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THE SCOPE OF PROTOZOOLOGY[1]

TWENTY-ONE years ago when I first began the study of protozoa, biologists in general were inclined to look upon these animals mainly as a means of entertaining amateur microscopists in their idle hours. Since then the subject has developed in widely different directions and protozoa have found a place in the deeper problems of biology; indeed, they are considered important enough to warrant the establishment of several chairs of protozoology in different parts of the world.

I am frequently asked to tell what protozoology is, and occasionally find difficulty in correcting the impression that a protozoologist is a primitive and undeveloped zoologist; but difficult as this sometimes is, I find even greater difficulty in giving an adequate idea of the scope of protozoology. I have chosen, therefore, as the subject of this lecture, this very general topic. In it I have no pet hypothesis to develop, nor scientific nut to crack, but desire only to point out the nature of the work done in protozoology as a basis for a definition of its scope.

Up to 1890 the work on protozoa was largely descriptive. The first discoveries by Leeuwenhoek in 1675 gave a new lease of life to the theory of spontaneous generation which had received some hard knocks through the direct experiments of Redi, Malpighi and Harvey. The new discoveries with the microscope merely added fuel to the fire of the later nature philosophers, which, however, mostly went up as smoke theories, such as that of organic transmi-

[1] Lecture delivered at the Marine Biological Laboratory, June 30, 1911.

gration, as developed by Buffon in France, and Needham in England. These naturalists saw in the Leeuwenhoek animalculæ only the disintegrated and free-living parts of higher animals and plants. It can not be stated positively, but there is nevertheless some reason for believing that the smouldering embers of this philosophic fire were kept alive by Oken and Goldfuss in Germany, and by Bichât in France and finally fanned into the full blaze of the cell theory by Schleiden and Schwann, ninety years afterwards.

In the meantime the work of O. F. Müller (1786), and especially that of C. G. Ehrenberg (1833–1838) and F. Dujardin (1835–1841) had resulted in some taxonomic order amongst these microscopic forms which Cuvier had generously included in the animal kingdom under the name of chaos animalculæ. Other important steps were taken by von Siebold in 1845 who first described protozoa as single-celled organisms; by Max Schultze in 1863, who showed that the living substance "sarcode" of protozoa is the same as the living substance "protoplasm" of higher animals; and by Bütschli in 1875 who gave the final evidence in support of the unicellular nature of protozoa by showing that the nucleus of the protozoan cell is similar to that of the tissue or egg cell, and like the latter, divides by karyokinesis.

Bütschli's later work of 1882–88 gave the real ground work on which modern protozoology rests. Summarizing all of the preceding discoveries and bringing together the disconnected observations and theories of his predecessors, he gave us in these approximately 1,700 pages of acute criticism careful observations, lucid descriptions and logical deductions, a masterful zoological treatise such as rarely appears in these days.

I have arbitrarily chosen the year 1890 as a dividing point in the history of protozoology. Before this the work was chiefly descriptive and taxonomic, after this it became more speculative and experimental, although it also developed along the quite unexpected lines of practical biology and public hygiene. For my purpose here I shall not speak of the splendid descriptive work, especially on parasitic forms, that has been done since 1890, but will devote my time to a short statement of the activities in certain other lines of protozoology, especially the cytologic, pathogenic and general biological.

I. THE CYTOLOGIC SIDE

In a strict sense all work on protozoa might be classed as cytological since it has to do with the single cell. But there are two ways of looking at these cells. We may regard them, on the one hand, as morphological units of structure comparable with the single tissue cell, or, on the other hand and following Whitman in his interpretation of the egg cell as an organism, we may regard them as complete organisms performing all of the functions of higher animals. Looked at from this point of view the inadequacy of the cell theory as applied to protozoa is obvious.

In a strictly morphological sense then protozoology includes the study of cell structures homologous with the morphological elements of egg and tissue cells—but these structures are more primitive, more generalized, and, in a sense, more easily correlated with their functions in the cell.

