XIV. *On the Arrangement of the Muscular Fibres in the Ventricles of the Vertebrate Heart, with Physiological Remarks.* By James Bell Pettigrew, *M.D. Edin.; Assistant in the Museum of the Royal College of Surgeons of England; Extraordinary Member and late President of the Royal Medical Society of Edinburgh, &c. &c. Communicated by* John Goodsir, *Esq., F.R.SS. L. and E., Professor of Anatomy in the University of Edinburgh.*

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The principal part of the following communication was presented to the Royal Society of London, in November 1859, and formed the subject of the Croonian Lecture for 1860. An abstract of it was published in the 'Proceedings' of the Society for April of that year. It was subsequently withdrawn for extension and revision, and I have to express my regret that the time occupied in this work has, from various unforeseen causes, been much longer than I anticipated.

The paper, as now presented, consists of four parts or sections,—the first section being devoted to the anatomy of the ventricle of the fish; the second to the anatomy of the ventricle of the reptile; the third and fourth treating of the ventricles of the bird and mammal. I have adopted this arrangement, because the structure of the ventricle in the fish and reptile is to a certain extent rudimentary, and a knowledge of it forms an appropriate introduction to the more intricate structure met with in the ventricles of the bird and mammal.

Of the ventricles more particularly examined in the fish, may be enumerated those of the salmon, shark, sunfish, fishing frog, turbot, and cod; in the reptile, those of the frog, turtle, tortoise, snake, and alligator; in the bird, those of the duck, goose, swan, turkey, capercailzie, eagle, and emu; and in the mammal, those of man, the mysticetus, dugong, porpoise, seal, armadillo, lion, giraffe, camel, horse, ox, ass, sheep, hog, hedgehog, dog, and deer.

VENTRICLE OF THE FISH.

In the fish, as is well known, the heart consists of two portions, one auricle and one ventricle. The shape of the ventricle in the salmon, which has been selected as typical of this division of vertebrate animals, is that of a three-sided pyramid, the base of which is perforated by two openings. These openings conduct to a conical-shaped ventricular cavity of comparatively small dimensions, the capacity of which is increased by its giving off numerous canals, which tunnel the ventricular wall in all directions, particularly towards the apex. The walls of the ventricle are accordingly of great thickness, and destitute of that solidity which characterizes the walls of the ventricles of the bird and mammal.

The fibres composing the ventricle of the fish consist of three layers—an external layer, a central transverse layer, and an internal one. The fibres of the external layer issue from the auriculo-ventricular opening and the opening for the bulbus arteriosus—some arising from the tendinous rings surrounding these apertures, others being continuous with corresponding fibres in the interior. Their course on the base is from before backwards, and is more or less circular; *i. e.* they flow in curves from either side of the auriculo-ventricular and arterial openings, towards the basal margin, over which they bend in graceful folds, to appear on the anterior and posterior borders and surfaces. On the borders, especially the posterior ones, they arrange themselves in parallel lines, and are continuous with each other at the angles and at the apex, where they are also continuous with the fibres of the internal layer. On the surfaces, the fibres of the superficial layer pursue a somewhat vertical direction, a certain number of them curving slightly upon themselves, and dipping beneath others having a more superficial position. The object of this arrangement is, to permit the superficial layer to furnish fibrous filaments which traverse the wall of the ventricle in a direction from without inwards, and which from this circumstance may be designated the perforating fibres. These perforating fibres connect the external and internal layers with each other, and with the fibres of the transverse or circular layer. Their function is obviously to approximate the various layers during the contraction of the ventricle, this approximation being rendered necessary by the ventricular walls of the fish, as has been explained, being tunnelled in various directions by canals proceeding from the ventricular cavity—these requiring to be emptied of blood during the systole.

When the external layer, which in the fish is comparatively thin, is removed, the transverse layer, with here and there the cut ends of the perforating fibres, is exposed. The fibres of the transverse layer are more or less circular, and differ from the fibres of the superficial layer in running at right angles to them; they moreover occur in fasciculi arranged in parallel lines, and may be readily separated from each other. The transverse layer is of considerable thickness, and is connected with the external and internal ones by fibres which it gives off to, and receives from both. The appearance presented by the ventricle of the fish, when the transverse layer is taken away, is somewhat porous, owing to the ends of the perforating fibres, and the orifices of the canals which permeate the substance of the ventricle from within, being at this stage of the dissection exposed. On tracing the perforating fibres whose ruptured extremities are thus brought into view, their connexion with the fibres constituting the internal layer may be clearly made out.

The fibres of the internal layer are continuous, in many instances, with the external fibres at the base, apex, and other portions of the ventricular wall, and are best exposed by cutting into the ventricular cavity, and dissecting from within outwards. They proceed in well-marked fascicular bundles from apex to base, and resemble in their general character the carneæ columnæ of the ventricles of the bird and mammal. They differ, however, from the carneæ columnæ in question in having a more highly reticulated structure. Situated within the reticulations, are a vast number of minute orifices communicating with the ventricular cavity, and conducting to canals of various sizes. These canals freely unite with each other, and, as they penetrate the ventricular wall only to certain depths, may on this account be denominated terminal canals. They serve to increase the size of the ventricular cavity, and render the ventricle lighter than it would otherwise be.

The ventricle of the fish may be regarded as a conical-shaped muscular bag, the fibres of which are curiously interwoven to secure the greatest amount of strength with the least possible material, and, what is not less desirable in a physiological point of view, to ensure that the organ shall contract in all directions, the more thoroughly to eject the blood from its interior. There is, however, in the ventricle under consideration, as far as I have been able to discover, no principle in the arrangement similar to that which, as I shall endeavour to explain, occurs in the ventricles of the higher vertebrata.

VENTRICLE OF THE REPTILE.

The form of the ventricle of the reptile's heart is intermediate between the well-defined pyramidal shape in the fish, and the finely rounded conical form of the ventricles in the bird and mammal. Thus it has the dorsal surface flattened, as in the fish, while the two anterior surfaces present a somewhat convex outline.

The arrangement of the fibres in the ventricle of the reptile is so similar in many respects to that met with in the ventricle of the fish, that a separate description appears unnecessary. There are, however, points of difference deserving of notice. The fibres composing the external and internal layers in the ventricle of the reptile are more decidedly vertical than in that of the fish, and run with fewer interruptions from the base to the apex, and from the apex to the base. This difference is well seen in the ventricle of the python and alligator, and is an approach to what is found in similar layers in the ventricles of the bird and mammal. The external layer in the ventricle of the reptile is thinner than in the ventricle of the fish, the internal layer being comparatively much thicker. The transverse layer, in the ventricle of the reptile, is also thinner than in the ventricle of the fish, the perforating fibres which run between the external and internal layers being on the contrary increased both in number and size. The perforating fibres have further a tendency to split up and give offsets to run athwart the ventricle in the direction of the transverse layer, and in this manner supply the deficiency in its thickness. The ventricular cavity of the reptile is smaller than in the fish, while the number of terminal canals which proceed from it to ramify in the ventricular wall is greater. This circumstance renders the wall of the ventricle of the reptile at once thicker and less dense than that of the fish. Lastly, the ventricular cavity of the reptile is variously shaped, according as the septum is absent or present and partially or fully developed.

VENTRICLES OF THE BIRD.

The ventricles of the bird so closely resemble those of the mammal in appearance and structure, that one description will suffice for both. Care however will be taken, when explaining the construction of the right ventricle of the mammal, to discuss at length the peculiar fleshy valve which in the bird occupies the right auriculo-ventricular orifice. This valve constitutes, I may remark, the distinguishing feature between the ventricles of the bird and mammal.

VENTRICLES OF THE MAMMAL.

The ventricles in the mammal are subject to considerable variation as regards shape. In the porpoise they have their dorsal or posterior surface flattened, and their anterior surface very slightly rounded, as in the higher reptiles.

In the mysticetus the ventricles are compressed laterally, and so resemble those of the higher fishes. In the dugong and rhytina, they are characterized by having two very distinct and widely separated apices, as shown in Plate XIV. fig. 42.

The general appearance presented by the ventricles of the mammal is familiar to all, it being that of an irregular cone slightly twisted upon itself. The posterior surface of the cone is flattened, as in the ventricle of the fish and reptile, and on account of the obliquity of the base is shorter than the anterior surface. The anterior surface, which is divided into two by an oblique sulcus or furrow, is, on the contrary, rounded and prominent, and presents a characteristic convex outline. Two margins or borders are usually described—a right inferior or acute margin (margo acutus), and a left superior or obtuse one (margo obtusus). As, however, these margins vary somewhat in different hearts, no general description concerning them can be strictly applicable. In the hearts of the ass, American elk, and deer tribe generally, the ventricles are rounded and taper towards the apex, so that the right margin appears almost as obtuse as the left; while in those of the armadillo and carnivora, the ventricles, which are not taper but purse-shaped, have likewise the right side very obtuse*. The idea therefore of an acute margin ought perhaps to be confined to the right side of the human heart and a few others, such as the heart of the seal and hog, both of which bear a considerable resemblance to that of man.

The base of the cone formed by the ventricles of the mammal, as is well known, is perforated by four openings. These openings are surrounded by fibrous rings, and conduct to conical-shaped *spiral* cavities†, which vary somewhat in size according as the carneæ columnæ are absent‡ or present, and the musculi papillares feebly or fully developed.

Considered as a muscle, the heart, and especially the ventricular portion of it, is peculiar. Being in the strictest acceptation of the term an involuntary muscle, its fibres nevertheless possess the dark colour, and transverse markings, which are charac-

* Between these extremes in shape may be ranked the ventricles of the camel, horse, ox, giraffe, calf, hare, rabbit, &c.

† See photograph of a wax cast of the interior of the ventricles of a deer's heart, Plate XII. figs. 16 & 17, and transverse sections, Plate XV. figs. 49 to 53 inclusive.

‡ The ventricles of the American elk are devoid of carneæ columnæ, as are likewise those of the red deer (Plate XV. fig. 48).

teristic of the voluntary muscles. Unlike the generality of voluntary muscles, on the other hand, the fibres of the ventricles, as a rule, have neither origin nor insertion; *i. e.* they are continuous alike at the apex of the ventricles and at the base. They are further distinguished by the almost total absence of cellular tissue as a connecting medium *—the fibres being held together partly by splitting up and running into each other, and partly by the minute ramifications of the cardiac vessels and nerves †.

The manner in which the fibres are attached to each other, while it necessarily secures to the ventricles considerable latitude of motion, also furnishes the means whereby the fibres composing them may be successfully unravelled; for it is found that by the action of certain reagents, and the application of various kinds of heat, as in roasting and boiling ‡, the fibres may be prepared so as readily to separate from each other, in layers of greater or lesser thickness.

The crowning difference, however, and that which it is the especial object of the present paper to treat, is the arrangement of the fibres themselves—an arrangement so unusual and perplexing, that it has long been considered as forming a kind of Gordian knot in anatomy. Of the complexity of the arrangement I need not speak, further than to say that VESALIUS, ALBINUS, HALLER §, and DE BLAINVILLE || all confessed their inability to unravel it.

Of those who have written more particularly on the structure of the mammalian heart, may be mentioned LOWER ¶ (1669), BARTHOLIN ** (1678), WINSLOW †† (1711),

* The little cellular tissue there is, is found more particularly at the base and apex of the ventricles, and is so trivial as to be altogether, though wrongly, denied by some. See article "On the Fibres of the Heart," by Mr. SEARLE, in the 'Cyclopædia of Anatomy and Physiology,' p. 652.

† When the vessels of the ventricles are injected in the cold state with some material which will stand heat (as, for example, a mixture of starch and water), and the heart boiled, the larger trunks from either coronary artery are found to give off a series of minute branches which penetrate the ventricular wall in a direction from without inwards—these branches, when the dissection is conducted to a certain depth, appearing like so many bristles transfixing the ventricular wall. As, moreover, the cardiac nerve-trunks accompany the trunks of the coronary vessels, while the nerve-filaments cross the smaller branches of the vessels, and the muscular fibres, (to both of which they afford a plentiful supply of nerve-twigs,) the influence exerted by the vessels and nerves, in uniting or binding the muscular fibres to each other, is very considerable. Vide Inaugural Prize Dissertation by the author, "On the Arrangement of the Cardiac Nerves, and their connexion with the Cerebro-spinal and Sympathetic Systems in Mammalia," deposited in the University of Edinburgh Library, March 1861.

‡ Of the various modes recommended for preparing the ventricles prior to dissection, I prefer that of continued boiling. The time required for the human heart, and those of the small quadrupeds, as the sheep, hog, calf, and deer, may vary from four to six hours; while for the hearts of the larger quadrupeds, as the horse, ox, ass, &c., the boiling should be continued from eight to ten hours; more than this is unnecessary. A good plan is to stuff the ventricular cavities loosely with bread crumbs, bran, or some pliant material before boiling, in order, if possible, to distend without overstretching the muscular fibres. If this plan be adopted, and the ventricles soaked for a fortnight or so in alcohol before being dissected, the fibres will be found to separate with great facility. VAUST recommended that the heart should be boiled in a solution of nitre; but nothing is gained by this procedure.

