must obviously have gone off the branches—either to ordinary ones or to pairs of fruit-spikes.

Myriads of the vegetable fragments both from Oldham and Halifax are drilled in all directions with rounded insect or worm borings, and further traces of these xylophagous animals are seen in innumerable clusters of small Coprolites of various sizes; the size of those composing each cluster being uniform.

Desirous of verifying Count Castracane's alleged discovery of Diatoms in coal, specimens of twenty-two examples of coal from various localities in Yorkshire, Lancashire, and Australia were reduced, after the Count's method, to a small residue of ash. This work was done for me in the chemical laboratory of Owens College through the kindness of Professor Roscoe. Like Mr. F. Kitton, of Norwich, the Rev. E. O'Meara, of Dublin, and the Rev. G. Davidson, of Logie Coldstone, I have failed to discover the slightest trace of these organisms in coal.

The last objects described are some minute organisms from the Carboniferous limestones of Rhydmwyn, in Flintshire, and which were supposed by Professor Judd to have been siliceous Radiolarians from which the silica had disappeared and been replaced by carbonate of lime. I fail to find any confirmation of this conclusion. The objects appear to me to constitute an altogether new group of calcareous spherical organisms that may either have been allied to the Foramnifera, or have had some affinities with the Rhabdoliths and Coccoliths. I have proposed for several species of the organisms the generic name of *Calcisphæra*. Myriads of objects of similar character, but of larger size, constitute the greater portion of a Corniferous limestone from the Devonian beds of Kelly's Island, U.S.A.

II. "Observations on the Physiology and Histology of *Convoluta Schultzii*." By P. Geddes. Communicated by J. Burdon Sanderson, M.D., F.R.S., Professor of Physiology in University College, London. Received March 10, 1879.

Part I.—*Physiology*.

Chlorophylloid green colouring matters are known to exist in the tissues of a not inconsiderable number of animals belonging to very various invertebrate groups—Protozoa, Porifera, Cœlenterata, Vermes, and even Crustacea;* but all information as to the function of chlorophyll in the animal organism is wanting. Wöhler, it is true, found many years ago that *Chlamydomonas*, *Euglena*, &c., evolve oxygen in sunlight, and Schmidt prepared from *Euglena viridis* a body isomeric

* See list in Sach's "Botany," Eng. ed., p. 687, note.

with starch, though of widely different properties, his paramylon;* but these facts seemed as much to point towards the algoid nature of these long disputed organisms† as to warrant our supposing a more or less vegetable mode of life in animals so well organised, and so evidently carnivorous as Cœlenterates and Turbellarians, especially as the only recorded experiment, that of Max Schultze‡ on *Vortex viridis*, yielded a totally negative result. Some such hypothesis, however, can hardly help recurring to the observer of the light-seeking habit of *Hydra viridis*.

Last spring, when at the Laboratoire de Zoologie Expérimentale of M. de Lacaze-Duthiers, at Roscoff, I was much interested by the green Rhabdocœle Planarian,§ *Convoluta Schultzii, O. Schm.*, crowds of which, lying at the bottom of the shallow pools left by the retreating tide, resembled at first sight patches of green filamentous algæ. Their abundance in fine weather on the surface of the white sand, covered only by an inch or two of water apparently to bask in the sun, was very striking, at once suggesting that their chlorophyll thus so favourably situated must have its ordinary vegetable functions. I accordingly returned to Roscoff in the autumn to make experiments.