First, as to the structure of protoplasm. We are generally agreed at present that it is inaccurate to speak of any one structure as common to all protoplasm, but many cytologists, amongst whom Bütschli, working chiefly on protozoa, was the first, believe that the different types are referable to one common generalized type which Bütschli described as alveolar in structure. A simple example of such modification of the alveolar into denser plasm can be easily demonstrated in the protruding pseudopodium of *Amœba proteus*. Here the endoplasmic alveoli become drawn out into ellipsoidal forms, the alveolar walls come together and fuse, forming the characteristic denser ectoplasm. Another good example of the same metamorphosis may be seen in the formation of the temporary membrane which appears between the ectoplasm and the endoplasm of *Actinosphærium eichhornii*.

Second, as to nuclei. The study of protozoan nuclei has taught us that a definite, formed nucleus is not essential for cell life. There are many cases amongst the protozoa where there is no morphological nucleus, but the functions of this organoid of the cell are presumably performed by fragments of chromatin distributed throughout the protoplasm. Such is the case, for example, in *Dileptus gigas*, where each granule at cell division elongates and divides. When formed nuclei are present they are provided with a firm and thick membrane which does not disappear during division as in nuclei of higher animals and plants. The chromatin also, is not arranged in a reticulum as in higher forms, but is usually massed in one or several solid bodies termed karyosomes. These have often been called chromosomes, but such use of the term is incorrect, for these karyosomes in many cases break down into finer granules which are secondarily fused into elements strictly homologous with chromosomes of higher forms. In the protozoa therefore we have abundant material for working out a possible evolution of these important elements of higher cells, from generalized conditions of the parasitic amœbæ to the formation of primitive chromosomes in *Noctiluca* or *Paramecium*. In such primitive forms the number of chromosomes is always greater than in metazoa, more than two hundred having been counted in *Paramecium caudatum*.

Third, as to the centrosome. Cytological study of protozoa gives much more direct evidence of the function of this organ of the cell than does its study in egg or tissue cells. In protozoa it is undoubtedly a kinetic center of the cell in the sense of being the central organ in different types of movements. Many types of Heliozoa, such as *Acanthocystis* or *Sphærastrum*, have a definite central granule in the resting cell. At division periods this divides and forms a spindle; the nucleus is drawn into the nuclear plate and connected by fibers with the divided centrosome, and the outcome is a typical karyokinetic figure. After division the spindle fibers and astral rays grow out from the central granule to form the axial filaments of the actinopodia, which in some species of *Acanthocystis* and *Artodiscus* have a vigorous springing movement. In *Dimorpha* both actinopodia and flagella are present and, both having the same origin, we are led to the conclusion that flagella, in this case at least, are little more than naked axial filaments. Similarly, in various types of flagellates, *e. g.*, *Trypanosoma, Herpetomonas, Crithidia*, etc., the flagellum forms by outgrowth from the centrosome thus proving the intimate connection between the locomotor apparatus of the organism and its centrosome.

In many cases this kinetic center is inside of the nucleus—giving what Boveri called the centronucleus type of nucleus. In such cases the axial filaments of *Heliozoa* abut against the nuclear membrane (*e. g.*, in *Actinophrys, Actinosphærium, Camptonema*, etc.), and during division the intra-nuclear centrosome divides first. In all cases the kinetic center appears to be formed from chromatin, or at least from nuclear material and seems to be made up of a special kind of nucleoplasm. Frequently, as in *Trypanosoma*, *Trypanoplasma* and allied forms, the kinetic center emerges from the nucleus as in *Heliozoa*, but is accompanied by a small amount of chromatin thus forming a second nucleus which Woodcock has aptly named the kinetonucleus. Such double nuclei, which, it may be pointed out, are in no way homologous with the dimorphic nuclei of infusoria, have led Hartmann, Nägler, Prowazek and some others to form a special group of protozoa termed the *Binuclearia*. The point of view leading to this artificial group has been ably criticized by Dobell.