§ El. Phys. tom. i. p. 351.

|| Cours de Physiologie, &c. tom. ii. p. 359.

¶ Tractatus de Corde, &c. London, 1669.

** Dissert. de Cordis structura et usu. Hafniæ, 1678.

†† "Sur les Fibres du Cœur et sur ses Valves," Mém. de l'Acad. Roy. de Paris, 1711.

SENAC * (1749), HALLER † (1757), WOLFF ‡ (1780–1792), GERDY § (1823), and REID || (1839). The writings of these investigators, although differing in minor matters, agree on the whole, as may be seen by a hasty reference to the more prominent views entertained by them. As early as 1669, Dr. RICHARD LOWER promulgated the idea that the external fibres of the ventricles of the mammal proceed in a spiral direction from left to right downwards; the internal fibres proceeding from left to right upwards. The fibres, according to this author, are continuous at the apex, and form an imperfect figure of 8. In this opinion LOWER was followed by GERDY, who, however, maintained that the external and internal fibres make a more perfect figure of 8 than that given by LOWER, and added that all the fibres of the heart form loops, the apices of which look towards the apex of the heart. This idea of GERDY'S with reference to the looped arrangement of the fibres at the apex was combated in recent times by Dr. DUNCAN, jun., of Edinburgh ¶, who says, GERDY commits a grave error when he asserts that all the fibres of the heart form loops *the apices of which look towards the apex of the heart*, since the number of tops (and by this Dr. DUNCAN means loops) *which look in the opposite direction, or towards the base*, is not less. Adopting the suggestion of Dr. DUNCAN, it follows that the fibres composing the ventricles form twisted loops, *which look alike towards the apex and the base.* FREDERICK CASPAR WOLFF furthered the investigation, by showing the possibility of dividing the muscular substance composing the ventricles into bands; whilst SENAC in the last century, and Dr. JOHN REID in this, gave a new interest to the subject, by showing that the fibres of the external and internal surfaces of the ventricles are more vertical in direction than the deeper or more central fibres, which more approach to the circular. Such are a few of the more important facts ascertained by successive investigators.

Having myself in the summer of 1858 made numerous dissections, upwards of 100 of which are preserved in the Anatomical Museum of the University of Edinburgh **, I have arrived at results which appear to me to throw additional light on this complex question, and which seem to point to a law in the arrangement, simple in itself, and apparently comprehensive as to detail. This law will be adverted to subsequently.

Summary of Facts established in the present Memoir.

The following are a few of the more salient points demonstrated, which the reader

* Traité de la structure du Cœur, de son action, &c. Paris, 1749.

† Elementa Physiologiæ, tom. i. 1757.

‡ "Dissertationes de ordine fibrarum muscularium Cordis," in Acta Acad. Petropolit. 1780–1792.

§ Recherches, Discussions et Propositions d'Anatomie, Physiologie, &c. 1823.

|| Cycl. of Anat. and Phys., article "Heart." London, 1839.

¶ See extract from Dr. DUNCAN'S unpublished manuscript, given by Dr. JOHN REID in Cycl. of Anat. and Phys., article "Heart," p. 592.

** These dissections obtained the Senior Anatomy Gold Medal of the University, in the winter of 1859.

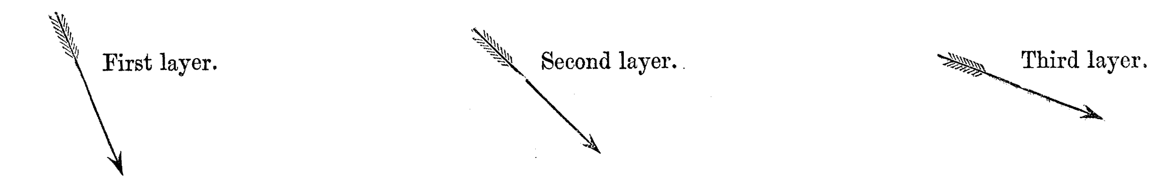
may corroborate by a reference to the accompanying Plates, engraved from photographs taken by myself from the dissections.

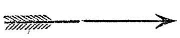
I. By exercising due care, I have ascertained that the fibres constituting the ventricles are rolled upon each other in such a manner as readily admits of their being separated by dissection into layers or strata, the fibres of each layer being characterized by having a different direction.

II. These layers, owing to the difference in the direction of their fibres, are well marked, and according to my finding, are seven in number—viz. three external, a fourth or central, and three internal.

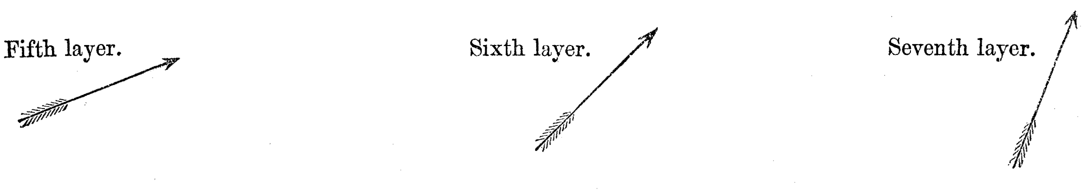
III. There is a gradational sequence in the direction of the fibres constituting the layers, whereby they are made gradually to change their course from a nearly vertical direction to a horizontal or transverse one, and from the transverse direction, back again to a nearly vertical one. Thus, in dissecting the ventricles from without inwards, the fibres of the first layer, which run in a spiral direction from left to right downwards, are more vertical than those of the second layer, the second than those of the third, the third than those of the fourth—the fibres of the fourth layer having a transverse direction, and running at nearly right angles to those of the first layer. Passing the fourth layer, which occupies a central position in the ventricular walls and forms the boundary between the external and internal layers, the order of arrangement is reversed, and the fibres of the remaining layers, viz. five, six, and seven, gradually return in an opposite direction, and in an inverse order, to the same relation to the vertical as that maintained by the fibres of the first external layer. This remarkable change in the direction of the fibres constituting the several external and internal layers, which is observed to occur in all parts of the ventricular walls, whether they be viewed anteriorly, posteriorly, or septally, has in part been figured by SENAC *, and imperfectly described by REID †, but has not, so far as I am aware, been prominently brought forward by any one. A few arrows will illustrate the gradation in direction referred to.

External layers proceeding from left to right downwards of the spectator (posterior aspect).



 Fourth or circular layer occupying a central position in the ventricular walls.

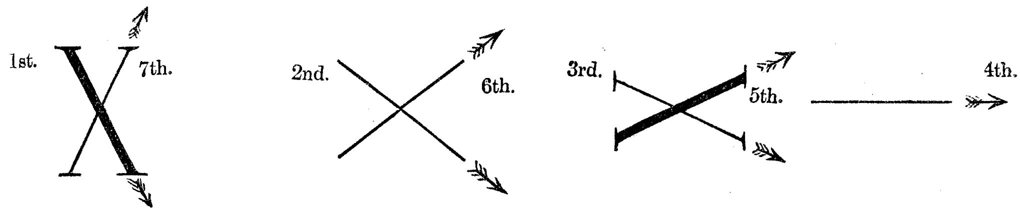
Internal layers proceeding from right to left upwards of the spectator (posterior aspect).



* *Op. cit.* tom. i. and Appendix to tom. ii.

† *Op. cit.* p. 591.

IV. The fibres composing the external and the internal layers are found at different depths from the surface, and from the fact of their pursuing opposite courses cross each other,—the fibres of the first external and last internal layers crossing with a slight deviation from the vertical, as in the letter X; the succeeding external and internal layers, until the fourth or central layer, which is transverse, is reached, crossing at successively wider angles, as may be represented by an ⋈ placed horizontally:—



V. The fibres composing corresponding external and internal layers, such as layers one and seven, two and six, &c., are continuous in the left ventricle at the left apex, and in the right ventricle in the track for the anterior coronary artery, the fibres of both ventricles being for the most part continuous likewise at the base *.

VI. From this distribution of the fibres, it follows that the first and seventh layers embrace in their convolutions those immediately beneath them, while these in turn embrace those next in succession, and so on until the central layer is reached—an arrangement which may in part explain, alike, the rolling movements and powerful action of the ventricles.

VII. The fibres of the right and left ventricles anteriorly and septally are to a certain extent independent of each other; whereas posteriorly many of them are common to both ventricles; *i. e.* the fibres pass from the one ventricle to the other,—an arrangement which induced WINSLOW † to regard the heart as composed of two muscles enveloped in a third. It will be evident from this distribution of the fibres, that while the ventricles are for obvious reasons intimately united, they nevertheless admit of being readily separated.

VIII. If the hinge-like mass of fibres (common fibres) which unite the right ventricle to the left posteriorly be cut through, and the right ventricle with its portion of the septum detached, the left ventricle will be found to be nearly as complete as it was before the separation took place, and to consist of four sets of conical spiral fibres—two external and two internal sets.

On the other hand the right ventricle, and its share of the septum, consists only of conical-shaped spiral fragments of fibres, or at most of flattened rings—a circumstance which, when taken in connexion with others to be mentioned presently, has induced me

* The late Dr. DUNCAN, jun., of Edinburgh, was aware of the fibres forming loops at the base, but seems to have had no knowledge of the continuity being occasioned by the union of the fibres of corresponding external and internal layers, or that these basal loops were prolongations of like loops formed by similar corresponding external and internal layers at the apex—a view which the author believes is here set forth for the first time.

† Mémoires de l'Académie Royale des Sciences, 1711, p. 197.

to regard the left ventricle as the typical or complete one, the right ventricle being a mere segment or portion nipped off at some period or other from the left.

IX. If the right ventricular walls be cut through immediately to the right of the track for the anterior and posterior coronary arteries, so as to detach the right ventricle without disturbing the septum, and the septum be regarded as forming part of the left ventricular wall, it will be found that the fibres from the right side of the septum, at no great depth from the surface, together with the external fibres from the left ventricular wall generally, enter the left apex in two sets; and if their course in the interior be traced, they are observed to issue from the left auriculo-ventricular opening, also in two sets; in other words, the left ventricle is bilateral. I would particularly direct the attention of investigators to this bilateral distribution of the fibres, as it has been hitherto overlooked, and furnishes the clue to the arrangement of the fibres of the left ventricle.

X. The double entrance of the fibres at the left apex, and their exit in two portions from the auriculo-ventricular opening at the base, are regulated with almost mathematical precision; so that while the one set of fibres invariably enters the apex posteriorly, and issues from the auriculo-ventricular opening anteriorly, the other set as invariably enters the apex anteriorly, and escapes from the auriculo-ventricular opening posteriorly. But for this disposition of the fibres, the apex and the base would have been like the barrel of a pen cut slantingly or lopsided, instead of bilaterally symmetrical as they are.

XI. The two sets of fibres which constitute the superficial or first external layer of the left ventricle, and which enter the left apex in two separate portions or bundles, are for the most part continuous in the interior with the musculi papillares, to the free ends of which the chordæ tendineæ are attached. These columns occupy different portions of the left ventricular cavity, and give a very good idea of the symmetry which prevails throughout the left ventricular walls.

Lastly. The apex is opened into and enlarged, and the auriculo-ventricular orifice widened, by the removal of consecutive external and internal layers, from the fact of the left ventricular cavity tapering in two directions and forming a double cone.

There are other points worthy of mention, such as the construction of the septum, fleshy pons, and conus arteriosus, the varying thickness of the right and left ventricular walls, the shape of the right and left ventricular cavities, &c. To these, however, allusion will be more conveniently made subsequently.

As the structure of the ventricles, with one or two exceptions, is the same in all mammals, *man included*, I have chosen to describe the arrangement of the fibres in the ventricles of the sheep and calf, from the readiness with which the hearts of these animals may be obtained. My descriptions, however, will by no means be confined to them.

Points to be attended to in the dissection of the left or typical ventricle. The points to be kept more particularly in view when dissecting the left ventricle are these:—

1st. The different angles made by the fibres of the several layers, with an imaginary vertical line drawn from base to apex, as they issue from the auriculo-ventricular opening and enter the apex.

2nd. The varying direction of the fibres on the body of the ventricle, produced by the different angles which the fibres of the several layers make with the imaginary vertical referred to.

3rd. The double entrance of the fibres at the apex, and their exit in two sets from the left auriculo-ventricular opening.

4th. The manner in which the apex is opened into, and enlarged, by the removal of successive layers.

5th. The gradual increase in the thickness of the layers when the dissection is conducted from without inwards. This is in all probability owing to the more internal or deeper layers being the first formed. Thus the seventh or deepest internal layer, which I am inclined to think is developed before the sixth, goes on increasing *pari passu* with it; while the seventh and sixth increase equally with the fifth, which is a later formation; and so on until the first, which is the thinnest layer, is reached. That this explanation has its foundation in truth, is probable from the fact that, in imitating the process by which I believe the left ventricle is formed, the seventh or most internal layer supplies a basis of support for the more superficial layers—just in the same way that the smaller and more central turns of a shell form the basis of support for the peripheral or more superficial turns*.

