ANATOMY AND PHYSIOLOGY

OF

ANODONTA FLUVIATILIS.

By GEORGE B. SIMPSON.

ANODONTA FLUVIATILIS.

Several years ago while making a collection of fresh-water shells, I naturally desired to know something of their anatomy and physiology. I found no book treating specially of that subject, though I found one or more chapters in several books, but to me they did not seem to be just what was needed by a beginner, the articles were either without illustrations or the illustrations were few and very poor. I have written this article with the hope that it may be of use to beginners, and also to some who have contented themselves with collecting the shells paying no attention to the living animal within. To those who are advanced in similar knowledge, this article may seem simple, but it must be remembered that very simple things are frequently formidable to beginners. I had intended to follow this article with others on the anatomy and physiology of other bivalve and univalve shells, but the delay in printing has been so great that I have not done so. At that time I was more interested in Unionidæ, and selected one of their number, *Anodonta fluviatilis*, for dissection and explanation.

By boiling the animal for a short time, the intestinal canal, nerves, arteries, etc., are much more easily found than by dissecting an alcoholic specimen; though the animal is distorted by boiling still a very good idea of the position of the different organs is formed, and the dissection of a specimen which has been kept in alcohol for some time is rendered much easier, the student knowing just where to look for the different organs: to dissect an animal just from the water would be almost if not quite impossible for a beginner. A very slight addition of chromic acid to the alcohol in which some of the animals are kept, will be of help in dissecting certain parts.

Simpson 1881

All dissections were made by myself, and all the drawings are directly from nature by myself; only in two or three instances has the microscope been used, nearly all the parts described can be seen without the use even of a simple lens.

The Anodonta consists of an outer part called the shell or exo-skeleton, and the animal inclosed within the shell. The shell is composed of two valves united dorsally by means of an elastic ligament.

The parts of the animal which will be described in detail are the mantle, gills, labial palpi, muscles, body, foot, viscera, nerves, liver, stomach, heart, pericardium, renal organ, vascular system and organs of generation.

When the shell of the Anodonta (and these remarks apply also to the genera Unio and Margaritana) is held with the ligament or attached portions of the shells upward, and the larger, most convex portion, the most distant from the eye, the valve at the right hand is called the right valve (Pl. 4, fig. 1, r.v.); that at the left, the left valve (Pl. 4, fig. 1, l. v.); the part the most distant from the eye, the anteror portion (Pl. 4, fig. 1, a. p.); the nearest to the eye, the posterior portion (Pl. 4, fig. 1, p. p.); the upper part the dorsal (Pl. 3, fig. 1, d. p.), and the lower part the ventral portion. Where the same letters occur on Pl. 3 as on Pl. 4, the same parts of the shell are designated. On the dorso-anterior portion of each valve is a more or less prominent, blunt elevation called the umbo or beak. (Pl. 3, fig. 1, umb.)

Posterior to the umbones, uniting the dorsal margins of the valves, is an elastic horny portion of the exo-skeleton, designated the ligament (Pl. 4, fig. 1, lig.), which antagonizes the action of the adductor muscles, and has a tendency to keep apart the ventral margins of the valves.

The ligament when the shell is open is of nearly equal thickness; when the shell is closed by the action of the adductor muscles, the outer portion of the ligament becomes stretched and the inner portion compressed and folded; when the muscles relax, the ligament assumes its natural form and in doing so draws apart the ventral margins of the shell.

The ligament is said to be external, though it is covered for about one-half of its width by an extension of the shell. This ligament is composed of two parts, the outer and thinner portion the epidermal, and the inner portion the cartilagenous, composed of both perpendicular and horizontal fibres.

The shell or exo-skeleton consists of three distinct layers, the outer one is designated as the epidermis (Pl. 4, fig. 3), and consists of a thin membrane which is uncalcified, that is, without lime in its composition, and varying in color from olive green to brown. Immediately

beneath the epidermis is the prismatic layer (Pl. 4, figs. 4, 6, pr.), seemingly composed of solid prisms, but if this portion of the shell is placed in dilute acid the interior of each prism is dissolved, leaving the walls entire, showing that the layer is made by the deposition of calcareous matter in prismatic, generally hexagonal cavities, which are themselves formed by the superimposition of fenestrated laminæ, secreted by the margin of the mantle. (Pl. 4, fig. 6, pr.)

The third or inner layer of the shell is formed by the superimposition of very thin diagonal layers, which overlap each other and is known as nacre or the nacreous layer. (Pl. 4, figs. 5, 6, nac.)

The interior of the shell presents an irridescent appearance, which is caused by the refraction of the light by the edges of the overlapping layers. The prismatic portion being secreted by the edge of the mantle extends slightly beyond the nacreous portion. If any thin shell is held to the light the prismatic portion can easily be seen with the aid of a simple lens. Near the margin of the shell, the prismatic portion is the more prominent, while on all other portions the nacreous layer is thicker than the prismatic, generally from two to four times the thickness.

The epidermis (Pl. 4, fig. 3), shows no structure, though showing under the microscope pigment cells (Pl. 4, fig. 3, p.c.), being without lime in its composition, it serves to resist the action of carbonic acid gas, which is contained in greater or less quantities in all fresh water, and which, but for the protection of the epidermis, would destroy the nacreous and prismatic portions of the shell. On portions of the shell, generally the umbo, from being the longest exposed, where the epidermis has been worn away, the shell is often much eroded. The same conditions occur on other portions of the shell where by accident the epidermis has been broken away. Sometimes between the other layers the animal secretes a layer of epidermis, thus arresting the progress of erosion; layers occurring in this manner are usually colorless.

The formation of the shell, according to all or nearly all the writers on this subject, is not continuous, but occurs at successive periods; but this explanation is not entirely satisfactory. The secretion of the shell is involuntarily performed by the animal and can no more be arrested by the will of the animal than the formation of bone in the human body can be continued or not according to the will.

There are numerous elevations on the exterior of the shell; in thin shells these elevations have corresponding undulations in the interior. The shell of the Anodonta being usually very thin, the interior corresponds in form to the exterior. The Anodonta is without the teeth of the Unio or Margaritana, but below the ligament there are two thickened projections or rudimentary teeth. (Pl. 11, fig. 1, r.t.)