Fourth, as to chromidia. Goldschmidt and others of the Munich school have interpreted a number of indeterminate structures of tissue cells as chromidia or granules of chromatin discharged from the nucleus. Waiving the question for the present as to whether such objects are chromidia or chondriosomes of unknown origin, there is no doubt whatever that chromidia of nuclear origin occur in protozoa and play a most important rôle in their vital processes. In rhizopods especially, chromidia are formed during, or prior to, the period of maturity, by nuclear secretion, nuclear dissolution or nuclear fragmentation, the granules becoming individually, or after fusion, the nuclei of conjugating gametes. It thus becomes possible to speak of a special germ plasm in protozoa as distinct from somatic plasm. Such chromidia are to be distinguished from the products of nuclear degeneration which occur under abnormal conditions of feeding or environment and which are more analogous to nuclear degeneration and granulation-tissue formation in higher animals.

There remain many lines of research in protozoan cytology, especially in the direction of maturation and fertilization phenomena, only a few forms having been adequately studied. The enigmatical third division in maturation has evidently some connection with sex, since this division is heteropolar in *Didinium*, *Paramecium caudatum* and *P. bursaria*, the smaller nucleus migrating, the other stationary, during conjugation. Splendid results lie at the end of patient study in this line of research.

II. THE PATHOGENIC SIDE

The development of this branch of protozoa study was so rapid and so spectacular and seemed to arise so unexpectedly out of a clear field, that many investigators, especially pathologists and other medical men, are inclined to regard it as constituting the whole of protozoology. Up to 1890 only two human diseases were suspected of being caused by protozoa. These were dysentery and malaria. To-day more than fifteen human diseases are known or suspected to be of protozoan origin.

Parasitic amœbæ were first observed in the human intestine in victims of dysentery by Lösch in 1875. He had no hesitation in claiming them to be the cause of dysentery and named the organism *Amœba coli*. Other pathologists, however, soon found similar organisms in the intestines of normal men and Lösch's claim was discredited. Councilman and Lafleur in 1891 found two types of amœbæ, one of which—*A. coli*—was considered a harmless commensal, the other, which they called *Amœba dysenteriæ*, they claimed to be the cause of tropical dysentery. Casagrandi and Barbagallo in 1897 were the first to actually prove that the *coli* form is harmless. They also suggested the new generic name *Entamœba* for these parasitic amœbæ, believing that the differences between them and free forms like *Amœba proteus* are great enough to justify a generic distinction. In this they were followed by Schaudinn in 1903, who succeeded in causing dysentery in cats by feeding them with isolated cysts of the pernicious type which, ignoring the prior specific name *dysenteriæ,* he called *Entamœba histolytica.* The harmless type he called *Entamœba coli* and confirmed Casagrandi and Barbagallo by repeated experiments on cats and upon himself.

Similarly with malaria a few observations were made prior to 1890, but the most valuable work was done after that date. In 1881 Laveran, a French military doctor in Algiers, discovered organisms in the blood of malaria victims. He announced them as the cause of malaria under the name *Oscillaria malariæ,* this generic name being changed four years later to the more incongruous name of plasmodium by Marchiafava and Celli. Another important point was made by Golgi in 1886, in demonstrating that the characteristic paroxysms of the victim coincide with the simultaneous reproduction of the parasites.

It is impossible here, to give the names of the scores of observers who have added some point or other in connection with these parasitic organisms, or to give credit for the first suggestion as to their mode of transmission. After the facts of transmission were proved, numerous claimants of the honor of first suggesting the possibility of mosquitoes carrying malaria or yellow fever, turned up. Theirs is but an empty honor, however, and I dare say they are entitled to all the glory they can get from proclaiming their clairvoyance from the house tops. We are, however, justified in having no little national pride in the fact that two of our countrymen, Smith and Kilbourne, in 1893 actually proved for the first time the transmission of disease-causing protozoa by blood-sucking arthropods. The honor for their discoveries and patient observations and experiments on Babesia in connection with Texas fever in cattle was not shouted from the ridge pole, but came with the fact that their results were immediately applied to human diseases. To Smith and Kilbourne, then, belong a great part of the credit and honor of paving the way to the present-day control of malaria and sleeping sickness, and the practical extinction of yellow fever in epidemic form.