External layers of the left ventricle of the Mammal.

Superficial or first external layer. On looking at the left auriculo-ventricular opening of the sheep and calf posteriorly (Plate XII. fig. 1, *b*, and Plate XV. fig. 46, *b*), when the serous membrane, fat, vessels, and nerves have been removed, the fibres are seen to issue from it in fascicular bundles, and to curve over its margin all round (*d*, *f*).

The fibres on leaving the opening lose to a considerable extent their fascicular character, and naturally arrange themselves in two sets,—the one set proceeding from the anterior portion of the opening (*d*), and the anterior half of the septum (*e*); the other from the posterior portion of the opening (*f*), and the posterior half of the septum (*g*). On the body of the ventricle the fibres spread out to form a smooth muscular sheet, both sets pursuing a spiral nearly vertical direction from left to right of the spectator. In their course they gradually change their position on the ventricular wall, the fibres from the anterior portion of the opening and the anterior half of the septum winding round and appearing on the *posterior surface*, the fibres from the posterior portion of the opening and the posterior half of the septum, on the contrary, winding round and appearing on the *anterior surface*. On nearing the apex, which they do in graceful curves (Plate XII. fig. 9), the two sets of fibres become more strongly defined, the fibres of either set converging and overlapping to a greater or less extent. At the apex both sets (*f g*, *e d*) curve rapidly round and form a whorl or vortex of great beauty,—the fibres from the anterior portion of the opening and septum curving into those from

* For a detailed account of this view, see p. 484.

the posterior portion of the opening and septum, and entering the apex *posteriorly* (Plate XII. fig. 10, *d*), to become continuous with the fibres of the carneæ columnæ and anterior musculus papillaris (Plate XII. fig. 13, *y*); the fibres from the posterior portion of the opening and septum curving into those from the anterior portion of the opening and septum, and entering the apex *anteriorly* (Plate XII. fig. 10, *g*), to become continuous with the fibres of the carneæ columnæ and posterior musculus papillaris* (Plate XII. fig. 13, *x*).

The fibres, therefore, which issue from the auriculo-ventricular orifice anteriorly, enter the apex posteriorly, and *vice versâ*—an arrangement which is accounted for by the fibres of the superficial or first external layer, from the time they leave the base until they reach the apex, making one turn and a half of a spiral. As the fibres of the carneæ columnæ and musculi papillares, which constitute the seventh or last internal layer, also make a turn and a half, from the time they leave the apex until they reach the base, the external and internal fibres always return to points not wide of those from which they started. It was, no doubt, this circumstance which induced LOWER and GERDY to describe the external and internal fibres as forming a more or less perfect figure of 8†, these investigators differing as to the completeness of the figure from having, in all probability, described different and deeper layers‡. The bilateral distribution of the fibres, which extends to all the layers, has hitherto escaped observation, but is clearly established by my dissections. Viewed in connexion with the musculi papillares and the segments of the bicuspid valve, it is, as I shall endeavour to show, of considerable physiological importance. The object of the two sets of fibres curving into each other at the apex §, is evidently threefold: first, to secure symmetry, structural and

* The fibres of the carneæ columnæ and musculi papillares pursue a spiral nearly vertical direction, from right to left upwards, so that they cross the fibres of the superficial or first external layer; for an explanation of the course and direction of the fibres of the first and seventh layers, see A, B, C, D, E of diagrams 3 & 4, Plate XVI.

† WINSLOW altogether, though wrongly, denied the crossing of the external and internal fibres (Mémoires de l'Acad. Roy. 1710, p. 197).

‡ Great assistance may be obtained in comprehending the scheme of the arrangement of the fibres, by occasionally referring to the diagrams contained in Plate XVI. In these diagrams the fibres are represented by lines drawn at intervals, the object being to furnish the reader with a transparent ventricle, which will enable him to analyze its structure by tracing the fibres composing the several layers throughout their entire extent. Thus at A A′ of diagram 4, the fibres of the superficial or first external layer are indicated, the fibres of the seventh or last internal layer being seen at E E′ of diagrams 4 & 6. In diagram 5 the fibres of the second layer are represented by the lines marked B B′, the fibres of the sixth or corresponding layer being marked D D′. In diagram 4 the fibres of the third and fifth layers are marked B and D, and the fibres of the fourth or central layer are seen at C of diagrams 4 & 6, and at C C′ C″ of diagram 5. In diagram 3 the lines are drawn at still wider intervals, and show how the external fibres A, B, become internal (D, E) by turning upon themselves at the apex C, where they also enter the interior. Diagrams 7 & 10 show how the external fibres A B, C D enter the apex in two sets at opposite points, viz. at E and F, while diagram 11 shows how the internal fibres are arranged in two sets (X and Y) in the interior.

§ The auriculo-ventricular orifice at the base is also closed by two symmetrical structures, viz. the anterior and posterior segments of the bicuspid valve.

functional; second, to obtain for the apex, which is the weak part of the ventricular wall, great strength with comparatively little material *; and third, to procure for the fibres constituting the external and internal layers, which envelope all the others, a latitude and universality of motion which go far to account for the freedom and force with which the left ventricle contracts.

The fibres of the superficial or first external layer arise, as a rule, from the fibrous ring surrounding the aorta (Plate XII. fig. 1, *a*, and Plate XV. fig. 46, *a*), and from the auriculo-ventricular tendinous ring (Plate XV. fig. 46, *n*). A few, however, are continuous, beneath the auriculo-ventricular tendinous ring, with the fibres of the carneæ columnæ † (Plate XV. fig. 47, *d*).

The fibres of the superficial or first external layer, with their internal continuations the fibres of the seventh or last internal layer, overlap and embrace the fibres of all the other layers, viz. those of two, three, four, five, and six,—an arrangement due, not, as was supposed, to the greater length of the fibres composing the first external and the last internal layers, but to the direction and position of the fibres of these layers on the ventricle—the fibres of the superficial or first external layer and those of the seventh or last internal one pursuing an almost vertical spiral direction on the body and wider portion of the ventricle, and appearing longer by twisting rapidly round the apex or narrow part, the fibres of the deeper layers pursuing a more oblique spiral direction on the body or wider portion of the ventricle, and appearing shorter from not reaching to the apex or narrow portion.

Second external layer of the left ventricle (*Mammal*). The fibres of the second external layer (Plate XII. fig. 2), like those of the first, advance spirally from left to right downwards in two separate sets (*f g*, *d d' e*),—the one set proceeding from rather more than the anterior half of the septum, and the anterior and inner portion of the auriculo-ventricular opening (*d*); the other from rather less than the posterior half of the septum, and the posterior and outer part of the opening (*f*). At the apex the fibres from the anterior portions of the opening and septum go to form the posterior half of the apicial orifice (Plate XII. figs. 2 & 11, *k*), where they become continuous with the anterior fibres of the sixth layer (Plate XII. fig. 6, *n n''*); while those from the posterior portions of the opening and septum enter into the formation of the anterior half of the apicial orifice (Plate XII. fig. 11, *l*), and become continuous with the posterior fibres of the sixth layer (Plate XII. fig. 6, *o o'*). I use the term apicial orifice, because the apex is opened into when the two sets of fibres which constitute the first layer

* The apex in the ventricle of even the horse does not exceed the eighth of an inch in thickness. This deficiency in the thickness of the ventricular wall, which, during the dilatation of the organ and the first stage of contraction, ensures great freedom of motion, is prevented from operating injuriously during the latter stages of contraction, by such portions of the musculi papillares as are situated at the apex plaiting into each other so as entirely to obliterate the apicial cavity.

† It is a great mistake to imagine that all the fibres of the ventricles arise from the auriculo-ventricular tendinous rings, the fact being that, with the exception of the fibres of the first and seventh layers, they are continuous beneath them. These rings are more fully developed anteriorly than posteriorly, and the ring which belongs to the left ventricle is stronger than that which belongs to the right.

(Plate XII. fig. 11, *f g*), are removed. The fibres of the second layer are similarly arranged at the apex to those of the first; *i. e.* they converge slightly and curve upon each other prior to doubling upon themselves to alter their direction and enter the interior. The fibres of the second layer differ from those of the first in being more fascicular, and in issuing from the auriculo-ventricular orifice and entering the apex more obliquely, the effect of which is to render their direction on the body of the ventricle slightly more transverse. They vary also somewhat from the fibres of the first layer in not quite extending either to the apex (Plate XII. compare *k* and *l* with *f g* of fig. 11) or the base (Plate XII. compare *n′ n″* with *q* of fig. 6)—an arrangement which, as it also prevails in the deeper layers, satisfactorily accounts for the ventricular wall tapering towards the apex and the base respectively, as shown in a vertical section (Plate XII. figs. 13 & 14, *s*). The varying thickness of the ventricular wall towards the apex was well known to GERDY*, DUNCAN†, and REID‡, and wrongly, as I think, attributed by them to a supposed difference in the length of the fibres composing the different portions of it, rather than to the position and direction of the fibres themselves, which appear to me to afford the true explanation. The fibres of the second layer further differ from those of the first in their arrangement at the base, most of them being continuous in this direction with the fibres of the sixth layer (Plate XII. fig. 6, *o n*). The continuity of the fibres of the second external layer at the base with corresponding internal fibres, is strictly analogous to the continuity of the external fibres with the internal ones at the apex—the only difference being that at the apex the external fibres, in order to become internal, *involute* or turn in, whereas at the base the internal fibres, in order to become external, *evolute* or turn out. That the same principle which turns in the external fibres and secures their continuity with corresponding internal ones at the apex, also turns out the internal fibres and renders them continuous with corresponding external fibres at the base, is probable from the fact, that the borders formed by the union of the external with the internal fibres at the base and at the apex are convex, and identical as regards structure; in other words, the fibres composing both borders advance spirally, the *external* fibres winding from above downwards and bending over the circular edge, forming the apicial orifice in a direction *from without inwards* (Plate XII. fig. 11, *k l*, and Plate XVI. fig. 55, *e f*), the *internal* winding from below upwards and bending over the convex border surrounding the auriculo-ventricular or basal orifice in a direction *from within outwards* (Plate XII. fig. 7, *n′*, and fig. 8, *o″*). The borders which limit the ventricle towards the apex and the base when the first layer is removed are consequently composed of loops or doublets of fibres (Plate XVI. fig. 55, *e f*, and Plate XV. fig. 47 *d*). Dr. JOHN REID §, in speaking of the left apex, says, "when the point is removed the *circular edge* is left entire, and is formed of another series of fibres, which, like those taken away, advance spirally from the base to the apex, and turning over the edge ascend in the opposite direction, continuing their course after being reflected." The converse of these remarks holds true of the fibres at the base.

* *Op. cit.* † *Loc. cit.* p. 591. ‡ *Loc. cit.* p. 591. § *Loc. cit.* p. 592.

Third external layer of the left ventricle (Mammal). The fibres of the third external layer (Plate XII. fig. 3) resemble in their more important features the fibres of the second layer just described, and advance spirally from the base to the apex and from left to right in two distinct sets (*f g*, *d d′ e*). They differ, however, from those of the second layer in their position on the ventricle. The set which enters more particularly into the formation of the anterior half of the apicial orifice proceeds from the posterior third of the septum, and the posterior half and anterior third of the auriculo-ventricular opening; while that which enters into the formation of the posterior half of the apicial orifice (*k*) proceeds from the remaining anterior part of the auriculo-ventricular opening, and the anterior two-thirds of the septum. Arrived at the apex, which is now greatly widened, they bend or double upon themselves in a direction from without inwards, and reverse their course to enter the interior, where they become continuous with the two sets of fibres forming the fifth layer (Plate XII. fig. 5, *o o′*, *n n′*). The fibres of the third layer differ from those of the second in being arranged in smooth fascicular bands, and in issuing from the auriculo-ventricular opening and entering the apex very obliquely —an arrangement which causes the fibres on the body of the ventricle (*f d′*) to pursue an almost transverse direction. They differ also from the fibres of the second layer, in not extending quite so far either towards the apex (Plate XII. compare *k* of fig. 3 with *k* of fig. 2) or the base (compare *n′ n″* of fig. 5 with *n′ n″* of fig. 6), and in being confined to more central portions of the ventricle—a circumstance which, as has been already explained, accounts for a vertical section of the ventricular wall tapering towards the apex and the base. The fibres of the third layer further differ from those of the second in exhibiting a less degree of crowding at the apex—for the very obvious reason that the apicial orifice, on account of the conical shape of the ventricle, becomes larger and larger with the removal of each successive layer.