The mode of procedure was evidently to expose the Planarians to sunlight to observe whether any gas was evolved, and if so to analyse it qualitatively and quantitatively. After one or two trials a form of apparatus—the simplest possible—was found, which answered admirably. It merely consisted of a couple of the round shallow glass dishes used in the laboratory as small aquaria, the edge of one fitting as nearly as possible, when inverted, into the bottom of the other. Into the larger vessel were put Planarians enough to cover the bottom; it was then gently sunk in the pneumatic trough (a tub of sea water), and the smaller, also full, inverted into it. The apparatus was then placed on a shelf in the sunshine, and left to itself. The movements of the animals were greatly accelerated by the exposure, and in a quarter of an hour minute bubbles of gas were to be seen in the film of mucus plentifully secreted by the Planarians. These bubbles rapidly increased in number and volume until they buoyed up the whole sheet of mucus with its entangled Planarians and grains of sand to the top of the water in the inverted dish. Here the evolution of gas continued more actively than ever, until the animals had disengaged themselves and descended to the bottom, there to recommence as before, the mucus meanwhile dissolving and allowing the bubbles freely to unite. Thus the first half of the inquiry was answered in the affirmative.

* Gorup Besanez, "Traité d'Analyse Zoochimique," p. 127.

† *Euglena* is claimed by both Sachs and Claus in their manuals of Botany and Zoology respectively.

‡ "Beiträge zur Naturgeschichte der Turbellarien."

§ "Neue Rhabdocœlen." Wiener Sitzungsb., 1852.

The determination of the nature of the evolved gas was readily effected. On transferring the quantity produced in one or two vessels to a small test-tube, and plunging into it a match with red hot tip, there was to be seen the white glow characteristic of dilute oxygen. A large glass tube of tolerably even calibre, about 75 centims. long, was sealed at one end, and bent at about two-thirds of its length from that point at an angle of 60°. It was then filled with water, and the water in the long sealed arm almost entirely replaced by gas at the pneumatic trough. This comparatively large quantity of gas, about 60 centims. cube, was obtained by exposing a dozen or so of apparatuses exactly similar to that described, except that bell-jars, sealed funnels, &c., sometimes replaced the upper flat dish, and white soup plates the lower. They were set agoing about noon, and the abundant gas yielded by thus exposing a surface of nearly a third of a square metre covered with Planarians was collected at sunset.

On agitating the gas with a solution of potassic hydrate a barely appreciable absorption of carbonic anhydride took place, but on the addition of pyrogallic acid with renewed agitation, the intense brown coloration, with rapid and considerable ascent of the fluid in the long arm of the tube, confirmed the presence of a large percentage of oxygen.

The results of many experiments varied from 43 to 52 per cent. of oxygen; the higher number representing the amount of gas given off by freshly collected Planarians, and the lower that yielded on the second or third day of their subjection to experiment. In order to judge of the degree of accuracy which I could obtain by this rough method of analysis, I estimated by it the oxygen of common air, and obtained 19·9 per cent. instead of 20·9. Allowing for this loss of about 5 per cent., it may safely be asserted that the gas evolved by these animals does not contain less than from 45 to 55 per 100 of oxygen.

The Planarians are little the worse after a 24 hours' journey from Roscoff to Paris, and when placed in an aquarium they instantly betake themselves to the side next the window, and live there resting on the bottom or clinging to the side for four or five weeks without food. They certainly diminish considerably in size, yet I have little doubt that they go on decomposing CO_2 and assimilating the carbon even in the dull winter daylight, for when kept in darkness they generally died much sooner.

The conspicuousness of the Planarians on the sandy beach, far from the shelter which rocks or algæ might afford, has been already mentioned, and at first sight one is apt to think that they must be the easy prey of all the larger shore-frequenting animals, and to wonder that so many escape. But the observation made by Wallace and Belt for so many higher animals—that conspicuously coloured forms are

nauseous and uneatable—holds good here. So strong and disagreeable is the odour, to which the taste doubtless corresponds, that this alone might be relied upon as a protection against the least fastidious of fishes or Crustaceans.

The chemical examination of the animal yields results of interest. Treated with alcohol, a yellow substance, contained in small elongated vesicles, aggregations of which are dotted over the integument, dissolves out very rapidly, yielding a golden solution without definite spectrum. This has of course nothing to do with xanthophyll. Continued treatment with alcohol dissolves out the chlorophyll, of which the magnificent green solution is tolerably permanent. As former observers have shown, it has a red fluorescence, and gives a spectrum closely resembling that of vegetable chlorophyll.