The repeated suggestions that mosquitoes might transmit malaria were brilliantly proved true by Ross in India in 1897–99, and Grassi, Bignami and Bastianelli in 1898–99 in Italy. The former showed that bird malaria is transmitted only by species of *Culex,* the others, that various types of human malaria are transmitted solely by species of *Anopheles.* Stages in development of the parasites in the mosquitoes were made out by Grassi and others, and the last step was taken in the direction of proof by Schaudinn, who, in 1902, watched under the microscope, the penetration of his own blood corpuscles by sporozoites fresh from the proboscis of an infected mosquito.

The transmission of yellow fever by mosquitoes of the genus *Stegomyia* was proved in 1900–01 by the American commission consisting of Reed, Carroll, Agramonte and Lazear, and so clearly and minutely was the prophylactic routine worked out, that epidemics of yellow fever are now a matter of history. Should one occur in any civilized community, it would surely indicate ignorance or criminal carelessness on the part of the health authorities. The cause of yellow fever, however, is still unknown; when discovered, the cure for the disease will surely follow just as its prevention followed the discovery of its mode of transmission.

After the malaria problems were cleared up, discoveries of other protozoan diseases followed in quick succession. Kala azar, dum dum fever, oriental sore and allied diseases of the far east, were found by Leishman, Donovan, Wright, Christophers, Patton and others, to be due to a flagellated protozoon of the genus *Herpetomonas,* and transmitted by bed bugs.

Sleeping sickness, the great scourge of central Africa, was hunted down by the indefatigable David Bruce in 1903, who showed that it is transmitted by a tse tse fly, *Glossina palpalis.* This discovery followed his brilliant researches of 1894–97 when he traced the cattle disease called "nagana" and the "tse tse fly disease" of cattle to the same protozoon—*Trypanosoma brucei*—and showed that a tse tse fly—*Glossina morsitans*—is the intermediate host. The final observations on human sleeping sickness were possible through the earlier discoveries by Lewis in 1879 on a trypanosome of the rat; by Forde (1901) and Dutton (1902) of a trypanosome in victims of Gambia fever which was regarded up to that time as distinct from sleeping sickness. This organism was named by Dutton *Trypanosoma gambiense.* Also, in 1903, Castellani discovered a trypanosome in the cerebrospinal fluid of victims of sleeping sickness and named it *Trypanosoma ugandense.* Bruce showed that the trypanosomes of the two diseases are the same and that Gambia fever is the initial phase of the fatal disease.

Time does not permit even the naming of other species of trypanosomes found in warm- and cold-blooded animals; nor of the many researches that have resulted in the discovery of intermediate hosts amongst leeches, flies and lice. Much has certainly been accomplished, but there still remains a great and undeveloped field for research in the life histories of the various species.

Perhaps the most spectacular discovery in connection with protozoa and disease was that of Schaudinn in 1905, when in a short publication he announced the discovery of spirochætes in syphilitic lesions. This modest little paper of four or five pages has been the inspiration of thousands of titles, most of which have added little or nothing to Schaudinn's original work, the majority dealing with technical methods, a few with morphological changes and the life history, and a few, notably Robert Koch's, with treatment. Other spirochæte diseases, such as yaws or frambesia, human relapsing fever and tick fever, or diseases of cattle and poultry, have been shown to be transmitted by ticks of one species or other, but *Treponema pallidum,* as Schaudinn finally called the spirochæte in syphilis, is apparently transmitted solely by contact.