On the interior of the shell, near the anterior dorsal margin, is seen a comparatively large oval marking, caused by the attachment of the anterior adductor muscle (Pl. 11, fig. 1, a.a.); just posterior to this are two other impressions, one at the upper and the other at the lower portion; the upper one is caused by the attachment of the anterior retractor muscle (Pl. 11, fig. 1, a. r.), the lower one by the attachment of the protractor pedis muscle (Pl. 11, fig. 1, p. p.), and are known respectively as the anterior retractor and the protractor pedis muscular impressions.

At a short distance from the post-dorsal margin, near the angle formed by the junction of the hinge-line and posterior slope, is another large marking formed by the attachment of the posterior adductor muscle (Pl. 11, fig 1, p. a.), and is known as the posterior adductor muscular impression. Immediately anterior to the upper portion of this impression, is a smaller nearly circular impression, formed by the attachment of the posterior retractor muscle and is known as the posterior retractor muscular impression. (Pl. 11, fig. 1, p. r.) Extending from the umbo to each adductor muscular impression, is a faint, gradually enlarging marking, caused by the adductor muscles, forming continuous impressions as they changed their position with the advancing growth of the shell. (Pl. 11, fig. 1, mar.) Connecting the posterior and anterior muscular impressions is a line, corresponding in curvature with the ventral margin of the shell, known as the pallial line, and formed by the attachment of the mantle to the shell by means of numerous muscles along this line. (Pl. 11, fig. 1, p. l.; Pl. 5, fig. 1, p. l.) Near the umbo are several impressions caused by the attachment of adductor muscular fibres. (Pl. 11, fig. 1, m.f.)

The thickness of the shell varies in different localities, even when only a short distance apart, and does not depend upon the amount of lime (of which substance the shell is principally formed) in the water, but upon the power of the animal to absorb, and assimilate it into a shell; thin fragile specimens being found in water, rich in lime, and others more massive, in waters where that material is much less abundant. That the thickness of the shell is not due to the amount of lime in the water is shown by the fact that several species occur in the same stream, some having massive and others fragile shells; *Unio undulatus* having a shell one-fourth of one inch or more in thickness, and *Unio gracilis* with a shell one-twentieth of an inch in thickness, occur in the same locality. The conditions favorable for the development of one species may be unfavorable for the development of another, even of the same genus. In the canal at West Troy, N. Y., specimens of *Anodonta implicata* are found of very large size, the shells free from erosion, while *Anodonta fluviatilis*,

though of frequent occurrence, is always small, seldom or never exceeding three inches in length, thin and much eroded. All the species occurring at this locality, with the exception of *A. fluviatilis*, viz., *A. implicata*, *U. complanatus*, *U. radiatus*, *U. ochraceous*, *U. cariosus* and *U. nasutus* occur in much better condition than in any other locality in this part of the State. In a pond situated less than a mile from this locality, *A. fluviatilis* is found of unusually large size and but slightly eroded; specimens five inches in length, with a height of three inches and a diameter of two and one-half inches are abundant, and some are found measuring more than six inches in length and three and one-half inches in height, as large and perfectly preserved specimens as occur in any locality, while with the exception of this species there is not another shell, in the pond, either bivalve or univalve. In another locality a mile below Albany where *Sphærium rhomboideum* is found in abundance and of unusually large size, *Anodonta fluviatilis*, though of frequent occurrence, is very small; the largest specimen I have seen, among a collection numbering many hundreds, measures two inches in length.

A. fluviatilis thrives best in ponds, but is found in quite rapid streams, though even then the most favorable localities are in the comparatively quiet portion of the stream.

The largest specimens I have seen, were found in the pond mentioned above, near the mouth of a sewer, where the mud was of a slimy character and offensive to the smell. It is claimed that the male and female may be distinguished by the comparative diameter and general shape of the shell, but I have not been able to so distinguish them. In the fall of 1879 I collected about one hundred and fifty specimens of varying size — the shells were of different shapes and proportions, some quite flat, others extremely gibbous, the diameter sometimes being greater than the height. Among the first sixty I opened, there was not a single male, the outer gills of each specimen being filled with young. The remaining specimens were placed in a tank, and for several months undisturbed; when I removed these animals from the shells I found only four individuals without young in the outer gills, and as some of the animals had extruded a portion of the young from the gills, it is possible that the individuals above mentioned may have had the young in the gill pouches earlier in the season but had extruded them all. Though I am not prepared to say that the sexes are not distinct, the fact that nearly every specimen had young in the gills would seem to indicate that condition. When my attention was first called to it, it was too late to make any farther collections that season. The growth of an animal during a year, I have not been able to determine; an individual which I have kept for ten months has gained in length in that time only one-fourth of an inch, but it seems probable that their growth in their natural habitat must be much greater than this.

In a certain locality in a stream near Albany, *Unio pressus* is quite abundant in a rapid portion, about two hundred feet in length. I have collected all the large specimens each year for three years. The water being so shallow that every portion of the bottom can be seen, and yet each year they appear equally abundant and of full size, showing that their growth must be quite rapid.

When out of water, and exposed to the sun, the Anodonta will live but a short time; placed in a cool, somewhat damp situation, life will continue for several days. Other members of the family Unionidæ are much more tenacious of life. According to DESHAYES, de Conch, pp. 81–84, a specimen of Anodonta from Cochin China reached Paris in a living condition after having been wrapped in dry paper for a period of more than eight months; similar instances are mentioned concerning *Unio litoralis* (Drap.), *Spatha rubens* (Lam.) and an Australian species of Unio, the last surviving two hundred and thirty-one days. None of those with which I have experimented have survived more than seven days, and the greater portion of them died within two or three days.

The popular belief that the removal of a bivalve from the shell is instantly fatal to the animal is erroneous. While making the drawings illustrating this article, I cut through the muscles attached to one of the valves, removing the valve; and, after some hours occupied in making the drawing (Pl. 5), I removed the animal entirely from the shell, cutting away the mantle from one side, and spent about an hour in noting the action of the ventricle and auricles. The action of the heart at this time, eight hours after the valve was removed, was full and regular.