Fourth or central layer of the left ventricle (Mammal). When the three external layers have been removed, the fourth or central layer (Plate XII. fig. 4) is exposed. This layer may be denominated the circular layer, or layer of transition, from the fact that the fibres entering into its formation are circular, and form the boundary between the external and internal layers. It differs from the other layers as regards the quality and the direction of its fibres, and as regards its position in the ventricular wall—the fibres composing it being aggregated into strong fascicular bands, whose course is neither from left to right downwards as in the external layers, nor from right to left upwards as in the internal ones, but horizontal or transverse. This peculiarity in direction, which causes the fibres of the fourth layer (*f g*, *d d′ e*) to run at nearly right angles to those of the first (*j*) and seventh layers (Plate XII. fig. 7, *o n*), is accounted for by the fact that in the fourth layer, the fibres of the third layer terminate or double upon themselves, while the fibres of the fifth layer (Plate XII fig. 4, *k*) begin. In other words, the fourth layer, while it belongs neither to the third layer nor the fifth, forms the connecting or transition link to both, as may be seen by a reference to Plate XII. fig. 4, where the fibres (*d d′ e*) are seen to turn directly upon themselves (*k*).

The fibres of the fourth layer, like those of the other layers, are composed of two sets (*fg*, *d d' e*), the one proceeding from the entire septum and a limited portion of the auriculo-ventricular opening on either side of the septum anteriorly and posteriorly, the other from the outer aspect of the auriculo-ventricular opening and its remaining anterior and posterior portions. Although the fibres of the fourth or circular layer form the boundary between the external and internal layers, they do not on this account occupy the centre of the ventricular wall, as may be seen on transverse section (Plate XV. fig. 50). On the contrary, the circular layer (*e*) is found considerably nearer the exterior (*c*) than the interior (*d*) of the ventricular wall—an arrangement which was to be expected, since the layers, as was stated, increase in thickness from without inwards. The aggregate of the external layers, or those to the outside of the circular layer, is consequently much less than the aggregate of the internal ones. The fibres of the fourth layer are from their position embraced by the fibres of all the other layers—viz. those of one and seven, two and six, and three and five. The amount of spiral made by them is rather less than one full turn (Plate XII. fig. 4, *f g*, *d d' e*).

Internal layers of the left ventricle of the Mammal.

Fifth layer. When the three external and the fourth or central layer are removed, one is immediately struck with the change, or rather complete reversal, in the direction of the fibres. Thus the fibres of the fifth layer (Plate XII. fig. 5), which are the internal continuations or counterparts of those forming layer three, instead of proceeding in a spiral direction from base to apex and from left to right, proceed in a spiral direction from apex to base and from right to left; the reason of which is obvious when it is recollected that the fibres of the fifth layer, when the layers are numbered from without inwards, form the first of the internal layers—*i. e.* of those layers found to the inside of the central layer, where, as has been explained, the order in the arrangement of the fibres is reversed.

The fibres of the fifth layer, like the other layers described, consist of two sets (*o*, *n*); they, however, pursue a very oblique course, and in this respect resemble the fibres of the third layer, which they cross at a very obtuse angle. They moreover fold or double upon themselves in an outward direction at the base (Plate XII. compare *n'* with *n''* of fig. 5*), and in so doing alter their direction (*n''*), and become continuous with the two sets of fibres forming the third external layer (Plate XII. fig. 3, *f g*, *d e*). The fibres of the fifth layer are also continuous with the two sets of fibres forming the third layer at the apex (Plate XII. fig. 3, *k*). The amount of spiral made by them from the time they leave the apex until they reach the base, rather exceeds one full turn (Plate XII. fig. 5, *o o'*, *n n' n''*). The fibres of the third and fifth layers embrace or overlap the fibres of the fourth or central layer, they themselves being embraced by the fibres of the first and seventh and the second and sixth layers.

Sixth layer of the left ventricle (*Mammal*). The fibres of the sixth layer (Plate XII.

* In this figure the internal fibres (*n'*) are seen twisting or bending over in an outward direction to become continuous with the external fibres (*n''*).

fig. 6) are the internal continuations of the twofold set of fibres forming the second external layer. They wind in two portions (o, n), in a spiral slightly vertical direction from right to left upwards, or from apex to base, so that they cross the fibres of the second layer at a somewhat acute angle. At the base they fold upon themselves in an outward direction, and form flattened bands ($n' n''$), which become continuous with corresponding bands belonging to the second layer (Plate XII. fig. 2, $f g$, $d d' e$). The amount of spiral made by the fibres of the sixth layer from the time they leave the apex until they reach the base, is rather under a turn and a half. Taken together, the fibres of the second and sixth layers embrace in their convolutions the fibres of the third, fourth, and fifth layers, they themselves being overlapped by the fibres of the first and seventh layers.

Seventh or last internal layer of the left ventricle (*Mammal*). The fibres of the seventh or last internal layer (Plate XII. figs. 7 & 8), as was stated when describing the first or superficial layer, form the carneæ columnæ and musculi papillares, especially the latter. When the two sets of fibres which constitute the superficial or first external layer are traced from above downwards, the anterior set, as was explained, is found *to enter the apex posteriorly* (Plate XII. fig. 10, d), to become continuous with the fibres *of the anterior musculus papillaris* (Plate XII. figs. 12 & 13, y) and those of the carneæ columnæ next to it—the posterior set *entering the apex anteriorly* (Plate XII. fig. 10, g), and becoming continuous with the fibres *of the posterior musculus papillaris* (Plate XII. figs. 12 & 13, x) and the adjoining carneæ columnæ. The musculi papillares and carneæ columnæ therefore occupy a variable position in the interior of the ventricle,—the anterior musculus papillaris winding in a spiral almost vertical direction from below upwards, and from right to left, from *the interior of the apex posteriorly* to occupy *an anterior position*; the posterior musculus papillaris winding in a corresponding direction from *the interior of the apex anteriorly*, and curving round to occupy *a posterior position*. The musculi papillares, as will be seen from this description, are not the simply vertical columns usually represented (Plate XII. fig. 14, x, y), but vertical *spiral* columns (Plate XII. fig. 13, x, y). The musculi papillares are seen to advantage in the ventricle of the giraffe, camel, lion, horse, ox, ass, deer, seal, and dog. They occur in various stages of development *.

Most commonly they appear as conical-shaped spiral bodies, which project into the ventricular cavity and extend, in moderate-sized hearts, from the extreme apex to within half an inch or so of the base. At the apex, where they may be said to originate, and where they project least into the cavity, their spiral nature is very distinct †.

Towards the base, where their spiral direction is less marked, and where they project most into the ventricular cavity, they terminate in free blunted extremities, which are obliquely cut from below upwards, and from within outwards. As the chordæ tendineæ connect the blunted extremities in question with the segments of the bicuspid valve,

* In the American elk (Plate XV. fig. 48, y) they are so rudimentary as scarcely to attract attention.

† To see the spiral course pursued by the musculi papillares, the ventricle should be opened anteriorly, the incision being carried not quite to the apex, as represented at Plate XII. fig. 13, x y.

and through them with the auriculo-ventricular tendinous ring, the musculi papillares may be said to be continuous at the apex and the base respectively. On some occasions the musculi papillares spring from the interior of the apex in two fascicular bundles, the fibres of each bundle radiating and rapidly increasing in number as the apex is receded from; in others they spring from several smaller fasciculi, the fibres of the fasciculi being arranged in two sets and remaining more or less distinct, so that each musculus papillaris has a bifid appearance (Plate XII. fig. 15, $x, y\,y'$). The musculi papillares are principally of use in regulating the spiral action of the bicuspid valve, which they do through the instrumentality of the chordæ tendineæ. They are also useful, from projecting into the ventricular cavity, in reducing the blood to a state of quiescence during the diastole. During the systole they act as spiral lavers, and scoop the blood out of the interior of the ventricle by communicating to it a gliding spiral movement.

Situated between the musculi papillares, and, in fact, occupying the spiral interspaces or hollows occasioned by their projecting into the ventricular cavity, are the carneæ columnæ. The carneæ columnæ, like the musculi papillares, proceed in a spiral nearly vertical direction from right to left upwards. They are more developed in some instances than in others. In the camel, red deer, and American elk they may be said to be altogether wanting (Plate XV. fig. 48). In the lion, leopard, horse, ox, and ass they are more or less rudimentary; while in the mysticetus, armadillo, giraffe, and sheep they attain a size which almost entitles them to rank with the musculi papillares themselves. In the human heart (Plate XII. fig. 15, z) the carneæ columnæ consist of irregularly shaped, rounded muscular bands, arranged so as to form an intricate network —some of the bands being attached at both extremities, others throughout their entire extent. A portion of the fibres of the carneæ columnæ are continuous with the fibres of the external layer at the base; others derive attachment from the fibrous ring surrounding the aorta, and from the auriculo-ventricular tendinous ring. Running between the carneæ columnæ and the musculi papillares are a series of delicate fibrous stays (Plate XII. figs. 13 & 14, r, and Plate XV. figs. 47 & 48, r), which hang loosely in the ventricular cavity. They vary in thickness with the size of the heart, and probably assist in coordinating the movements of the structures between which they are found. The spiral interspaces or hollows occupied by the carneæ columnæ, to which a passing allusion has been made, are two in number, a larger and a smaller. They both extend from the extreme apex to the extreme base. The larger groove or interspace proceeds from *the outward or lateral aspect of the apex*, and winds in an upward and inward or septal direction, until it reaches *the apex of the inner segment of the bicuspid valve*, where it bifurcates—the one portion conducting to the aortic orifice, with which it communicates, the other to the base of the segment, where it terminates. The smaller groove or interspace proceeds from *the septal side of the apex*, and winds in an upward and outward or lateral direction, until it reaches *the base of the outer segment of the bicuspid valve*, where it likewise terminates.

These grooves are important physiologically; for I find that in them the blood is arranged in spiral columns during the diastole, and that towards the end of the diastole and the beginning of the systole, it is made to advance in spiral waves from beneath on the segments of the bicuspid valve, and communicates to these structures a distinctly spiral upward movement, the amount of upward motion being regulated by the chordæ tendineæ to prevent retroversion and regurgitation. As the systole advances and the musculi papillares contract with the other portions of the ventricular wall, the segments of the valve are gradually drawn down by the chordæ tendineæ in an opposite direction to that by which they ascended and tightened upon the rapidly diminishing columns of blood, so that they form a spiral dependent cone, whose apex is directed towards the apex of the ventricle*.

Cast of the interior of the left ventricle (Mammal).

That the fibres of the seventh layer have a spiral direction and enclose a conical-shaped spiral cavity, may be readily ascertained by a reference to Plate XII. fig. 17, which is taken from a photograph of a wax cast of the interior of the left ventricle of the deer. On carefully examining the engraving in question, the cavity will be found to taper and twist towards the apex (*z*), and also, though to a less extent, towards the base (*b*). The diminution of the cavity towards the base is so slight that it might be overlooked, were it not that it renders the auriculo-ventricular orifice more easily closed than it would otherwise be.

Transverse sections of the left ventricle (Mammal).

The amount of spiral made by a cast of the left ventricular cavity, as ascertained by transverse sections, rather exceeds a turn and a half. This is proved by dividing the ventricle transversely into six unequal portions, by placing the sections in exactly the same positions, and by comparing the long axes of such portions of the cavity as are found in the sections with each other, and with the long axis of the cavity of the right ventricle. It is necessary to make the sections unequal, as the spiral formed by the cavity is much more rapid towards the apex than the base—the success of this demonstration depending on making the section in such positions as will intersect the spiral at every half turn of its progress. I have given views of five of the sections alluded to; and it will be observed that in the first two sections towards the base (Plate XV. figs. 49 & 50), the long axis of the cavity (*b*) of the left ventricle is at right angles to the long axis of the cavity of the right ventricle (*l*). In the third section (Plate XV. fig. 51), the long axis of the cavity (*b*) of the left ventricle is parallel with the long axis of the cavity of the right ventricle (*l*), showing that the left ventricular cavity has made half a spiral turn. In the fourth section (Plate XV. fig. 52), the long axis of the left

* For a detailed account of the action of the mitral and tricuspid valves, see paper by the author "On the Relations, Structure, and Function of the Valves of the Vascular System in Vertebrata," Transactions of the Royal Society of Edinburgh, vol. xxiii. p. 761.

ventricular cavity (*b*) is again at right angles to the long axis of the cavity of the right ventricle, making it evident that the cavity of the left ventricle has made a full spiral turn; and in the fifth section (Plate XV. fig. 53) the long axis of the left ventricular cavity is again parallel with the long axis of the cavity of the right ventricle, showing that the left ventricular cavity has made an additional half turn. If another section had been made at the extreme apex, probably an eighth of a turn more would have been obtained, as the spiral in this direction is very rapid. The object of the cavity twisting suddenly upon itself at the apex is obviously to protect the ventricular wall, where thinnest, from undue pressure; for it is plain that a fluid injected into a conical-shaped spiral and therefore tortuous cavity will not be transmitted to the apex with the same degree of force as it would if the cavity were not spiral.