One of my students this spring made the comment that most of the references I had given in connection with pathogenic protozoa seemed to fall within the period of 1900–05. The observation was entirely correct and the fact is undeniable that the last five years have given little of value in this branch of protozoology, while in the preceding five-year period not only were the majority of protozoan diseases discovered and their means of transmission established, but that period gave us Mesnil and Mouton's method of cultivating parasitic amœbæ on artificial media, and the brilliant researches of Novy and MacNeal resulting in an entirely new method for the study of parasitic flagellates. Since that period few new discoveries have been made; culture methods have been extended to the spirochætes and some good observations have been made on the interrelationships of parasitic flagellates and hæmosporidia. In my opinion, however, this branch of protozoology has seen its period of greatest development and, save for the working out of life histories, the protozoologist may well turn over the pathogenic protozoa to the departments of medicine, public hygiene and public sanitation.

In preparing this lecture I was tempted to dwell longer on this interesting and important phase of protozoology and to give a detailed account of the trials and difficulties experienced in establishing the causes of protozoan diseases. Also I should like to speak at length on the probable causes of smallpox, scarlet fever, rabies, trachoma and molluscum contagiosum, and about the many fruitless attempts to trace human cancer to protozoa, but I must hasten on to a third, and, as I believe, the most important, branch of protozoology, general biology.

III. THE BIOLOGICAL SIDE

Here the field of protozoology expands so widely that I can speak of only a few topics, for the problems are fundamental and universal and merge into those which every biologist is striving to solve.

Verworn in 1888 made the statement that protozoa seem to have been especially adapted by nature for the purposes of the physiologist, for here, in the single cell, are performed all of the functions which higher animals perform. This was twenty-three years ago and the fact that strikes us to-day is that, in spite of the vast amount of work done in the subject, these same fundamental vital activities remain almost as obscure as they were then. Some progress, nevertheless, has been made. The early experiments of Balbiani, Verworn, Gruber, Hofer and a score of others demonstrated that enucleate fragments of cells could not secrete, grow nor continue to live, while Verworn in 1891 showed that the isolated nucleus is equally impotent. The axiom was thus laid down that nucleus and cytoplasm are equally important for the proper performance of vital activities.

At this earlier period it was thought that great light would be thrown upon the vital functions of higher animals through study of the simpler activities in protozoa, especially in the directions of (1) digestion and assimilation, (2) irritability, (3) growth and reproduction, (4) regeneration, (5) sex and fertilization, (6) death and physical immortality, etc., but it was soon discovered that under the mask of simplicity lie hidden the same great problems which puzzle biologists in every other field of study. Let me illustrate briefly some of these points.

1. *Digestion and Assimilation*.—The early observations by Le Dantec, Meissner, Fabre-Domergue, Greenwood and others from 1888–1894 demonstrated the presence of some mineral acid in connection with proteid digestion in different types of protozoa, and it was suggested that some simple ferment, acting in an acid medium, is responsible for digestion in these single cells. This suggestion was confirmed by Hartog and Dixon in 1901, who isolated a proteolytic ferment active in an acid medium; but the subject became more complicated when Mouton and Mesnil in 1902–03 isolated a proteolytic ferment that was active in an alkaline medium, and suggested that the digestive ferment in protozoa is more like trypsin than pepsin. Finally, Nierenstein and Metalnikoff, in 1903–07 showed that both types of ferment are involved, digestion beginning with

an acid reaction, followed by an alkaline reaction, and conforming in a general way with the digestive processes in higher animals. Few physiologists have attacked the problem of assimilation in protozoa. Verworn, however, in his "Biogenhypothese," has outlined a theoretical conception of the combination of protoplasm molecules with the products of proteid digestion and based on the Ehrlich side-chain hypothesis.

2. *Irritability.*—Jennings's splendid studies on the behavior of protozoa and lower metazoa have shown that all forms can not be interpreted as simple units of protoplasm reacting to all external stimuli by the same simple reflex. A *Poteriodendron,* on its simple protoplasmic and filamentous stalk, has but the one reaction, contraction of the stalk, but a *Stentor, Vorticella* or *Paramecium* has not only one but several forms of reaction which are frequently so coordinated as to defy analysis. The reactions, furthermore, vary apparently with the physiological state, or, presumably, with physical and chemical states of the protoplasm. Protozoa are thus similar to the lower metazoa and, with them, have been drawn into the field of comparative psychology.