The heart continues its action for a considerable time after all apparent muscular force has been lost. I once noticed in the tank one of the Anodontæ, to all appearances dead, the shell gaping, the foot protruding, no contraction occurring on handling, and no evidence of life apparent. Not having time to dissect it that day, I laid it away in cold water; about twenty-four hours afterward I removed the animal from the shell, not the slightest contraction occurring, and yet the heart was distinctly beating, though slowly.

THE MANTLE.

(Plate 6.)

If a shell be opened by inserting a knife between the valves and cutting, close to the shell, the anterior and posterior muscles, a thin, semi-transparent membrane will be observed completely investing the

animal and lining the interior of the shell, extending between the rudimentary teeth of the Anodonta and the strong teeth of the Unio and Margaritana. This membrane is called the pallium or mantle.

The mantle is divided into two lobes, each one lining a single valve of the shell; they are united along the dorsal portion, and free along the ventral portion, and are pierced by the anterior and posterior adductor muscles.

The mantle is attached to the shell by small muscles near the umbones or beaks and along the pallial line.

The impressions left by the umbonal muscles on the shell are comparatively faint; those left by the muscles of the pallial line are frequently quite distinct. The edges of the mantle meet on the upper portion of the anterior adductor muscle, and shortly blend, showing the line of junction by a narrow, slightly elevated ridge, which continues for nearly one-half the distance to the posterior muscle, then becoming stronger, more elevated, gradually increasing in height and width to a point a little anterior to the posterior adductor muscle. At this point the edges become free, though the lobes are united below; the edges at first lie close together, but gradually become more separated, continuing thus to the posterior part of the shell, where they are entirely free.

The ridge on the dorsal portion of the united mantle is caused by the insertion of the mantle between the rudimentary teeth. Behind the body of the animal the outer lamellæ of the gills are attached to the mantle lobes, the inner lamellæ to the outer lamellæ of the inner gills, the inner lamellæ of the inner gills are attached to each other, thus forming a connection between the lobes, and dividing the space between them into two parts or cavities. The inferior and largest cavity is known as the branchial or pallial chamber; the superior is known as the anal or cloacal chamber. At the posterior portion of the branchial and cloacal chambers are situated, respectively, the rudimentary ventral or inhalent siphon (Pl. 5, i. s.) and the dorsal or exhalent siphon (Pl. 5, e. s.) formed by the thickened portion of the mantle, just within the edge, which is capable of considerable expansion and contraction. When the animal is undisturbed the shell is generally slightly opened, the siphons expanded and projecting beyond the edges of the valves (Pl. 3, i. s.). The portion of the mantle representing the inhalent siphon has numerous tentacles (Pl. 3, i. s.; 4, fig. 9), which are developed from the inner portion of the mantle. On the exhalent siphon they exist only in a rudimental state, though in some species of Unio the tentacles on the exhalent siphon are of nearly or quite the same strength as the tentacles of the inhalent siphon. The tentacles of the inhalent siphon, in a moderate sized specimen of this species, are about two mm. in length and .35 mm. in diameter, consisting generally of a hollow tube, largest at the base and gradually diminishing in size to the end; occasionally they are forked at the end. They are covered with cilia or microscopical filaments, which keep up a rhythmical motion, causing currents of water to constantly enter the branchial chamber. The two lobes of the mantle are not joined below the inhalent siphon. The lower portion of the exhalent siphon is formed by the uniting of the gills; the upper portion by the uniting of the two lobes of the mantle.

On the dorsal part of the animal is an essentially oval space, which is the pericardial cavity. The portion of the mantle over this space is extremely thin and quite transparent. The rest of the mantle to the pallial line is thicker, but still semi-transparent; from the pallial line to the free edge, the mantle is considerably thickened; at the edge it is very much thickened, and is divided into two portions or lips, between which is a smaller ridge. The epidermis is deposited by that portion of the mantle consisting of this ridge, a fringe of the epidermatic layer being usually found adhering to it. The prismatic layers are deposited by that portion of the mantle nearest the edge; the nacreous layers by the other portion of the mantle. Numerous blood vessels extend through the mantle, frequently branching and anastomosing (Pl. 5, v. e.). Below the pallial line, in the thickened portion of the mantle, are numerous radiating muscular fibers, more plainly apparent on the posterior portion (Pl. 5, m. f.).

The mantle is also supplied with nerves proceeding from the cerebral and posterior ganglia (Pl. 5, a. m. n., p. m. n.) which will be spoken of more fully under the head of the nervous system.

The mantle is composed of two layers, the inner one consisting of ciliated epithelium cells, and the outer and shell-producing layer consisting of non-ciliated cylindrical cells.

THE CILIA.

(Plate 7, fig. 1.)

The cilia are extremely minute and delicate hair-like processes, varying in length from $\frac{1}{12000}$ to $\frac{1}{1000}$ of an inch. The name is derived from the Latin word *cilium*, an eyelash. The cilia, during life, and sometime after death, keep up a constant, rapid, regular motion. Water or any fine substance coming in contact with them is rapidly propelled in the direction of the movement of the cilia.

Cilia occur not only in mollusca, but also in mammals, birds, reptiles, actinia, echinoderms, etc. The motion of the cilia does not cease with the death of the animal, but if the parts are kept moist the motion will continue for some time afterward. In examining the gills of an Anodonta, about thirty hours after they had been removed from the animal, in the meanwhile remaining in water, the movement of the cilia was apparent, as regular and rapid as during the life of the animal; how much longer the movement may have continued I do not know.

The cause of the rapid, rhythmical motion of the cilia has not been satisfactorily explained. This movement continues after the apparent death of the animal. The integrity of the cells to which they are attached is necessary to the movement, for as soon as these shrink from want of moisture, or are destroyed from any cause, the movement of the cilia ceases.