Vertical section of the left ventricular wall (Mammal).

On making a vertical section of the left ventricle between the musculi papillares (Plate XII. figs. 13 & 14), the ventricular wall (*s*), like the ventricular cavity, is observed to form a double cone, the apices of which point towards the apex and base of the ventricle respectively, the bases, which are united in the upper portion of the middle third, corresponding with the thickest part of the ventricular wall. The varying degree of thickness in the ventricular wall is traceable to the fact, that the outermost and innermost layers extend further towards the apex and base than those which come next, and these, again, further than those which succeed them, and so on until the central layer is reached—this being of least extent, and confined indeed to about the middle third of the ventricle. Thus into the apicial portion of the ventricular wall, where thinnest, only one layer enters, viz. the superficial or first external*. Into a second portion, a little above the apex, two layers enter, the first and the seventh; into a third or higher portion four, viz. the first and the seventh, the second and the sixth; while into a fourth, or still higher portion, which corresponds with the upper part of the middle third, the whole seven layers enter. Tracing the thickness of the ventricular wall in an opposite direction, *i. e.* from the base towards the upper part of the middle third, the same changes present themselves, although in a less marked degree. Thus the extreme base consists of two layers, the continuations in fact of those forming the second part of the apex; the second portion of four, the third of six, and so on—an arrangement which accounts for the ventricular wall being thicker towards the base than towards the apex†.

Recapitulation of facts connected with the left ventricle (Mammal). Before leaving the left ventricle, it may be well to recapitulate briefly the points more particularly dwelt upon. They are the following:—

* This portion of the ventricular wall is formed by the external fibres turning round in a circular direction, to alter their direction and become continuous with the internal, the external and internal fibres, in virtue of their spiral direction, not crossing each other until removed an appreciable distance from the apex.

† The septum also tapers in two directions, more particularly when, as in the present demonstration, it is regarded as forming part of the left ventricle.

1st. It has been shown that the walls of the left ventricle, when the septum is included, are composed of four systems of spiral fibres, two external and two internal; the external systems running from left to right downwards from base to apex; the internal systems from right to left upwards from apex to base.

2ndly. That these spiral fibres are arranged in layers or strata, which increase in thickness from without inwards, and that the fibres composing them have each a different course, whereby they change their direction from the nearly vertical to the horizontal, and from the horizontal back again to the nearly vertical.

3rdly. That the fibres composing the strata alluded to are as nearly as may be of the same length, and enter the apex and issue from the auriculo-ventricular orifice at the base in two distinct parcels or bundles.

4thly. That the two sets of fibres forming the external layers are continuous at the apex and at the base with the two sets of fibres forming the internal layers, and give rise to twisted continuous loops, pointing to the apex and base respectively; the more superficial loops embracing in their convolutions the deeper or more central ones.

5thly. That the apex is opened into, and the apicial and basal orifices (on account of the double cone formed by the ventricular cavity) widened, by the removal of such strata as are found to the outside of the central stratum.

6thly. That the ventricular wall, like the ventricular cavity, tapers towards the apex and the base, the tapering towards the apex being very considerable, that towards the base being less appreciable.

7thly, and lastly. That the septum is of nearly the same thickness as the left ventricular wall, and must be dissected *pari passu* with it, if the left ventricle is to be considered complete in itself.

The right and left ventricles, septum, &c. considered relatively (Mammal).

By far the simplest way to regard the right ventricle is, to consider it as a segment of the left one—a view which is favoured both by the actual structure, and all that is at present known of the fœtal development of the organ. In works on embryology it is stated that at first the heart consists of a mass of nucleated cells; that by and by it assumes the form of *an elongated sac or dilated tube*; that about the fourth week *a septum begins to arise up internally, which proceeds from the right side of the apex and anterior wall of the cavity*, in the direction of the base, where the arterial bulb leads off; and that about the eighth week this interventricular septum is complete. It is further stated that the walls of the ventricles are, comparatively speaking, *very thick, the thickness of both being about the same*; but that on approaching the full period the left begins to be the thicker of the two—a change which was *à priori* to be expected, seeing that after birth the left ventricle has to perform nearly twice as much labour as the right.

Beginning therefore with the left or typical ventricle constructed as described, it appears to me that in order to produce the right ventricle, and explain the relation existing between the right and left ventricles anteriorly, posteriorly, and septally, all that is necessary is to push in the anterior wall (Plate XVI. diag. 15, *a*) in an antero-posterior direction until it touches the posterior one (B), in imitation of the constructive process. As however, in pushing in the anterior wall until it touches the posterior one a double septum is produced which is unattached posteriorly, it is necessary, to complete the structure, to suppose the fibres forming the posterior border of the septal duplicature as coalescing with corresponding fibres of the posterior wall, until the central layer is reached (Plate XVI. diag. 17, K); whilst the fibres of the two halves of the duplicature itself pass through and are blended with each other to the same extent (E J). If the constructive process be so imitated, it will be seen that not only are two ventricles (C, D) produced, each of which has fibres peculiar to itself (I H, F E), but, what is remarkable, that these ventricles are united to each other posteriorly (K) and septally (E J) by a series of fibres, which are common to both, *i. e.* fibres which belong partly to the one ventricle and partly to the other, precisely as in the ventricles themselves. The fibres moreover of the left or principal ventricle form four systems of conical spirals, two external and two internal—the former winding from above downwards from left to right, to twist rapidly round in a whorl at the apex, where they are continuous with the two internal systems *, winding in an opposite direction, from below upwards and from right to left.

The fibres of the right ventricle, on the other hand, form only segments of spirals—they being continuous with each other not at one point as in the left ventricle, but throughout the track for the anterior coronary artery (A). That the foregoing arrangement approaches very closely to, if it is not identical with, that occurring in the ventricles of the adult heart, may be ascertained in various ways.

1st. When the right and left ventricles (Plate XIII. figs. 18, 21, & 24) are dissected from without inwards, the layers constituting the right ventricular wall ($f'f''$) gradually increase in thickness, and pass through the several changes in direction met with in the layers of the left ventricular wall ($d\ d'$), clearly showing that the right and left ventricles are constructed on the same type. As, however, the left ventricle, as will be shown presently, is the more complete of the two, it is more natural to suppose that the right ventricle is a segment of the left one, than the reverse.

2ndly. When both ventricles are dissected at the same time, the fibres forming the external layers posteriorly (Plate XIII. fig. 21) are for the most part common alike to the one ventricle and the other†; in other words, the fibres on the back part of the left ventricle (*f*) cross over the posterior coronary track (*j*), and pass on to the right

* The external and internal systems, as has been explained, are rendered continuous at the base by bending over until they meet each other. Similar remarks apply to the fibres at the base of the right ventricle.

† The fibres forming the left apex are peculiar to itself, and belong exclusively to the left ventricle. This distribution of the fibres is accounted for by the fold which I believe forms the right ventricle beginning fully half an inch above the apex in question.

ventricle ($f' f''$); whereas in front, with the exception of a large cross band at the base (Plate XIII. fig. 20, *n*), which is evidently for the purpose of binding the ventricles more securely together anteriorly, the fibres of the right and of the left ventricle respectively dip in (Plate XIII. fig. 23, *r*) at the anterior coronary track ($o\, o'$), as if altogether independent of each other.

3rdly. When the fibres on the anterior aspect which belong to one or other of the ventricles are traced into the septum, and the ventricles forcibly separated (Plate XIV. fig. 45) in a line corresponding with the course which the fibres peculiar to each ventricle naturally take, the right ventricle (*k*) claims, as its share of the partition alluded to, rather less than one-third of its entire breadth (*l*), the remaining two-thirds (*n*) going to the left ventricle (*m*). Why the right ventricle should claim less than a third of the septum is difficult to explain, unless it be that this portion of the septum, belonging as it does more particularly to the right ventricle, represents the right half of the septal fold atrophied to half its original dimensions (Plate XVI. diag. 16, K), in common with the other portions of the right ventricular wall (F)*. The right ventricular wall after birth, it will be remembered, is only half the thickness of the left (Plate XV. compare $c'' d''$ with $c\, d$ of fig. 51). This view seems probable from the fact, that the septum in some places (Plate XV. fig. 50, $c' d'$) is nearly a third thicker than the left ventricular wall ($c\, d$) between the papillary muscles (x, y)—an excess in breadth which very nearly corresponds with what would be obtained when allowance is made for the right and left halves of the septal duplicature passing through each other, until the central layer in either is reached, and for the atrophy of the right half of the septal fold as suggested.

4thly. When the cut ends of the common fibres found on the left ventricle, *i. e.* those to the outside of the central layer (Plate XIII. fig. 25, *f*), are applied to the fibres forming the two-thirds of the septum (*g*) which belong to this ventricle, they are ascertained to agree in direction, and would, if united, give rise to four complete systems of conical spirals (two external and two internal), these conical spiral fibres being continuous with each other at the apex and also at the base; whereas the fibres of the right ventricle and its share of the septum, treated in the same way, although likewise continuous at the base and in the track for the anterior coronary artery, consist merely of spiral fragments (Plate XIV. fig. 35, $f\, g$, $d\, d'$), and represent only a part of a more complete system

* In this explanation I have supposed that the right ventricle and the right half of the septal fold have become atrophied to half their original bulk, in accordance with the law that structure and function are related to each other as cause and effect—the efforts required for maintaining the pulmonic circulation being probably about half those required for the maintenance of the systemic. The converse, however, of this explanation is equally true, and might be adopted with the same result as far as the comparative thickness of the ventricles is concerned. Thus, instead of supposing that the right ventricle and its half of the septal duplicature becomes atrophied, it might be assumed, in accordance with the same law, that the left ventricle and its half of the septal duplicature becomes hypertrophied to twice its original dimensions, the right ventricle and its share of the septum remaining stationary.

—a portion nipped off as it were from the perfect cone. (Compare $c''d''e'$ with $c\,d\,d'$ of fig. 50, Plate XV., and E F with H I of diag. 17, Plate XVI.)

5thly. When casts of the interior of the ventricles are taken, the left ventricular cavity (Plate XII. fig. 17), in accordance with the more perfect arrangement of the fibres forming the left ventricle, supplies a highly symmetrical double conical screw, the right ventricular cavity (Plate XII. fig. 16), although it has the same twist, furnishing only an incomplete portion.

6thly. When the so-called common fibres posteriorly (Plate XIII. fig. 21, $f\,f'$) are dissected, layer after layer, synchronously with the independent anterior fibres (Plate XIII. fig. 23, $p\,q$), both sets are seen to pass through the same changes in direction; in other words, they proceed from left to right downwards, gradually becoming more and more oblique as the central or transverse layer is reached.

7thly, and lastly. When the fibres of the septum (Plate XIII. figs. 19, 22, & 25, $g\,e$) are dissected, layer after layer, with the other portions of the ventricular walls (Plate XIII. figs. 18, 21, & 24, $f\,f'$), they are observed to pass through the same changes in direction; *i. e.* they pursue a spiral course from left to right downwards, becoming more and more oblique as the central layer (Plate XIII. fig. 28, $f\,g$, $d\,e$) is reached, after which they reverse their course and become more and more vertical in an inverse order. They consist moreover of three kinds: first, such as, properly speaking, belong to the right ventricle (Plate XV. fig. 45, l); secondly, such as belong more particularly to the left ventricle (n); and thirdly, such as belong partly to the one ventricle and partly to the other (Plate XV. fig. 50, e'). Thus, in dissecting the septum from the right side, the fibres first met with belong almost exclusively to the right ventricle. These fibres, if traced from below upwards like the other internal fibres of the right ventricle, proceed from right to left. Traced from above downwards, their direction is just the reverse, or from left to right; and it is important to note this circumstance, as the internal fibres of the right ventricle become mixed up on the septum, at no great depth from its surface, with fibres belonging exclusively to the left ventricle*, the direction of which is also from left to right downwards. There is therefore a portion of the septum in which the internal fibres of the right ventricle are mingled with the external fibres of the left, and where the two sets pass through each other as the fingers of the one hand might be passed between those of the other. The fibres found still deeper, and which in fact constitute the left two-thirds of the septum, belong exclusively to the left ventricle. These points may be readily established by dissection.

External layers of the right and left ventricles (Mammal).

Superficial or first external layer. If the ventricles are dissected together (Plate XIII. figs. 18 & 20), the fibres of the superficial or first external layer posteriorly (Plate XIII.

* The existence of these fibres in the right third of the septum induced me, when describing the left ventricle, to regard the septum as forming a part of its walls.

fig. 18) run in a spiral almost vertical direction* from left to right downwards, some of them proceeding to the left apex (d''), others to the right ventricle (f'); and if an incision be made through the right ventricular wall (Plate XIII. fig. 19), a little to the right of the posterior coronary track, and the breach dilated to expose the septum and the interior of the right ventricle, it will be seen that the fibres on the right side of the septum (g) follow a similar course. On the anterior aspect of the ventricles (Plate XIII. fig. 20) the fibres also pursue a spiral nearly vertical direction from left to right downwards†; but there is a great difference between them and the fibres on the posterior aspect.

