus in the cells of these plants would be amusing, if they were not a bit tragical. The Cyanophyceae were, for many years, considered as consisting of anucleated cells. Then it was found that they possess chromatin. This could do for a nucleus except that it was not aggregated in one mass, as in ordinary nuclei. So the notion of "diffuse nuclei" was created and readily accepted. But, a real nucleus should divide by mitosis. Sure enough, mitotic figures, although strange ones, having but a vague resemblance to typical mitotic figures, were observed. Finally, it was shown[7] that the chromatin of the Cyanophyceae has nothing whatever to do with the cellular division and that it appears to be an accidental and insignificant part of the cell. So now, as 50 years ago, the more plausible conclusion is that the Cyanophyceae consist of cells without nuclei.

In the case just mentioned the significant fact concerning the cell theory is the existence of cells without nuclei. That some investigators have been victims of the theory should not be brought as a charge against it, since it is not its content which is responsible for the mischief but the mere fact that it is a theory and, therefore, as we said, a dangerous tool.

The history of the development of the cell theory and its present status can be summarized as follows. One hundred years ago, Schleiden, a botanist, and Schwann, a zoologist, were struck by the fact that most plants and animals are built on the same plan, that is, by the juxtaposition of cells.[8] This interesting similarity led these two pioneers to generalize the observed fact. So they formulated the cell theory. During the one hundred years which have since elapsed, a number of new observations have been made which are not in good agreement with the theory: in particular, the existence of the coenocytes, their biological features, the similarity of differentiation in acellulars, monocellulars and pluricellulars, and the biological properties of infracellular units. Consequently, the theory of Schleiden and Schwann appears to the modern unbiased observer as a rather daring and unjustified generalization.

The body of biological knowledge which grew and developed so enormously during this century finds itself now enclosed in a tight carapace which hinders its further development. But our contention is that the carapace has cracked and that, after an instar period of one hundred years, the molting time has come. We invite the biologists, on the occasion of this centenary, to band together for removing the carapace.

A new theory will necessarily replace the old one. We expect that, in the elaboration of this new theory, consideration will be given to the fundamental fact that in the higher animals, when the developing embryo has reached a certain size, it undergoes a division into metameres, superimposed to the division into cells, while the less differentiated and usually smaller organisms (as the hydra) do not divide into metameres but have ordinarily their body partitioned into cells, and the smallest and least differentiated forms (as the bacteria) do not present any known partition. According to a new theory based on these principles, the cell would then cease to be the "fundamental structural and functional unit" of any living matter and the cellular structure would become, in the last analysis, simply one of the various methods used by nature to partition a large mass of protoplasm.

OBITUARY

ROYAL NORTON CHAPMAN

ON December 2, 1939, died Royal Norton Chapman in Minneapolis, after a short illness, and thereby was removed from active service in the science of animal ecology, one of its most distinguished servants.

Royal Norton Chapman was born in Morristown, Minnesota, on September 17, 1889, and after preparatory work at Pillsbury Academy in Owatonna, he entered the University of Minnesota, taking the degree of B.A. in 1914 and M.A. in 1915. Following this he was Schuyler fellow in entomology at Cornell University, taking his doctorate there in 1917. His University of Minnesota appointments began as a scholar in animal biology, in 1912, and ended as dean of the graduate school and professor of ecology, beginning July 1, 1939. In the interim he was a Guggenheim Memorial Foundation fellow, and traveling professor of the International Education Board of the Rockefeller Foundation, 1926–1927, and for nine years, from 1930 to 1939, the director of the experiment

[6] H. W. Beams and R. L. King, SCIENCE, 84: 138, 1936.

[7] G. Poljansky and G. Petruschewsky, *Arch. Protistenk.*, 67: 11, 1929.

[8] *Cf.* the title of Schwann's mémoire.