The cilia occur on the inner side of the mantle, on the labial palpi, the foot, tentacles of the siphon, the margins of the plates of the outer side of the gills, in the mouth, stomach and alimentary canal, and on the tentacles of the siphon. If a few grains of any colored matter, for instance, carmine, is placed in the water near the posterior portion of an Anodonta, as it lies in the water in its natural position with the shell slightly expanded, it will be observed to enter the branchial cavity, and in a short time afterward to pass out at the exhalent siphon. The cause of this is the action of the cilia. The movement of the cilia on the interior of the mantle is toward the anterior end, and the water entering the branchial siphon is consequently forced in that direction. The movement of the cilia on the margins of the plates of the gills is from the ventral to the dorsal portion, and by them a portion of the water being forced toward the anterior end, is diverted from its course and passes over the gills from their ventral to their dorsal margins, aërating the blood in the capillaries. From the dorsal portion of the gills to the posterior portion, the movement of the cilia is toward the posterior end; in this manner the water which has passed over the gills is forced out through the dorsal siphon.

The portion passing to the anterior part of the animal is conveyed, by the action of the cilia of the palpi to the mouth, by the cilia of the mouth and œsophagus into the stomach, and from the stomach through the intestinal canal, passing out of the anus; the nutritive portion having been digested and assimilated.

MOUTH, STOMACH, ALIMENTARY CANAL.

(Plates 6, 10, 11, 13.)

The mouth or oral aperture consists of a broadly oval, nearly circular, horizontal aperture (Pl. 6, m., Pl. 13, figs. 4, 5, m.), situated in the anterior portion of the body, just beneath the adductor muscle. The mouth is simply an opening or cavity, without any trace of a masticatory apparatus. The lining of the mouth consists of ciliated epithelium cells, continuous with the labial palpi, or, as they are designated by some authors, the oral tentacles. The mouth connects with the stomach by a very short œsophagus, the lining of which also consists of ciliated epithelium, the food being conveyed to the stomach by the action of the cilia.

The stomach (Pl. 6, s.), which is situated just back of the anterior adductor muscle, is irregular in shape, the general form being round or oval, with several depressions and plications which are stronger on the inner surface. The stomach is invested by the liver (Pl. 6, l.), with which organ it is connected by the minute orifices in the cæcal tubes of the liver. On the right side, the stomach communicates with a blind sac, the nature and use of which body is not definitely known. It varies in size at different times of the year, being found most prominent after winter. Various explanations and conjectures have been made regarding the use of this organ, but nothing is known with certainty. The general direction of the œsophagus and stomach is toward the dorsal margin.

The intestine proceeds from the left side of the stomach; as soon as it leaves the stomach it turns downward at an angle of a little more than 45 degrees to the hinge-line (Pl. 6, fig. 1, i. c.).

The measurements given below are from a specimen, the body and foot of which combined are five centimetres in length and three in width; of course in larger and smaller specimens, the individual measurements would be different, but the comparative measurements would be the same.

The intestine proceeds from the stomach downward and backward with a slight curvature till within a short distance of the posterior margin of the body, a little above the foot; it then turns toward the dorsal side for a short distance, corresponding in curvature to the margin of the body. At about midway between the dorsal and ventral margins of the body (that is, the body proper and the foot), the curvature is toward the anterior and so continues to a point five millimetres below the renal organ, and a little less than two centimetres posteriorly to the stomach — for this distance the intestine is small, being about one millimetre in diameter. At this point the dorsal part of the intestine is slightly prolonged and firmly attached to the surrounding mass (Pl. 6, fig. 1, i. è.). The intestine here turns abruptly toward the right side and continues in that direction for the distance of three millimetres, then turning backward and continuing just posterior to and nearly parallel with that portion previously described to a point about two-fifths the length of the body from the mouth, where the ventral portion is slightly prolonged and attached to the surrounding mass (Pl. 6, fig. 1, i. ĉ.). The intestine thence turns abruptly toward the right side of the body. The portion of the intestine last described is somewhat larger than that first described, being about two millimetres in diameter, and at the point where it turns toward the right side it becomes somewhat clavate in shape, and is three millimetres in diameter: after turning to the right side it almost immediately turns toward the dorsal and posterior part of the body, crossing the portion first described nearer to the right side, continuing in this direction for the space of twenty millimetres, then curving toward the anterior. At this part the intestine is small, being about one millimetre in diameter. Almost immediately beyond the point where the direction of the curvature is toward the anterior, the intestine turns toward the left side and abruptly enlarges to a diameter of about five millimetres and continues nearly to the dorsal margin, parallel to and nine millimetres from that portion of the intestine proceeding from the stomach toward the post-ventral margin of the body. The intestine gradually becomes smaller as it approaches the dorsal surface, at that point being a little more than three millimetres in diameter; it here turns abruptly backward, leaving the body and passing through the ventricle, though entirely unconnected with that organ, thence over the posterior adductor muscle, and ending just beyond that muscle, opening into the cloacal chamber.

The intestine after leaving the body is called the rectum (Pl. 6, r.), the opening at the extremity is the anus (Pl. 6, a.).

The lining membrane of the intestine, throughout its entire length, has numerous strong transverse folds. On that portion of the intestine nearest to the ventral margin, a ridge commences which continues to the extremity.

Digestion takes place in the stomach, and the nutritive matter evolved transudes through the walls of the intestine and thus enters the system.

THE LABIAL PALPI.

(Plate 13.)

The labial palpi consist of two pairs of thin contractile, foliated lobes, two on each side of the body (Pl. 13, fig 5, l. p.). They are subtriangular in outline. The widest portion situated posteriorly. The following measurements are of the palpi of an animal eight centimetres in length: length, 17 mm., width at posterior portion, 8 mm., rapidly narrowing to the oral cavity (Pl. 11, fig. 3). The outer lamina passes above the mouth, the inner below, each becoming continuous with its fellow on the opposite side, and continuous with the lining membrane of the mouth and forming lips to that organ (Pl. 13, fig. 5). The dorsal margins of the outer palpi are attached to the inner face of the mantle, that of the inner laminæ to the foot. The outer and inner palpi of each side of the animal are united along a line designated by dots on fig. 6, Pl. 13. The outer faces of the laminæ are smooth and consist of a thin layer of epithelium; the inner faces, for two-thirds the length from the posterior portion, are strongly ridged transversely; the free edges of the palpi being crenulate. There are about eighteen ridges in the space of five millimeters. The summits of the ridges have comparatively large vibratile cilia (Pl. 13, fig. 7). At a point two-thirds of the length of the palpi distant from the posterior ends the transverse ridges abruptly terminate, and from that point to the mouth the ridges are irregular and longitudinal, also ciliated. When the animal is living the inner face of the outer palpi and the outer face of the inner palpi are slightly distant from each other. The current of water which contains the minute animal and vegetable substances constituting the food of the Anodonta, is by the cilia of the transverse ridges of the palpi carried toward the mouth, and by the action of the cilia of the longitudinal ridges directly to the mouth, and then by the cilia of the lining membrane of the oral cavity and short œsophagus, to the stomach.