Knowing that these animals decompose carbonic acid, and evolve oxygen, one naturally enquires whether they do not still more completely resemble green plants in fixing the carbon in the same way. To answer this question, the residue of the Planarians, coagulated and decolorised by repeated treatment with alcohol and ether, was boiled with water, and filtered off. The clear solution gave with iodine solution a deep blue coloration, which disappeared on heating, and reappeared on cooling, indicating the presence in quantity of ordinary vegetable starch.

To separate and purify this starch on a large scale, some hundred grammes of Planarians were repeatedly boiled in water. The solution (which had an intensely alkaline reaction) was treated with four or five times its bulk of strong alcohol, and allowed to stand for some days. The flocculent precipitate was collected, decolorised with ether, and washed with cold water. A great part of it dissolved, leaving the starch behind, and the filtered solution gave with iodine the red-brown coloration characteristic of dextrine. To ascertain whether this dextrine was naturally present, or had merely been produced at the expense of the starch by boiling in alkaline solution, fresh animals were treated with cold water, but the solution contained no dextrine. Treatment of a fresh microscopic preparation with iodine showed the presence of glycogen, in the colourless amœboid cells of the mesoderm, but there is no chemical means of separating glycogen from starch. Probably the best way of obtaining pure starch from these animals would be by imitating the mechanical process of the potato mill.

The intense alkalinity of the animals is very striking. Even in the fresh state, but still more when dried in the warm chamber, they give off vapours with an odour resembling that of trimethylamine, and in such abundance as to cause neighbouring solutions to yield the reactions of an alkaloid. A quantity of animals was distilled, and the alkaline fumes received in dilute hydrochloric acid. The resultant salt

was purified by repeated solution and recrystallization in absolute alcohol. With $PtCl_4$ it yielded a precipitate, which was kindly analysed for me by Dr. Magnier de la Source, and found to be the platino-chloride of methylamine: however, it is very probable that the volatile alkaloid was really more complex, but broke up in the distillation. The subject would repay the attention of a chemist. Trimethylamine has been obtained from many animal sources, and the production of this, or some nearly allied body, in such remarkable quantity by *Convoluta* seems to be a protective specialisation.

The ash of the *Convoluta* contains iodine, another analogy to the algæ.

As the *Drosera*, *Dionœa*, &c., which have attracted so much attention of late years, have received the striking name of Carnivorous Plants, these Planarians may not unfairly be called Vegetating Animals, for the one case is the precise reciprocal of the other. Not only does the *Dionœa* imitate the carnivorous animal, and the *Convoluta* the ordinary green plant, but each tends to lose its own normal character. The tiny root of the *Drosera* and the half-blanched leaves of *Pinguicula* are paralleled by the absence of a distinct alimentary canal and the abstemious habits of the Planarian.

It still remains to ascertain the behaviour of other green animals, and I hope to begin with *Hydra* and *Spongilla*,* as soon as the season permits.

Part II.—*Histology.*

The general characters of the animal have been already given by Schmidt, and I need only add that I have succeeded in making out the mouth, which lies, as usual in this genus, a little way behind the otolith. It is not a mere transverse slit, but is surrounded by a lip capable of slight protrusion, which evidently corresponds to the protrusible pharynx of higher Planarians. When feeling its way the animal has a curious habit of sharply retracting the terminal point of the anterior ends of the body, the head thus becoming bilobed, with a central depression. Each lobe becomes a sort of temporary tentacle, and these may be compared with the blunt permanent head lobes of allied forms. So too the animal "when extremely contracted" throws its smooth dorsal integument, not into irregular wrinkles, but into rounded papillæ, which remind one of the permanent dorsal papillæ of other Planarians.