3. *Growth and Reproduction.*—Spencer's theory of growth and reproduction was soon found to be as unenlightening with protozoa as with higher forms and deeper interpretations have been sought. Few have undertaken to formulate any theory of cell division from protozoa alone, but Hertwig in 1902 advanced a physical theory of growth and division based on his protozoa studies, which has had no little influence. This is now known as the "Kernplasmaspannungstheorie," or the nucleus-plasma-tension theory. Briefly stated, this theory is based upon the view that the ratio of nuclear mass to cytoplasmic mass is constant under certain normal conditions of the cell, and may be expressed by the ratio N/P. If either factor is increased without increase of the other, an "abnormal" condition ensues. If the P factor increases, as it does with growth, an increasing tension in the cell results in a disturbance of the nuclear conditions and an incitation to regulation by division. If, on the other hand, the nucleus plasma ratio is changed to the advantage of the nucleus, chromidia formation and cell degeneration are the outcome.

The bare statement of this theory makes it appear crude and infertile, for it is difficult to see how mass relations can be the cause of growth, division or depression, but if we see in the varying ratio of nucleus to cytoplasm only an index of the chemical interchange going on all the time between the several parts of the cell, and interpret such variations as effects rather than as causes, a more plausible explanation of the morphological relations of nucleus and cytoplasm is obtained. That excess of nucleus does not cause degeneration is shown by a simple experiment. If we cut *Paramecium caudatum* as shown in Fig. 1, *a,* the cut cell does not regenerate in the majority of cases, but divides in the original central plane of the organism (*b, c*). As a result of this division one normal (*d,* anterior) and one abnormal (*e,* posterior) cell results. The nucleus

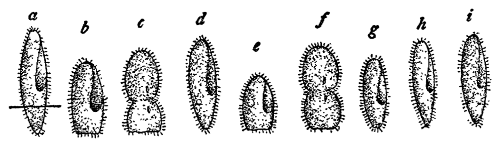

FIG. 1. Absence of regeneration in a cut *Paramecium caudatum.* *a,* normal cell showing plane of cut; *b,* anterior truncated fragment; *c,* division of truncated fragment in original center of cell; *d, e,* normal and truncated cells resulting from this division; *f,* division of second truncated cell.

divides equally as though the cell were perfect, hence the posterior cell has a reduced cytoplasm and a full size nucleus, or the ratio N/P is changed to the advantage of the nucleus. Nevertheless, this cell, in some cases at least, grows and divides again without regenerating the lost part and a second abnormal division (f) results in a second abnormal cell and a normal cell. Ultimately, however, the abnormality is lost and the normal form regained. Here, something more subtle than mass relations is at work and we are justified in looking for important results from the further study of protozoa along these experimental lines.

4. *Regeneration.*—The power of regeneration of the cell, also, is much less extensive than we were led to believe by the early experiments of Balbiani, Verworn, Gruber, Hofer, Prowazek and others. It seemed to follow from their experiments that any fragment of a protozoan, provided it contained some nuclear material, would regenerate quickly into a normal cell. Lillie showed that a piece as small as one twenty-seventh of the original animal would develop into a normal *Stentor*. The power to regenerate, however, varies not only in different races of the same species of protozoa, but also in the same cell at different inter-divisional ages. In four different races of *Paramecium caudatum* I have found that in one race only about one per cent. regenerated after cutting; in another about 10 per cent. regenerated; in a third race about 30 per cent. and in a fourth about 90 per cent. Here, then, is a well-marked racial difference in respect to regeneration.