THE LIVER.

(Plates 4, 6.)

The liver invests the stomach (Pl. 6, fig. 1, l.), and consists of a greenish brown sponge-like mass, formed of cæca or tubes arranged in racemose clusters, and communicating with the stomach by means of minute orifices; the cæca or tubes (Pl. 4, figs. 7, 11) are lined with epithelium cells.

The liver is abundantly supplied with blood and from the blood the cæcal tubes extract a fluid which resembles the bile of animals of higher organization, which fluid enters the stomach by means of the orifices previously mentioned, and aids in the process of digestion.

THE RENAL ORGAN.

(Plate 9.)

The renal organ, or organ of Bojanus is situated immediately below the pericardium. It is thus called after the name of its discoverer, Bojanus. This name has not been universally adopted and I shall use the term renal organ as being more appropriate.

The renal organ consists of two symmetrical lateral parts. Each part is separated into two chambers, the upper and the lower. The upper is the smaller and known as the non-glandular or pleural sac (Pl. 9, fig. 4, n. g. s.), the roof of which is formed by the floor of the pericardium. It is filled with water and is separated from the glandular portion by a thin transparent wall. The glandular sac is situated immediately below the non-glandular sac, and is filled with dark brown, nearly black granular matter (Pl. 9, fig. 4, g. s.). The non-glandular sac extends only to the posterior portion of the pericardium. The glandular sac extends below and in front of the posterior adductor muscle, and invests the tendons of the posterior retractor muscles. In the floor of the pericardium immediately below the place where the intestinal canal enters the body, are two small oval openings, with tumid lips (Pl. 9, figs. 4, 5, 7 o. p. g.). These openings communicate with passages through the glandular sac. (Pl. 9, figs. 4–7, o. p. g.) Near the posterior portion of the glandular sac these passages enter the non-glandular sac. (Pl. 9, figs. 4, 6, 7, o. e. s.) In the anterior portion of the non-glandular sac is a small opening which communicates with the epibranchial chamber, just back of the attachment of the inner gill to the body. (Pl. 9, figs. 4–7, o. b. c.) It will thus be seen that the pericardium indirectly communicates with the exterior. This arrangement will be more distinctly understood by referring to Pl. 9, fig. 7, where the passage is represented as a tube.

The walls of the vena cava are traversed by numerous small blood-vessels which pass from the vena cava to the gills.

The renal organ is, in all probability, analogous to the kidney of vertebrate animals. Its functions will be again spoken of under the head of circulation of the blood.

PERICARDIUM, HEART.

(Plate 9.)

From a point on the dorsal portion of the body just posterior to the umbo, to the posterior adductor muscles, is an oval cavity about twice as long as wide, inclosed above by the thin semi-transparent part of the mantle, and filled with a colorless fluid. This cavity is the pericardium (Pl. 9, figs. 1, 2, 3, p.), and differs in some important respects from the analogous organ in man and other vertebrate animals in which it consists simply of a sac filled with a fluid, facilitating the movements of the heart, while in the Anodonta and mollusca generally it contains blood as well as other fluid matter, and connects indirectly with the exterior. The movements of the heart may be observed through the thin mantle — when the mantle is removed the heart is laid bare. It consists of one median and two lateral chambers, respectively named the ventricle and auricles. (Pl. 9, figs. 1, 2, 4, v. au.) The ventricle is a sac of yellowish color, oval in form, contracting and expanding, not regularly and every portion at once, but in a peristaltic manner. In contracting and expanding the ventricle assumes different shapes, from nearly circular to elongate-oval. Continuing through the middle of the ventricle can be seen a portion of the rectum; at the anterior portion where the rectum enters, the ventricle is narrow, scarcely more than the diameter of the rectum. From the ventricle proceed two comparatively large tubes (Pl. 10, fig. 1, a. ao., p. ao.) the anterior and posterior aortæ. The anterior aorta (Pl. 10, fig. 1, a. ao.), leaves the ventricle immediately above the intestine, and enters the body in close contiguity to that organ. The posterior aorta passes below the rectum. The walls of the ventricle consist of two thin layers of epithelium, between which is a layer of muscular fibre, in which are delicate nerves proceeding from the posterior ganglia.

The auricles consist of nearly transparent sacs, pyramidal in form, connecting at their apex with the ventricle. The bases are attached to the walls of the pericardial cavity, and are about equal in length to the ventricle.

The pyramidal shape of the auricle is seen only when the ventricle is pushed to one side. Naturally the auricles lie close to the side of the ventricle, and when that organ is expanded are almost entirely concealed. The auricles contract, forcing the blood into the ventricle, when the ventricle contracts, the valve (Pl. 9, fig. 3) connecting the auricles and ventricle closes, and the blood is forced through the aortæ.

THE GILLS.

(Plates 7, 10.)

The gills are four in number, one outer and one inner gill on each side of the body. Each gill consists of two laminæ, united along their ventral edge, separated along their dorsal edge. The dorsal edge is essentially straight, the anterior, ventral, and posterior edges follow the curvature of the margin of the shell. The length of the gill is a little more than two-thirds the length of the shell; the width bears about the same proportion to the height of the shell, the length of the gill being a little less than three times the width. The outer gills are slightly larger and capable of greater extension than the inner gills. The anterior portion of the gills is situated at a distance, equal to one-fourth the length of the shell, from the anterior margin.

Their manner of attachment is as follows. The outer laminæ of the outer gills are attached to the interior of the mantle a short distance from the dorsal portion, just below the pericardial space. They continue attached until within a short distance of the posterior extremity. The inner lamina of the outer gill and the outer lamina of the inner gill are attached. The inner lamina of the inner gill are at the anterior portion attached to the foot, but soon become free and remain so for about one-half their length; back of the adductor muscle they are united, and the dorsal part of the gills form a partial floor across the space between the two lobes of the mantle, separating that space into the branchial and epibranchial chambers. The two laminæ of each gill are united by their plates. There are about sixteen of these plates in the space of five millimetres.