I will first notice an interesting point in the histology of the ciliated ectoderm. In teased preparations, kept cold, the ciliated cells often become amœboid, some of the cilia changing into slender finger-like or stout fusiform pseudopodia. These often retain their curvature parallel

* Sorby has suggested the probably partial vegetal mode of life of *S. viridis*, and resultant analogy to *Dionœa*. ("Quart. Journ. Micro. Sci.," 1875, p. 51.)

to the unaltered cilia, and I have even seen the finer pseudopodia contracting gently in time with the cilia of the same cell, thus establishing a complete gradation between the rhythmically contractile cilium and the amœboid pseudopodium through what is really a rhythmically contractile pseudopodium. Hæckel and others have accumulated many instances of the transformation of ciliary movement into amœboid and *vice versâ*, but I only know of one case in which the passage-form, the cilium-like pseudopodium, has been actually observed. Lankester,* speaking of developing spermatozoa of *Tubifex*, describes "very large active fusiform masses, exhibiting very rapid movements like a cilium, and possessing at the same time the character of a pseudopodium." It is important that Lankester's passage-form occurred during the transformation of amœboid movement into ciliary, while I find exactly the same thing during the reverse change; and it is not improbable that such ciliary pseudopodia may transitorily occur in many cases.

Perhaps no animal structure has received more varied and contradictory interpretations than the rod-like bodies (*Stäbchen, baguettes*) of the Planarian integument. "Max Schultze holds them for end-organs of nerves, Leuckart and many others for nettle-capsules, Schneider for *spicula amoris*, Keferstein for mucous glands, Graff for more or less developed nematocysts."† Two distinct kinds of organ exist in *Convoluta* and other Rhabdocœles, and have been confused under the same name; first, the heap of coloured rod-shaped bodies, the original "Stäbchen" of Max Schultze, which furnish in *Convoluta* the yellow solution already referred to, and, secondly, large and long spindle-shaped bodies, generally arranged singly, each containing a sharp brittle needle, of which the point lies close under the apex of the spindle. In a teased preparation they are generally empty, showing the tube in which the arrow lay, and with a little granular protoplasm hanging round the mouth like the smoke of the explosion. The dart is generally propelled for some little distance, but sometimes sticks in the mouth of the tube. Graff's view ‡ is certainly the right one, that these are offensive weapons, but they are constructed on so distinct a plan from those of Cœlenterates, that they might better be called sagittocysts than nematocysts. True nematocysts have been described in some other Planarians.

Below the epidermis lie the circular and longitudinal muscles, and beneath them comes the layer of chlorophyll-containing cells. These are clear and semi-fluid, more or less irregular in shape, but becoming spherical when separated. The chlorophyll is not collected into granules as in the higher plants, nor into drops as in the green cells of *Vortex viridis*, but is diffused throughout the whole pro-

* "Quart. Journ. Micro. Sci.," 1870, p. 292.

† Minot, "Studien an Turbellarien," "Semper's Archiv," III, 4, 1877.

‡ "Zeitsch. f. w. Zool.," xxv, p. 421.

toplasm of the cell, which is thus very intensely coloured. One, or sometimes two, nuclei are present, besides an irregular heap of granules. It was very difficult to break up the cell completely, and so liberate the granules, but in one or two fortunate preparations treated with iodine, the blue coloration assumed by many of these granules proved that we have here an actual deposit of starch, quite like that which Sachs has shown to take place within the chlorophyll granules of the plant. These starch granules are many of them so minute as to show Brownian movements; the larger are quite amorphous, and consequently exhibit no polarisation.

Deeper than the green layer, lie colourless granular nucleated cells, which may be spherical or branched. These yield with iodine the red-brown reaction of glycogen very conspicuously indeed. All the internal tissues of the animal are bathed in that abundant slimy protoplasm which has been so often adduced in evidence of the infusorian affinities of the lower Turbellaria. It exudes from all points of the body of a squeezed *Convoluta* in hyaline drops, which generally enclose a heap of cells of all sorts, and which often show amœboid movements. This semi-fluid protoplasm oozing through the loose cell meshes with every movement of the body may well serve instead of a special circulatory fluid. Digestion may also be effected by the amœboid protoplasm, for it is easy to confirm the statements of Claparède, Metschnikoff,* Ulianin,† and Graff,‡ as to the absence of any distinct alimentary canal.