Again, if we cut the large hypotrichous ciliate *Uronychia transfuga* just after division, both fragments will contain parts of the macronucleus, but only the micronucleus-holding fragment will regenerate. If cut from six to eight hours after division the result is the same, although the non-regenerating fragment lives for days. But if we cut the cell just prior to cell division, both fragments regenerate perfectly except for the absence of a micronucleus in one. The power to regenerate, therefore, varies in the same cell from a minimum just after division to a maximum just prior to division, a phenomenon lending support to the view that certain stuffs are accumulated during cell life up to a condition analogous to saturation, when the reaction follows, in this case regenerative processes. With such activity the accumulated stuff is used so that regeneration does not follow mutilation immediately after, or for some time after, cell division. Certainly the generalization that nucleated fragments of protozoa will regenerate is not well founded.

Similarly with other early generalizations. The classic experiments of Maupas seemed to prove that Weismann's theory of the potential immortality of protozoa was wrong. Later research confirmed Maupas in the main, until to-day Weismann's theory, in its original form at least, is untenable, protozoa having the same potential of immortality that metazoa have, no more and no less. Later research, however, has given highly variable results in studies of the life history, and again we find an individuality in different races of the same species. Woodruff's remarkable and enigmatical results with *Paramecium caudatum,* for example, show that earlier conclusions and generalizations were premature.

One general conclusion, however, seems to be well established, viz., that the protozoon's life history runs in cycles of asexual and sexual phases. The beautiful work of Schaudinn in 1899, on the life cycle of *Coccidium schubergi,* gave the model followed by subsequent investigators in working out life histories of other forms, and there is no doubt now that the protozoon life cycle involves more or less definite asexual and sexual periods. In parasitic protozoa the sexual phase, including maturation, conjugation and fertilization, undoubtedly leads to renewed vigor of the race, or to a new power of asexual development, and to this extent at least, the time honored view of Bütschli's (1876) that conjugation is a means of the "Verjungung" or rejuvenation of the cell, is warranted.

Associated with these alternate phases in the life history are the remarkable changes which accompany development of the sexual phase. These, involving the problems of sex, are particularly important in connection with the nuclear changes whereby a specific germinal chromatin is formed, sometimes at an early stage, in the asexual phase, and persisting as a germ plasm until used in the formation of gamete nuclei.

I have now given enough of the scope of protozoology to indicate that the protozoologist, far from being a strict specialist, rather immodestly claims the greater part of the whole field of biology as his own, and I would define protozoology, therefore, as that branch of the biological sciences which deals with the application of biological problems to, and with search for their solution in, the lowest group of animal organisms—the Protozoa.

Gary N. Calkins

SYNTHETIC METALS FROM NON-METALLIC ELEMENTS[1]

It is one of the most striking facts of chemistry that three fourths of all the elements are metals. But it is no less remarkable that metallic properties are confined exclusively to elements in the free state or, in case of alloys, to combinations of typically metallic elements.

In recent years the theory of the nature of the metallic state has been steadily developing into more and more precise form, so that to-day we have, in the electron theory of matter, a very satisfactory explanation for all of the characteristic properties of metals. Inasmuch as it is just a century since Davy proposed his celebrated metallic ammonium theory, we may now well consider whether metallic properties are, of necessity, confined to elements in the free state.

During the last two decades a vast amount of experimental evidence has been accumulating that electricity is granular in structure, though such a conclusion was strongly indicated three quarters of a century ago by Faraday's discovery of the facts epitomized in the law of electro-chemical equivalents as first pointed out by Helmholtz in 1881. The granules or ultimate atoms of electricity are now called corpuscles or electrons. The charge of the electron is negative in sign. In fact we have decisive experimental evidence of only this one kind of free electricity, positive electrification of a body, being from this standpoint merely a deficiency of electrons.

J. J. Thomson has shown how from the conception of an atom made up of electrons rotating in a sphere of positive electrification, there follows a simple explanation of many of the properties of an atom, including valence; a univalent atom, if negative, being one that can gain an electron, if positive, one that can lose an electron. A bivalent can gain or lose two electrons. A trivalent atom, three, etc. According to this hypothesis the most fundamental property of an atom of an element is this

[1] Read at the meeting of the American Chemical Society, Minneapolis, December, 1910.