It is in the spaces or pockets formed by these plates and the laminæ of the gills, in the outer gills, that the young of the Anodonta remain after being expelled from the ovaries, until they arrive at a certain stage of development. The outer gills when filled with young are very much distended, the thickness being several millimetres. The form of the young shells can be distinguished only by the aid of a lens, and in their form they differ so much from the parent, that to a person who had not read a description of or critically studied them, their true character would not be apparent.

The outer face of each lamina is composed of flat plates (Pl. 7, fig. 1, g. p.) supported or rendered firm by chitinous rods (Pl. 7, fig. 1, ch.), cylindrical in shape, two rods in each plate. Apparently these rods are short, regularly arranged in pairs, with a short space between each pair without rods, but on close examination, they will be seen to be continuous though at regular distances very slender. The edges of these plates have large cilia (Pl. 7, fig. 1, ci.), which keep up a constant motion. These plates support on one side a mesh-work of capillaries (Pl. 7, fig. 2), arranged in bands, the space between each band equal to the width of the band. The gills possess nerves which will be described under the head of the nervous system.

MUSCULAR SYSTEM.

(Plate 8.)

The principal muscles are the anterior and posterior adductors, the anterior and posterior retractors, and the protractor pedis; in addition to these there are two small muscles near the umbo, and small muscles along the pallial line.

The anterior and posterior muscles are cylindrical bundles of fibres, which pass transversely from one valve to the other, and serve to keep the valves closed, antagonizing the action of the ligament. Whenever from the will of the animal or from any cause the muscles of the animal are relaxed, the valves open by the action of the ligament.

The anterior adductor (Pl. 8, a. a.), is situated near the anterior margin, the base a little above a median line; it is oval in shape, about one-third longer than wide.

The posterior adductor (Pl. 8, p. a.) muscle is situated on a line with the anterior, a little more distant from the posterior margin than the anterior muscle is from the anterior margin; it is one and two-thirds larger than the anterior muscle, about one-third longer than wide. The protractor pedis muscle is situated just posterior to the base of the anterior adductor muscle (Pl. 8, p. p.); it is fan-shaped in appearance, spreading over a large portion of the body and foot (Pl. 8, fig. 2, p. p.), very near the surface. If the body is scraped gently with a knife the strong muscular fibres will be immediately seen. This muscle acts in opposition to the anterior and posterior retractor.

The anterior retractor muscle (Pl. 8, fig. 1, a. r.) has its origin just posteriorly to the upper part of the anterior adductor muscle. The impression made by the attachment of the muscle to the shell being about one-third the size of that of the anterior adductor. The greater portion of the fibres of this muscle pass downward toward the ventral and anterior margin of the foot, having their greatest development in the anterior portion, but some of the fibres pass upward, over and through the substance of the liver. The fibres are for the most part more deeply imbedded than either the protractor pedis or posterior retractor fibres.

The posterior retractor muscles have their origin just anterior to the upper portion of the posterior adductor (Pl. 8, fig. 3, p. r.). The impression made by the attachment of this muscle to the shell is about one-eighth the size of that of the posterior adductor muscle. It is at first a muscular stem, but soon spreads, continuing through the lower portion of the body and the foot, finding its greatest development in the foot. Some of the fibres pass among those of the protractor pedis, but as a rule they are beneath them.

At a short distance from the ventral margin the mantle is attached to the shell by numerous small muscles along a line essentially parallel with the margin of the shell; the impression of these muscles forming the pallial line. Their fibres extend to the ventral margin of the mantle, composing a large portion of that part of the mantle.

If a portion of the muscle is examined under the microscope it will be seen that the fibres are composed of spindle-shaped bands (Pl. 4, fig. 9), each of which contains an elongated nucleus. The space around the nucleus is clear, but the rest of the band contains a great number of granules, arranged in somewhat indistinct transverse rows.

THE NERVOUS SYSTEM.

(Plates 9, 12, 13.)

The nervous system consists of nerve centers or ganglia, connected by nerves designated commissural cords or commissures, and nerves proceeding from the nerve centers to different portions of the body, and known as peripheral nerves.

The nerve ganglia are designated as the anterior or cerebral, the pedal, and the posterior or parieto-splanchnic — a compound word derived from the Latin *parietes*, a wall, and σπλάγχνον, the intestine — and are so named because nerves of the mantle in part, the gills and of the viscera, were supposed to proceed from this ganglion; but the pedal ganglia furnish the nerves of the viscera, and the cerebral ganglia furnish nerves to a large portion of the mantle. The name being both unwieldy and calculated to mislead, I shall use the term posterior both as being simpler and precisely defining the position of the ganglion.

On Plate 9 is a figure showing the nerves in position, on Plate 13 the nerve centers enlarged, and on Plate 12 the nerves dissected out and enlarged twice. The same letters apply to each of the plates. The different nerves will, however, be more clearly distinguished on Plate 12.

The anterior or cerebral ganglia (Pl. 9, 12, 13, c. g.) are two in number, and are situated one on each side of the animal, just back of the lower portion of the anterior adductor muscle and between that muscle and the protractor pedis, very near the surface, so that when the shell is opened by cutting the muscles close to the shell, the ganglia are generally exposed. They are wider than thick. The anterior portion being the widest, gradually narrowing to the posterior portion, which is about two-thirds the width of the anterior; the length is a little more than the width of the anterior portion. The measurements in one specimen are as follows: width of anterior portion, one millimetre; posterior portion, two-thirds of one millimetre; length, one and one-half millimetres; thickness, a little less than two-thirds of one millimetre. On account of the two nerves proceeding from the upper portion, and the two from the lower portion, the ganglion presents an indistinct bilobate appearance.