On the posterior of the ventricles (Plate XIII. fig. 18) the fibres from the left auriculo-ventricular opening and the left ventricle generally ($d f$) cross the track for the posterior coronary artery (j), and are found also on the right ventricle ($f' f''$); hence the epithet common fibres; whereas on the anterior of the ventricles (Plate XIII. fig. 20) the fibres, with the exception of the cross band at the base already referred to (n), dip in at the anterior coronary track (o), to appear on the right third of the septum (Plate XIII. fig. 19, g, h), where they are continuous with fibres having a corresponding direction. The fibres occurring on the right side of the septum (Plate XIII. fig. 19, g, h), as well as those lining the interior of the right ventricle generally, are, for anything I can discover to the contrary, segmental portions lopped off or isolated by the primary notch or reduplication (Plate XVI. diag. 15, A; Plate XV. compare $k\ l$ with $m\ n$ of fig. 45) from the spiral nearly vertical fibres originally lining the interior of the left or typical ventricle. If this explanation be adopted, the great structural resemblance presented by the internal fibres of the right and left ventricles respectively is at once accounted for.

Septum Ventriculorum composed of two elements (*Mammal*). That two elements enter into the composition of the septum is probable for the following reasons:—

1st. If the right ventricle be detached a little to the right of the tracks for the anterior and posterior coronary arteries, and the septum dissected from the right side (Plate XII. figs. 1, 2, 3, & 4), many of the fibres ($g\ e$) at no great depth from the surface proceed without breach of continuity to the anterior wall (Plate XII. fig. 10, f) and apex (g) of the left ventricle, thus showing that they belong exclusively to the left ventricle; whereas a certain number of them, as has been stated, are ascertained to be continuous with the fibres on the outside of the right ventricular wall (Plate XIII. fig. 21, $f f''$), proving them to belong more particularly to the right ventricle.

* The superficial fibres from the right and left ventricles converge in the track for the posterior coronary artery in a manner resembling the letter V ($f f' j$)—an arrangement which is confined to the upper or basal third of the first layer. Ultimately these fibres curve round to enter the left apex anteriorly.

† In the superficial layers of the right ventricle anteriorly, the fibres at the root of the pulmonary artery interweave to a considerable extent, and are matted together. As a similar arrangement exists in the superficial layers of the left ventricle at the root of the aorta, it is just possible that the large vessels are thereby supplied with more secure points of attachment.

2ndly. The fibres of the right side of the septum, especially the right third of it, are densely matted together, and separate with greater difficulty than the fibres of the other portions of the septum and ventricular wall generally.

3rdly. The exact width of the septum (Plate XV. fig. 50, *c' d'*), as compared with the left ventricular wall (*c d*) between the musculi papillares (*x*, *y*), is in some parts nearly one-third greater—this increase in bulk affording a redundancy of material, which was to be anticipated, since the two halves of the septal fold (Plate XVI. diagram 16, H K) are supposed to have passed partially through, and become blended with each other (Plate XVI. diagram 17, E J).

4thly. Such of the fibres as are found near the centre of the right third of the septum cross each other slightly towards the base, and give rise to a curious Y-shaped arrangement at a point corresponding to the crossing which would be produced by the reduplication.

There are other arguments in favour of the septum being formed of two elements by a septal reduplication.

When, for example, the common fibres are dissected posteriorly, more or less interruption is experienced in their separation (particularly in the deeper layers) in a line corresponding with the track of the posterior coronary artery (Plate XV. fig. 54, *c c'*), where the fibres of the border of the reduplication (Plate XVI. diagram 16, G) are believed to have united with the fibres of the posterior wall (B).

The external fibres of the right ventricular wall moreover (Plate XIII. fig. 20, *d' f'*, and fig. 23, *p q*) enter the track for the anterior coronary artery (*o*) throughout its entire extent, for the purpose of appearing on the septum (Plate XIII. figs. 19 & 22, *g*), the track referred to corresponding with the rut which would be produced by the junction of the two halves of the septal duplicature (Plate XVI. diagram 16, A).

Lastly, the external fibres of the right ventricular wall enter the interior by simply bending or folding upon themselves (Plate XIV. figs. 34 & 35, *d e*, *f g*, and Plate XV. fig. 45, *k*, *o*, *l*)—an arrangement which presupposes a corresponding reduplication or folding in of the anterior wall at some period or other, and one which is altogether different from the arrangement of the external fibres of the left ventricle at the apex, where the fibres enter the interior in two divisions in a regular whorl (Plate XII. fig. 10, *g*, *d*, and Plate XVI. fig. 55, *e*, *f*).

Carneæ columnæ and musculi papillares of the right ventricle (*Mammal*). The carneæ columnæ of the right ventricle (Plate XIV. figs. 43 & 44) are in general better marked, and the musculi papillares more numerous than in the left—a modification traceable partly to the shape of the right ventricular cavity (Plate XV. fig. 49, *l*), and partly to the greater number of fixed points required for the attachments of the chordæ tendineæ distributed to the tricuspid valve.

In the right ventricle, as in the left, the carneæ columnæ pursue a spiral nearly vertical direction from right to left upwards, and are subject to great variation as regards size, number, and general appearance. The musculi papillares in this ventricle, although usually consisting of two as in the left (Plate XIV. fig. 43, *p p'*), are not necessarily limited to this number. In the camel and American elk the carneæ columnæ are altogether wanting, the musculi papillares (two in number) being alone present. In the heart of the armadillo and red deer the carneæ columnæ are feebly developed, the musculi papillares being generally three in number and small. In the heart of the sheep the carneæ columnæ are more fully developed than in the preceding, the musculi papillares being sometimes two in number, and sometimes three (Plate XIII. fig. 19, *h*). In the heart of the pig, leopard, and calf (Plate XIV. fig. 43) the carneæ columnæ are still more strongly developed, and appear in the form of thick muscular spiral ridges (*o*), which slightly intersect each other and cross the floor of the ventricle (*r'*), the musculi papillares being sometimes two (*h h'*), sometimes three, and sometimes four in number. In the porpoise, dugong, mysticetus, and human heart (Plate XIV. fig. 44) the carneæ columnæ are more or less reticulated, particularly in the two latter, the musculi papillares varying from two to four (*h h' h'' h'''*). This increase in the number of papillary muscles in the right ventricle, which might at first sight seem to interfere with the bilateral distribution of the fibres in the primary or typical ventricle, is accounted for by the fact that in the right ventricle the muscular fasciculi, from which the papillary muscles spring, do not always coalesce as in the left ventricle, but remain permanently apart. The musculi papillares of the right ventricle are less distinctly spiral than those of the left, and are somewhat flattened to suit the concavo-convex shape of the right ventricular cavity. They occupy the septal wall posteriorly (*h'' h'''*), and the right ventricular wall anteriorly (*h h'*). In the right ventricle, as in the left, many of the fibres of the carneæ columnæ (Plate XIV. fig. 43, *o'*) are continuous at the base with corresponding external fibres (*d' f*), such of them as are not continuous, together with the musculi papillares, being rendered so by the intervention of the right auriculo-ventricular tendinous ring (Plate XIV. fig. 43, and Plate XV. fig. 46, *n'*), the chordæ tendineæ, and the segments of the tricuspid valve (Plate XIV. fig. 44, *i'*).

Muscular valve of the right ventricle of the bird, how formed?

Distinction founded thereupon. In the right ventricle of the bird, where the tricuspid valve of the mammal* is supplied by a fleshy one, the continuity of the external with the internal fibres at the base is complete. This valve, as has been stated, forms the distinguishing characteristic between the ventricles of the bird and mammal, and differs essentially in its structure from all the other valves of the heart.

It consists of a solitary fold of muscular substance (Plate XIV. figs. 38, 40, & 41, *i*), which extends from the edge and upper third of the septum posteriorly (Plate XIV.

* The tricuspid valve, as its name implies, consists of three leaves or segments. As, however, the anterior segment, or that nearest the pulmonary artery, is larger than the posterior and internal segments, from which it is divided by a deeper notch than divides the posterior and internal segments from each other, some investigators regard the valve as consisting of two portions only; and I am inclined to assent to this view, from the bilateral nature of the left ventricle, and from my conviction that the right ventricle and every thing pertaining to it is a segment of the left.

fig. 39, *g*) to the fleshy pons anteriorly (*e*). The fold opens towards the interior of the ventricle (Plate XIV. fig. 40, *i*), in a direction from above downwards (Plate XIV. fig. 41, *i*), and is deepest at the edge of the septum posteriorly (Plate XIV. figs. 39 & 40, *g*). As it gradually narrows anteriorly (*i*), it is somewhat triangular in shape, its dependent and free margin (*g*) describing a spiral which winds from behind forwards, and from below upwards. The valve, from its substance and structure, may be appropriately termed the musculo-spiral valve, and is seen to advantage in the right ventricle of the emu (Plate XIV. fig. 41), swan (Plate XIV. figs. 38 & 39), turkey (Plate XIV. fig. 40), capercailzie, and eagle. It is composed of fibres from all parts of the floor and lower third of the right ventricle interiorly (Plate XIV. fig. 40, *j*), and from the upper third of the left ventricle and septum posteriorly (Plate XIV. figs. 39 & 40, *g*). The fibres from the lower third of the right ventricle interiorly, are spread over a large surface, and pursue a more or less vertical and slightly spiral direction. They gradually detach themselves in two portions (Plate XIV. fig. 40, *h*, *j*) from the right ventricular wall, and converge towards the centre of its middle third, where they form a flattened spindle-shaped muscular band (Plate XIV. fig. 40, *h*). Arrived at this point and continuing their spiral course, they diverge or spread out to assist in forming the inner and free leaf (*i g*) of the muscular fold (Plate XIV. figs. 39, 40, & 41, *g*)—one portion bending over in graceful spiral curves (Plate XIV. fig. 40, *i*) in a direction from within outwards and from below upwards, to become continuous with the superficial or external fibres at the base, a second portion bending over in like manner (e'') to become continuous with certain fibres from the upper third of the second layer of the septum and left ventricle posteriorly, a third portion (e''') pursuing a similar course to unite with the fibres from the upper third of the third layer of the septum and from the left ventricle. If that surface of the dependent or free leaf of the valve which is directed towards the right ventricular wall be examined, a fourth portion (*g*) is found to be continuous with the fibres of the upper third of the fourth or transverse layer. The muscular valve of the bird may therefore be said to be composed of the fibres entering into the formation of the several layers of the right ventricular wall, (the ventricular wall in fact bifurcates or splits up towards its base,) the external layers forming the outer wall of the valve, the internal layers, which are slightly modified, forming the inner. It is to this splitting up of the right ventricular wall towards the base (Plate XIV. fig. 41, *k*) that its greater tenuity in this direction, as compared with the right ventricular wall of the mammal (Plate XV. fig. 49, *f*), is to be traced. If the muscular valve be regarded as an independent formation, which it can scarcely be, it will be best described as a structure composed of fibrous loops, these loops being of three kinds and directed towards the base—the first series consisting of spiral nearly vertical fibres forming a somewhat acute curve, the second series consisting of slightly oblique spiral fibres forming a larger or wider curve, and the third series consisting of still more oblique fibres and forming a still greater curve. As the fibres composing the different loops act directly upon each other during contraction, the object of the arrangement is obviously to supply a moveable partition or septum which shall occlude the right auriculo-ventricular opening during the systole. The manner in which the several loops act is determined by their direction. Thus the more vertical ones, in virtue of their contracting from above downwards, have the effect of flattening or opening out the valvular fold, and in this way cause its dependent or free margin to approach the septum. The slightly oblique fibres, which contract partially from above downwards, but principally from before backwards, assist in this movement by diminishing the size of the right auriculo-ventricular orifice in an antero-posterior direction,—it remaining for the very oblique and transverse fibres, which contract from before backwards, and from without inwards, to complete the movement, by pressing the inner leaf of the fold directly against the septum—an act in which the blood plays an important part, from its position within the valve, this fluid, according to hydrostatic principles, distending equally in all directions and acting more immediately on the dependent or free margin of the valve, which is very thin and remarkably flexible. When a vertical section of the fold forming the valve of the bird is made, that portion of it which hangs free in the cavity is found to be somewhat conical in shape, the thickest part being directed towards the base, where it has to resist the greatest amount of pressure—the thinnest corresponding to its dependent and free margin, where it is applied to, and supported by, the septum. The upper border of the fold is finely rounded, and in this respect resembles the convex border which limits the right ventricle of the mammal towards the base.