The development of the generative products is of interest. An apparently ordinary mesoderm cell enlarges and divides into an oval mass of about 12—16 segments. The granular protoplasm of these is gradually drawn out into the very long spermatozoa, and thus each testicular mass is transformed bodily into a bundle of neatly folded spermatic filaments. The ova are also developed by the division of a mesoderm cell. There are no separate vitellaria, but the yolk granules seem to arise in the finely granular amœboid protoplasm of the developing ovum.

The "otolith" is transparent and strongly refracting. It is loosely contained in a capsule and shaped like a plano-convex lens, but with the plane under surface very rugged. I can form no hypothesis as to its function. In some forms what appears to be a nucleus is present, and the body is probably a modified epithelial cell.

Everywhere imbedded in the mesoderm are numerous small colourless cells scarcely so big as a frog's red blood corpuscle. These are more or less pear-shaped, with a large central cavity; and lining one

* "Zoologischer Anzeiger," 1878, p. 387.

† "Die Turbellarien vom Bucht von Sebastopol." Moscow, 1870.

‡ "Kurze Ber. über fortgesetzte Turbellarienstudien," Zeitch. f. w. Zool., xxx, Supp., p. 463.

side of the interior of this cavity and parallel to the long axis of the cell, are a number of distinct transparent homogeneous filaments inserted above and below into the ordinary granular protoplasm which constitutes the remainder of the cell. This division of the cell into a granular and a fibrillated portion is similar, as Dr. Malassez suggested to me, to that which obtains in the developing muscular cell of a tadpole's tail, and though also somewhat remotely, to the structure described by Lankester in the heart of *Appendicularia.** In a teased preparation, some of these cells are easily found in a state of rapid rhythmical contraction, giving as many as 100—180 energetic beats per minute. The form of the cell alters with every pulsation, shortening and broadening like a contracting muscle. This change of form is simply impressed upon the cell body by the contraction of the internal fibres, and does not therefore truly correspond to that observed in a muscle. Some cells also of extreme curvature (for hardly any two are quite alike) bend sharply and return with a spring. The movements soon become slow and inco-ordinate, and waves can be seen passing along the separate fibres independently of each other. The movement stops altogether and the cell bursts, but the fibres resist for some time longer the destructive action of the water.

I have never been able to observe any rhythmical contraction, but at most a feeble quivering within the cell while in the body of the animal, nor to make out any trace of definite arrangement. Max Schultze has described how the alimentary canal of the higher Planarians swarms with *Opalinæ*, and it is possible that these so singular structures may be excessively modified parasitic Infusoria. In any case, the main histological interest lies in the fact that these pulsatile cells cannot be classified either with ciliary or amœboid, with plain or striated muscular cells, but present a distinct type of contractile structure.

In one of these bodies, which had come to rest in the characteristic curved pear-like form, the nucleus-like body, which is often to be seen at one side, was distinctly seen to be in motion. It slowly dived under the contractile filaments, and moved steadily towards the opposite side, displacing the fibres slightly as it pushed its way. When it had reached the middle the cell had straightened into a perfectly symmetrical pear-shape, and by the time it had reached the opposite side the cell had curved to the same side. After a momentary pause it commenced to go back again, and the oscillation of this singular body along the transverse diameter of the cell, with the accompanying changes of form of the whole, continued with perfect steadiness for at least half an hour, enabling me to draw all the phases again and again. One whole oscillation occupied a little over a minute.†

* "Ann. and Mag. Nat. Hist." 1873, p. 88.

† Figures will be published in the "Archives de Zoologie Expérimentale."

I must express my warmest thanks to M. de Lacaze-Duthiers, in whose laboratories at Roscoff and Paris I have received the greatest hospitality. The chemical examination of the animal was conducted in the Laboratoire de Chimie Biologique, of M. le Professeur Gautier, to whom my best thanks are also due and tendered.

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