From the upper angle of the anterior portion (Pl. 9, 12, 13, c. c.) a commissural cord proceeds forward and upward, encircling the œsophagus and connecting with the cerebral ganglion of the opposite side. From the lower angle of the anterior portion (Pl. 9, 12, 13, a. a. n.) a peripheral nerve passes directly forward into the anterior adductor muscle, bifurcating when about half way through the muscle, and giving forth numerous filaments: from the lower part of the posterior portion a commissural cord proceeds, continuing to the upper portion of the animal, just below the generative orifice, thence through the glandular portion of the renal organ. Through the renal organ the cords from the cerebral ganglia, that is, one from each ganglion, are parallel and nearly contiguous to each other (Pl. 12, o. b. n.) until they approach the tendons of the posterior retractor muscles, when they separate, passing over the exterior of the tendons, then rapidly approaching each other, and uniting with the posterior ganglion (Pl. 9, 12, 13, p. s. g.).

From the upper angle of the posterior portion of the cerebral ganglion a commissural cord passes dorsally and posteriorly, for a short distance, nearly parallel with the commissural cord uniting the anterior and posterior ganglia (Pl. 12, p. e. c.; Pl. 13, fig. 2, p. e. c.); then turning toward the posterior and ventral portion, it passes through the substance of the liver, below the stomach, and unites with the pedal ganglia (Pl. 9, 12, p. g.). Sometimes branching from the nerve of the anterior adductor muscle, at other times proceeding directly from the ganglion just posterior to the insertion of that nerve, there is a somewhat finer one, which continues forward into the anterior portion of the mantle (Pl. 9, 12, a. m. n.). A peripheral nerve proceeds from the under side of the ganglion, about midway between the ends, and passes almost directly downward into the mantle (Pl. 9, 12, a. m. n.) bifurcating at a short distance from the ganglion — one branch continuing nearly directly downward, the other continuing toward the posterior portion, giving off several branches to the thickened muscular border of the mantle, continuing apparent to the unaided eye, for a distance of a little less than one-half the length of the mantle.

The pedal ganglia (Pl. 9, 12, p. g.) are situated in the body, about one-fourth of its length from the anterior margin, thus being a little posterior to the cerebral ganglia, and about one centimetre distant from them, situated midway between the sides of the body; they consist of two elongate oval bodies, which are joined to each other for about one-half their length, which is a little less than three millimetres; width, one millimetre. Their natural position is at an angle of forty-five degrees to a vertical line through the body. From the upper end proceeds the commissural cord connecting the cerebral and pedal ganglia (Pl. 9. 12, p. e. c.). From the lower end proceeds a peripheral nerve (Pl. 9, 12, p. h. n.), which continues on a line with the ganglion, having frequent branches, to one of which is attached the auditory organ (Pl. 9, 12. au. s.). From just beneath this nerve another nerve proceeds, having the same general direction, but smaller. A little an-

terior to the first-mentioned nerve is another nerve which bifurcates at a short distance from the ganglion, and continues in the muscular strata of the foot at an angle of ten degrees to the first-mentioned nerve; from this nerve, and also from the others described, proceed numerous filaments. From a point about midway between the ends proceeds another nerve, which continues almost directly toward the ventral margin among the muscular fibres; about midway between this nerve and the commissural cord is another nerve (Pl. 9, 12, an.), which continues directly toward the anterior portion of the animal, among the muscular fibres, bifurcating at a short distance from the ganglia. From the middle of the dorsal portion (Pl. 9, 12, m. n.) a nerve proceeds, continuing posteriorly at right angles to the length of the ganglion. The nerve proceeding from the pedal ganglia furnishes nerves to the muscles of the body and foot, and to the viscera.

The posterior ganglia (Pl. 9, 12, p. s. g.) are situated immediately below the posterior adductor muscle, and are so closely apposed as to present the appearance of a single bilobate ganglion. The bilobate appearance is more apparent than that of the cerebral ganglia, but they are much more closely united than the pedal ganglia; each ganglion is two millimetres long and one and one-half millimetres wide, and the inner margin is joined to its fellow throughout the entire length. From the anterior portion proceed the commissural cords (Pl. 9, 12, p. s. c.), connecting the posterior and cerebral ganglia. From the anterior angles of the ganglia (Pl. 9, 12, g. n.) proceeds a peripheral nerve, which for a short distance continues parallel with the commissural cord, then curving away from that cord turns quite abruptly backward, continuing along the junction of the exterior lamellæ of the inner gills and the inner lamellæ of the outer gills, branches entering the gills. From the posterior portion of the ganglia a very large nerve takes its origin, the diameter of which is equal to three times the diameter of the commissural cord. (Pl. 9, 12, p. n.) This nerve at first continues directly toward the posterior portion of the animal, branching at the distance of about seven millimetres from the ganglia (Pl. 9, 12, p. m. n.). The branch entering the mantle is first directed toward the ventral portion, gradually curving and becoming parallel with the ventral portion, and having frequent branches, which continue into the muscular portion of the mantle. This nerve is slightly smaller than the commissural cord. Almost immediately after this branch leaves the large nerve, that nerve again branches, the larger portion continuing toward the rudimentary branchial siphon, and its branches supplying that portion of the mantle with nerves (Pl. 9, 12, b. n.). Likewise the smaller portion proceeds toward the rudimentary exhalent siphon. In addition to these principal nerves, there are other small nerve filaments supplying the different organs of that portion of the animal with nerves.

The auditory organ consists of a sac attached to one of the branches of the nerve proceeding from the lower end of the pedal ganglion, is filled with colorless fluid, and contains a hard body called the otolith, which is covered with cilia and keeps up a constant rotary motion.

The sense of touch appears to be very acute, more especially in the foot proper; the slightest touch, when the foot is expanded, causing it to contract immediately.

Though possessed of an organ of hearing and without organs of sight, as far as our present knowledge extends, the Anodonta is much more sensitive to light than to sound. I have kept a large number in a tank for several months, and have thus had a good opportunity to judge of the effects of sound and light, and from the observations and experiments I have made, it seems certain that they are not affected by any sound which does not communicate a visible jar to the water.

That they are sensitive to light is shown by the fact that on bright days the rudimentary siphons are more fully expanded, and the inhalant and exhalant currents much stronger than on cloudy days or at night; at which times the shell is generally closed.

The use of the tentacles surrounding the inhalent siphon has not been satisfactorily determined. It is possible that they will prove to be organs of sight. It seems impossible that animals so sensitive to light should be without special organs of vision.