The spindle-shaped muscular band (Plate XIV. fig. 40, *h*), which from its connexion may be said to command the upper (e'') and lower (j) portions of the right ventricle interiorly, is obviously for the purpose of coordinating the movements of the muscular valvular fold; and as its position and direction nearly correspond with the position and direction of the musculus papillaris situated on the right ventricular wall of the mammal (Plate XIV. fig. 44, h'), it is more than probable that it forms the homologue of this structure. Indeed this seems almost certain from the fact that, if the ventricles of the bird be opened anteriorly (Plate XIV. fig. 40), and the band referred to contrasted with the anterior musculus papillaris of the left ventricle (y), both are found to occupy a similar position. The fleshy band therefore may be said to be to the muscular valve of the right ventricle, what the anterior musculus papillaris and its chordæ tendineæ are to the segments of the mitral valve. Compared with the tricuspid valve of the mammal, the muscular valve of the right ventricle of the bird is of great strength. As, moreover, it applies itself with unerring precision to the septum, which is slightly prominent in its course, its efficiency is commensurate with its strength. The prominence on the septum alluded to is very slight, and might escape observation, were it not that immediately below it the septum is hollowed out to form a spiral groove of large dimensions (e'' e''). This groove, like the valve, runs in a spiral direction from behind forwards, and from below upwards, and, when the valve is applied to the septum during the systole, converts the right ventricular cavity into a spiral tunnel, through which the blood is forced, on its way to the pulmonary artery. Such of the fibres of the superficial or first external layer of the right ventricle of the mammal as are not continuous with corresponding external fibres at the base arise in two divisions (Plate XIV. fig. 30, *d, f*),—the one from the fibrous ring surrounding the pulmonary artery (Plate XV. fig. 46, *k*) and aorta (*a*), and the anterior half of the fibrous ring surrounding the right auriculo-ventricular opening (*l*), together with a corresponding portion of the septum (*e*); the other from the posterior half of the fibrous ring (*n'*) surrounding the right auriculo-ventricular opening, the posterior half of the septum, and a limited portion of the left auriculo-ventricular tendinous ring posteriorly (*n*). In this layer, consequently, comparatively few of the fibres belonging to the left ventricle (Plate XIII. fig. 18, *f*) cross the posterior coronary groove (*j*) to become continuous with the fibres on the right (*f'*); and it is worthy of observation, that as the dissection advances the number of the so-called common fibres is augmented. This increase of the common fibres, which is gradual and follows a certain order, is referable to the source and direction of the fibres constituting the several layers. In the first layer, as has been explained, the common fibres proceed from a limited portion of the left auriculo-ventricular opening posteriorly; and as their direction is little removed from the vertical, few of them cross the posterior coronary groove to appear on the right. In the second layer, however, the common fibres proceed from the posterior and outer portion of the left auriculo-ventricular opening (Plate XIII. fig. 21, *f*), and, their direction being more oblique, a considerable proportion cross the posterior coronary groove (*j*). In the third layer (Plate XIII. fig. 24, *f d'*) the direction is still more oblique, and a greater number of the fibres consequently cross the groove referred to. In the fourth layer the direction of the fibres is horizontal (Plate XIII. fig. 27, *f d*), and the fibres almost all cross the groove in question. In the last-mentioned layer the fibres may be said to emanate from the left auriculo-ventricular opening all round. In speaking, therefore, of the fibres which are common to both ventricles posteriorly, it will facilitate the comprehension of their arrangement, to say that they radiate from different portions of the left auriculo-ventricular opening at different levels, these levels corresponding with the depth of the layer involved.

Peculiarities of the right ventricle of the mammal—fleshy pons—infundibulum—bone of the heart, &c. In the right ventricle, as in the left, the layers increase in thickness from without inwards; but there is this difference: the layers of the right ventricle are comparatively thinner than those of the left, owing to the fibres constituting them being more delicate. The greater delicacy of the fibres of the right ventricle may be explained either by an arrest of growth after birth, or to their becoming subsequently atrophied. The fibres of the right ventricle, as a rule, form only curves or segments of spirals (Plate XIV. figs. 36 & 37), a certain number of them anteriorly (especially those of the internal layers*) bending over and uniting with corresponding fibres from the right side of the septum to form a fibrous archway (Plate XIII. figs. 18, 21, 24, & 27, *m*), which

* The fibres of the external layers which enter into the formation of the fleshy pons, arise in many instances from the root of the pulmonary artery and aorta, and from the anterior portion of the right auriculo-ventricular opening.

separates the right auriculo-ventricular opening (*l*) from that of the pulmonary artery (*k*). This fibrous archway has been appropriately denominated the fleshy pons, and is more or less spindle-shaped, from the fact of its forming the boundary between the auriculo-ventricular and pulmonic orifices, the former of which is oval, the latter circular. It varies in size according to the dimensions of the heart. In the sheep, calf (Plate XIV. fig. 43, *m*), hog, leopard, deer, and seal it is usually about half an inch in breadth at its narrowest portion, and rather less than a quarter of an inch in thickness; while in the giraffe, camel, and horse it increases to twice these dimensions.

Another peculiarity in the right ventricle of the mammal, to which a passing allusion is due, appears in the form of a conical-shaped projection (Plate XIV. fig. 37, *w*), the so-called infundibulum (CRUVEILHIER), or conus arteriosus (WOLFF*), situated at the upper and anterior portion (*p*) of the ventricle. This projection, which communicates above or at its summit with the pulmonary artery (*k*), has the effect of lengthening the right ventricle towards the base to the extent of half an inch or so in moderate-sized hearts, and in this way makes up the deficiency of the right ventricle towards the apex.

The vertical measurement of the right and left ventricles is consequently nearly equal. The conus arteriosus is composed externally† of fibres which arise more immediately from the fibrous ring surrounding the orifice of the pulmonary artery (Plate XV. fig. 46, *k*)—these fibres having a plicated or tortuous arrangement (*c*), similar to that which occurs in the superficial layer of the ventricle of the fish and reptile. As, however, the fibres alluded to are separable into layers (Plate XIV. figs. 30 & 31, *k*), and are continuous with the fibres of the external layers of the right ventricle generally, with which they correspond in direction (*f d*), they are not entitled to a separate description. The more internal portions of the conus arteriosus are composed of the internal layers of the right ventricle. An additional peculiarity in the right ventricle of the mammal consists in the existence, in a large number of quadrupeds, of a curiously shaped bone (Plate XIV. figs. 30 & 31, *c*) which is imbedded in the right side (*a*) of the fibro-cartilaginous ring surrounding the aortic orifice. The bone in question, on account of its being more fully developed in some instances than in others‡, varies considerably as regards

* "This author drew a distinction between the conus arteriosus and the infundibulum, applying the former epithet to that portion of the ventricle from which the pulmonary artery springs, and which is prolonged upwards above the level of the rest of the ventricle. In the term infundibulum he included a larger portion of the ventricle, apparently that portion placed above a line drawn from the upper and right margin of the ventricle obliquely downwards to the anterior fissure. As the upper part of the right ventricle becomes gradually narrower, he supposed that it increases the velocity and impetus of the blood as it is drawn from the ventricle." (Acta Acad. Imper. Petropol. pro anno 1780, tom. v., vi. p. 209, 1784.)

† The arrangement of the fibres entering into the composition of the conus arteriosus interiorly is described at p. 479.

‡ BLUMENBACH (Comparative Anatomy, translated by Mr. LAWRENCE, p. 138) speaks of two bones as existing in the heart of the stag and the larger adult bisulca. According to Mr. W. S. SAVORY, two principal bones (a larger and a smaller), together with several irregular fragments, are found in the hearts of the larger ruminants. (Observations on the Structure and Connexions of the Valves of the Human Heart, 1851.) The author of the present paper has occasionally seen the fragments alluded to by Mr. SAVORY.

form. Usually it resembles the mould of a ploughshare; *i. e.* it is more or less triangular, and slightly bent or twisted upon itself to suit the curve of the aorta. That it performs no very important function, and is not necessary for the attachment of the fibres of the septum, is abundantly proved by its absence in a great number of instances. The *os cordis*, as it has been termed, is generally met with in the hearts of the horse, ox, sheep, and deer, and very rarely in man, the seal, pig, dog, hedgehog, hare, rabbit, and cat.

Lastly, the shape of the right ventricle is peculiar. Viewed vertically, it forms two irregular cones, a larger and inferior cone, and a smaller and superior one (the conus arteriosus). They spring from a common base and have widely separated apices. The bases of the cones correspond with a line drawn from the posterior portion of the right auriculo-ventricular opening (Plate XIV. fig. 31, *c*) to a point in the track for the anterior coronary artery, midway between the apex (*d*) of the right ventricle and the root of the pulmonary artery (*k*). The apex of the larger or inferior cone (Plate XIV. fig. 31) corresponds with the apex of the right ventricle (*d*), and the apex of the smaller or superior one with the root of the pulmonary artery (*k*). Viewed transversely or by means of transverse sections, the right ventricle is found to be concavo-convex (Plate XV. figs. 49, 50, & 51, *l*), its concavity being turned towards the convexity of the left (*b*); in other words, the right ventricle is as it were flattened out and applied to or round the left one. Viewed from before backwards, or in an antero-posterior direction, the right ventricle is found to be twisted upon itself (Plate XII. fig. 16, and Plate XIV. figs. 34, 35, 36, & 37), the two cones of which it is composed twisting in opposite directions—the larger or inferior cone (Plate XII. fig. 16, *l h m*, and Plate XIV. fig. 37, p' *q* q') in a direction from left to right downwards, the smaller or superior one (Plate XII. fig. 16, *h k*, and Plate XIV. fig. 37, *p w k*) in a direction from right to left upwards.

Second external layer of the right and left ventricles (*Mammal*). When the superficial or first external layer, which in the mammal is comparatively thin, is removed, the second layer (Plate XIII. fig. 21), composed of fibres similarly arranged to those taken away, is exposed. The fibres of the second layer posteriorly proceed in a spiral direction from left to right downwards, and are for the most part* common to both ventricles ($f f''$); *i. e.* the fibres found on the left ventricle (*f*) cross the posterior coronary track (*j*), and are found also on the right ventricle ($f' f''$); while the fibres on the anterior aspect, which also proceed in a spiral direction from left to right downwards, with the exception of a broad band at the base, dip in at the anterior coronary track to appear on the right third of the septum, where they are continuous with fibres having a corresponding direction (Plate XIII. fig. 22, *g*). The fibres of the second layer differ from those of the first in being slightly fascicular, and in issuing from the auriculo-ventricular openings (Plate XIII. fig. 21, *b l*) and entering the left apex and anterior coronary groove more obliquely. They further differ in having a more oblique direction. The fibres of the second layer are arranged in two sets, the one of which proceeds from rather

* A few of the fibres of the second layer proceed to the left apex only.

more than the anterior half of the septum and right auriculo-ventricular opening (l), and from the root of the pulmonary artery (k); the other from rather less than the posterior half of the septum and right auriculo-ventricular opening (l), and from the posterior and outer half of the left auriculo-ventricular opening (b). The number of fibres, consequently, which proceed from the left ventricle (f) to cross the track of the posterior coronary artery (j), to become continuous with fibres having a similar direction on the right ventricle ($f' f''$), is greater in the second layer than in the first.

Second layer of the septum—curious Y-shaped arrangement of the fibres—fibres of the right ventricle continuous anteriorly and posteriorly. The direction of the fibres of the second layer of the septum (Plate XIII. fig. 22, g) corresponds with the direction of the fibres of the second layer on the anterior and posterior aspects (ff', $d\,d'$) of the left ventricle, and with the direction of the fibres of the second layer of the right ventricle (Plate XIV. fig. 31, ff', $d\,d'$). In addition, the fibres of this and the succeeding layer diverge from each other at the upper third of the septum, and occasion an arrangement resembling the letter Y, the one portion bending over to assist in the formation of the fleshy pons anteriorly, the other, curving round to become continuous with the fibres of the right ventricle, having a like direction posteriorly (Plate XIV. fig. 31, $f\,d$). The fibres of the right ventricle (Plate XIV. fig. 35, $f\,d$), as was shown, *are continuous in the track for the anterior coronary artery* (o) with fibres having a similar direction on the septum ($g\,e'$). They are likewise in many instances *continuous with fibres from the septum, in the track for the posterior coronary artery* (Plate XIII. apply $g\,e$ to $f'\,d'$ of fig. 22), and form flattened rings. These points are best seen when the left ventricle is detached from the right, and the septum is dissected from the left side.