CIRCULATORY SYSTEM.

The blood of the Anodonta is colorless. The corpuscles are similar in form and structure to colorless blood corpuscles of man, and have the same continually changing movements. Owing to the soft jelly-like nature of the animal substance, it is extremely difficult to determine with accuracy many points in relation to the circulation.

From the ventricle of the heart proceed two aortæ (from the Greek word αορτή the heart), a name applied only to the arteries which proceed directly from the heart. The anterior aorta (Pl. 10, a. ao.) enters the body above and in close contiguity to the intestinal canal, bending slightly to the right, turning downward and a little posteriorly, one branch entering the mantle: just behind the anterior adductor muscle a large branch goes downward and runs parallel with the margin of the foot, between the muscular portion of the foot and the body proper, sending numerous branches down to the ventral margin of the foot. Immediately after this branch leaves the main artery it sends out a branch to the anterior adductor muscle, mouth, and other anterior portions of the body; the main artery continues posteriorly, dividing into three large branches, continuing over and between the folds of the intestine. The posterior aorta (Pl. 10, p. ao.), leaves the ventricle below the rectum, and just before reaching the posterior adductor muscle it bifurcates, and sends branches to the posterior adductor muscle, to the pericardium, and to the rectum. The larger branch passes over the posterior adductor muscle entering the mantle, and continues in the thickened portion of the mantle below the pallial line until it meets the branch from the anterior aorta. The blood is returned in the body by innumerable small veins, gradually growing larger toward the vena-cava. For a short distance before leaving the body there is a large sinus which is formed by the union of the larger veins, these connecting with the innumerable small veins; this sinus connects with a cavity situated beneath and between the two portions of the renal organ, which is known as the vena-cava, which connects with veins and capillaries of the gills. By the contraction of the ventricle the blood is forced through the anterior and posterior aortæ to the extremities, and is returned by the veins to the vena-cava; it then passes through the tissues of the glandular sac of the renal organ; it there loses its urea; the renal organ performing the same office as the kidneys of vertebrated animals, thence passing through the gills, and in the gills through a fine net-work of capillaries, and by contact with the air in the water becoming oxygenated, the gills performing the same functions as the lungs of vertebrated animals. The blood circulating through the thin portion of the mantle also becomes oxygenated to a certain extent, the action of the capillaries of the gills being supplemented by those of the mantle; from the capillaries of the gills the blood returns to the auricles and from them to the ventricle. The body sinus connects with the vena-cava by an oval opening, which is covered by a projection from the anterior side, which is held in place by a muscular cord; this arrangement of the valve permits the flow of blood from the sinus to the vena-cava, but effectually prevents any return. The auricles are connected with the ventricle by an oval opening; the "lips" of this orifice are very thin and extend into the ventricles (Pl. 8, fig. 4), they are in shape like a sack, with both ends open. At the orifice they are kept apart by their attachment to the margins of the orifice, but as they recede the two margins fall together. When the auricle contracts, the blood easily passes through this valve, but when the ventricle contracts, the margins fall together, preventing the return of the blood to the auricles and causing it to be forced through the aortæ.

The pericardium has direct communication, both with the blood system and also with the branchial chamber, and thus contains a mixture of blood and water.

The non-glandular sac of the renal organ connects with the branchial chamber, is filled with water and carries off the waste product separated from the blood by the action of the glandular sac.

SEX AND REPRODUCTION.

Formerly the Anodonta was considered to be androgynous or unisexual, that is, the male and female organs combined in one animal. Leeuwenhoek, in 1702, maintained that they were bisexual, though afterward changing his opinion. The former view is now accepted by nearly all writers on the subject, though it is still maintained by some that they are unisexual. The fact that the organs of generation in all individuals are very similar, and as far as my observation goes, during the breeding season fully nine-tenths of the animals have their gills distended with young, gives some plausibility to that belief, for if the animals are bisexual, we would naturally expect to find the sexes in about equal proportions. It is claimed also that from the greater room required by the female in the shell, owing to the distension of the gills with the young, that the shells of that sex are more gibbous than those of the male, but so far as *Anodonta fluviatilis* is concerned, that belief is an error, though undoubtedly true in regard to some species of Unio. Among the few Anodonta found by me, the gills of which did not contain young, were some, the gibbosity of which was so great that the thickness was nearly equal to the height, while among those, the gills of which did contain young, were some quite flat, the thickness scarcely exceeding one-fourth the height. That some of the animals were without young does not weaken the force of the argument of those believing in unisexuality, for even if the animals were hermaphroditic, from various causes there would, in all probability, be some without young. It seems to me that the simplest way to settle the matter would be, not microscopic investigations, but to collect large numbers at the time when the gills of the females are distended with young, if half or even one-third were without young it would nearly prove the bisexual view to be right; on the other hand, if nearly all were with young, the opposite would be proved. For certainly in order to fertilize the individuals in a pond or river, the males should be in considerable numbers. The generative organs, testes and ovaries consist of racemose glands, situated on each side of the subhepatic region of the body, the external openings of which are near the attachment of the inner gill to the body by the side of the openings of the pleural sac of the renal organ. The egg is globular and transparent. The spermatozoa are short rod-like bodies, with an active cilium. The yolk of the egg is prolonged into a short tube with open end, through which (according to Barry) the spermatozoa enter. The ova pass out of

the generative opening during the latter part of summer, passing into the cavity formed by the two lamellæ of the outer gills, and there remain until the following spring, when they are sufficiently developed to leave the protection of the parent.

The yolk divides into two portions, nearly, but not quite, separating. The valves are connected by a hinge; near the hinge line is an adductor muscle, which by its frequent contractions gives a flapping motion to the valves; in the angle formed by the junction of the two valves is a short hollow tube, from which is produced a long filament known as a byssus; the valves are slightly convex-trigonal in outline, presenting very much the appearance of a shield (Pl. 4, fig. 2), in no respect resembling the adult shell. The apex is prolonged into a serrated spine at right angles to the shell, the teeth or serrations are on the upper portion of the spine and are in two rows. After the valves have become definitely closed by the action of the adductor muscle, the halves are blended together, the gills are developed, the foot grows, the form of the shell changes, and the young Anodonta becomes like the parent in every respect except size.