Third external layer of the right and left ventricles (Mammal). The fibres of the third layer (Plate XIII. fig. 24) resemble in their course and general configuration the fibres of the second layer, and proceed in a spiral direction from left to right downwards anteriorly, posteriorly (ff', $d'\,d''$), and septally (Plate XIII. fig. 25, $g\,e$). They differ, however, from those of the second in being slightly more fascicular, in forming a thicker layer, and in having a direction which is almost transverse. The number of common fibres posteriorly (Plate XIII. fig. 24, ff'', $d'\,d''$) is greater in this layer than in the second, partly on account of their very oblique direction, and partly from their proceeding from the left auriculo-ventricular opening nearly all round. Such of the fibres as cross the posterior coronary track to appear on the right ventricle* posteriorly ($f'\,d''$), curve round in an anterior direction until they reach the track for the anterior coronary artery. Arrived here, they dip in at the anterior coronary groove (throughout its entire extent) to assist in forming the third layer of the septum (Plate XIII. fig. 25, $g\,e$). They also contribute to the Y-shaped arrangement of the fibres alluded to in layer two, the one arm or process giving off fibres to assist in building up the fleshy pons, the other giving off fibres to become continuous posteriorly with such as belong to the right

* In this layer, as in the last, a certain number of the fibres do not cross the posterior coronary groove, but proceed at once to the left apex.

ventricle. The fibres of the third layer (Plate XIII. fig. 24) are continuous with corresponding internal fibres at the base, and proceed from two sources—the one set from the posterior third of the septum and the posterior half and anterior third of the right and left auriculo-ventricular openings (*b l*), the other from the remaining anterior portions of the auriculo-ventricular openings and the anterior two-thirds of the septum.

Fourth or central layer of the right and left ventricles (*Mammal*). The fibres of the fourth layer (Plate XIII. fig. 27, *f d*), unlike the fibres of the other layers, run athwart the ventricles, or at right angles to an imaginary line drawn from the base to the apex. Their direction, which from this circumstance is more or less circular, is accounted for by the external fibres, which run in a spiral direction from left to right downwards, turning abruptly upon themselves in this layer (Plate XII. compare *f g*, *d e*, with *k* of fig. 4) to reverse their course and proceed in an opposite direction, viz. from right to left upwards (Plate XIII. fig. 27, *p q*). The fourth layer consequently forms the boundary between the external and internal layers in both ventricles*; and when it is removed the order of arrangement is reversed: the fibres, instead of proceeding from left to right downwards, becoming more and more oblique, proceed from right to left upwards, gradually returning to an imaginary vertical in an inverse order. The fibres of the right ventricle, it may be observed, pass through the several changes in direction referred to, more rapidly than those of the left; in other words, the fibres of the right ventricle, when the dissection is conducted from without inwards, change from the nearly vertical to the horizontal, and from the horizontal back again to the nearly vertical at comparatively slight depths from the surface, an arrangement evidently occasioned by the greater tenuity of the right ventricular fibres. The difference in the depths at which the layers of the right and left ventricles are found, introduces important changes in the appearance presented by the ventricles at different stages of the dissection. Thus, when the left ventricular wall is half dissected through posteriorly (Plate XV. fig. 54), the right ventricular one is quite dissected away†. I say posteriorly, because, as was explained, the left ventricular wall anteriorly is but little affected, owing to the manner in which the fibres common to both ventricles radiate from the latter. The fibres of the fourth layer proceed in flattened fascicular bands from the auriculo-ventricular orifices all round (Plate XIII. fig. 27, *b l*), and illustrate very well the comparative depths at which the layers of the right and left ventricles are found. On transverse section the outer half of the central layer of the left ventricle posteriorly is ascertained to be on the same level with the internal layers of the right ventricle. Such of the fibres of the fourth layer as are common to both ventricles proceed from left to right, and, having crossed the posterior coronary groove, curve round on the right ventricle until they reach the groove for the anterior coronary artery (Plate XIII. fig. 23, *o o'*), where they dip in (*r*) to traverse the septum (Plate XIII. fig. 28, *g e*) in an antero-posterior direction, and so

* The fourth layer of the right ventricle is represented at Plate XIII. fig. 28, *p q*.

† The right ventricle is only half the thickness of the left.

return to the posterior wall, where many of them are continuous with the fibres of the fourth layer of the right ventricle. The fibres which are not common, and which belong more particularly to the left ventricle, dip in at the posterior coronary groove to traverse the septum (Plate XV. fig. 54, *g*) in an opposite direction, or from behind forwards, where they are continuous with the fibres of the left ventricular wall.

Internal layers of the right ventricle (Mammal).

When the fourth or central layer of the right ventricle (Plate XIII. fig. 23, *p q*), which is on the same level with the more superficial portions of the central layer of the left one (Plate XIII. fig. 27, *f d*), is removed, there is no longer any continuity between the fibres of the right and left ventricles posteriorly; in other words, the common fibres, or those which pass from the one ventricle to the other, are dissected away, and the layers beyond or to the inside of the layer in question belong exclusively to one or other of the ventricles. This arrangement is apparently occasioned by the fibres of the posterior border of the septal duplicature (Plate XVI. diag. 16, G) passing through and becoming blended with those of the posterior wall, only until the central layer in either ventricle is reached (Plate XVI. diag. 17, K). The internal layers of the right ventricle (Plate XIII. figs. 26 & 29, and Plate XIV. figs. 32, 33, 36, & 37), as has been partially explained, are, according to my belief, segmented portions of similar layers isolated from the left or typical ventricle by the primary notch or reduplication. This hypothesis is, I may observe, countenanced by their possessing the general characters of the internal layers of the left ventricle without being so complete. The fibres of the internal layers of the right ventricle proceed in a spiral direction from right to left upwards (Plate XIV. fig. 32, *p p'*, *q q'*), the fibres of the several layers, when the dissection is conducted from without inwards, becoming more and more vertical (Plate XIV. fig. 33, *p p'*, *q q'*) as the interior is reached. They therefore pass through all the changes in direction through which those of the left ventricle pass—the fibres of the seventh or last internal layer crossing the fibres of the superficial or first external layer at an acute angle, the fibres of the second and sixth layers at a slightly obtuse angle, and the fibres of the third (Plate XIV. fig. 31) and fifth (Plate XIV. fig. 32) layers at a very obtuse angle. When, however, the spirals formed by the fibres of the internal layers of the right ventricle (Plate XIV. figs. 36 & 37) are examined or compared with the spirals formed by the fibres of the internal layers of the left ventricle (Plate XII. figs. 6 & 7), the segmentary nature of the former is at once apparent, these in no instance forming complete double conical spirals similar to those found in the left ventricle, but only spiral fragments, or at most flattened rings, such as would be obtained by isolating or detaching a portion of a perfect cone composed of the double conical spirals described.

Fifth layer of the right ventricle (Mammal). The fifth layer of the right ventricle (Plate XIV. fig. 32), from the fact of its being immediately to the inner side of the fourth central or transverse layer (Plate XIII. figs. 23 & 28, *p q*), is the first of the internal ones (Plate XIV. fig. 32, *p p'*, *q q'*). The fibres composing it proceed in a very oblique spiral direction from behind forwards and from right to left upwards; and are aggregated into well-marked fascicular bundles which are continuous anteriorly (Plate XIV. fig. 36, *o*) and for the most part posteriorly with fibres having a like direction on the right third of the septum (*p′q′*). They are continuous also with the fibres of the third external layer at the base. As the common fibres do not extend to, or implicate the internal layers, the fibres of the right third of the septum readily become continuous with internal fibres on the posterior wall having a corresponding direction (Plate XIV. fig. 32, *p q*). The fibres of the fifth layer (Plate XIV. fig. 32) split up or bifurcate at a point corresponding with the fleshy pons, into the formation of which they enter, the one half bending over in a direction from without inwards (*m*) to become continuous with fibres from the septum having a similar direction—the other half curving round the infundibuliform portion of the right ventricle anteriorly (*p′*) to dip in at the track for the anterior coronary artery (Plate XIII. fig. 26, *o*), from which they emerge with the septal fibres referred to. The fibres of the fifth layer seldom make more than one turn of a spiral, many of them, from terminating at the root of the aorta and septum anteriorly, making less.

Sixth layer of right ventricle (*Mammal*). The fibres of the sixth layer of the right ventricle (Plate XIV. fig. 33) agree in their more important features with the fibres of the fifth layer; *i. e.* they proceed in a spiral direction from right to left, or from behind forwards and from below upwards (*p p′*, *q q′*), the fibres bifurcating (*m q′*) to assist in forming the fleshy pons (*m*) and the infundibulum (*q′*). The fibres of the sixth layer agree with those of the fifth in being continuous anteriorly (Plate XIV.* fig. 37, *w*) and posteriorly (Plate XIV. fig. 33, *p q*) with fibres having a similar direction on the septum (Plate XIV. fig. 37, *p′q′*), and with corresponding external fibres (the fibres of the second layer) at the base (Plate XIV. fig. 31, *ff′*, *d d′*). The fibres of the sixth layer differ from those of the fifth in pursuing a slightly more vertical direction, and in not being quite so fascicular. They form the homologues of the fibres of the second layer.

Seventh or last internal layer of right ventricle (*Mammal*). The fibres of the seventh or last internal layer of the right ventricle are those principally engaged in the formation of the carneæ columnæ and musculi papillares of the right ventricle, and have been already described.

The points established with reference to the right ventricle are these:—

1st. Many of the fibres entering into the formation of the right ventricular wall proceed from the left auriculo-ventricular opening, so that the right ventricle is to a certain extent dependent for its existence on the left.

2ndly. The external fibres of the right ventricle, with the exception of a broad band at the base, limited to the first two external layers, dip in at the track for the anterior coronary artery, to appear on the septum.

3rdly. Many of the fibres, especially of the deeper layers, are continuous anteriorly

* In Plate XIII. fig. 29, the fibres in question (*p q*) are seen dipping in at the anterior coronary track (*o o′*).

and posteriorly, and form flattened rings, which accommodate themselves to the shape of the ventricle.

The points in which the fibres of the right ventricle differ from those of the left are the following:—

1st. They are more delicate.

2ndly. They form segments of spirals and flattened rings, instead of double conical spirals.

3rdly. The external fibres enter the anterior coronary groove to become internal, not at one particular point, as in the apex of the left ventricle, but throughout its entire extent, the broad band at the base excepted.

4thly. The fibres of the right ventricle form a constriction anteriorly (the so-called fleshy pons). This constriction separates the pulmonary artery from the auriculo-ventricular opening, and does not exist in the left ventricle, unless the septal segment of the bicuspid valve is taken to represent it.

Vertical section of the right ventricle (Mammal).

When a vertical section of the right ventricle is made posteriorly (Plate XIV. figs. 43 & 44, *s*), it is found to taper in two directions, as in the left. It differs, however, from a similar section of the left ventricular wall in being comparatively much thicker towards the apex. This arises from the manner in which the right apex is formed, and is readily explained according to the segmentary process which is believed to separate the right apex from the left *in utero*. Into the extreme apex of the left or typical ventricle, as was shown, only one layer enters; whereas into successive portions of the left ventricular wall (at slight removes from the extreme apex) two, three, and four layers enter. But the right apex is known to be separated from the right side of the left apex at a part considerably above its extreme point, and where the left ventricular wall is somewhat thickened; so that probably two or even three layers enter into the construction of the right apex.

Transverse sections of the right and left ventricles (Mammal).

What has been said with reference to the difference in direction of the several external and internal layers of the right and left ventricles and septum, the common nature of the fibres posteriorly, and their independent nature anteriorly, the varying thickness of the right and left ventricular and septal walls, the conical shape of the right and left ventricular cavities, &c., is fully borne out by transverse sections. When a transverse section of the ventricles of the deer is made half an inch or so from the base (Plate XV. fig. 49), the following phenomena are observed:—

1st. The cut ends of the more vertical fibres exteriorly ($c\,c'c''$) and interiorly ($d\,d'd''$) are nearly equal in number, and are seen to the outside and inside of the deeper or more central fibres. The prevailing direction of the central fibres, on the septum (e') and left ventricular wall (e), is more or less circular, owing probably to many of the internal fibres changing their direction at this point to become external. On the right ventricular wall the fibres composing the more central layers are distinctly seen to cross each other (*f*).

2ndly. The fibres which are common to both ventricles posteriorly, can be traced passing from the left ventricle to the right (*g*).

3rdly. The large fascicular bundles of fibres which constitute the carneæ columnæ ($o\, o'\, o''$), and the free ends of the musculi papillares with their chordæ tendineæ attached (*x y*), may be recognized surrounding the ventricular cavities (*b l*).

4thly. The shape of the left ventricular cavity at this point is oval (*b*), and of the right cavity concavo-convex (*l*).

5thly. The thickness of the left ventricular wall (*c d*) and the septum ($c'd'$) is as nearly as possible equal, that of the right ventricular wall ($c''d''$) being only half the thickness of either of the former.

6thly. The thickness of the ventricular walls, as a whole, is not quite so great in this section as it is three-quarters of an inch nearer the apex (Plate XV. fig. 50).

In a transverse section rather less than an inch and a half from the base (Plate XV. fig. 50) the same phenomena are repeated, with the following slight differences:—

1st. The aggregate of the external fibres ($c\, c''$) is considerably less than the aggregate of the internal ones ($d\, d''$), out of which the carneæ columnæ (*o*) and musculi papillares (*x y*, $h\, h'$) spring—an arrangement necessitated by the external fibres requiring in this instance to crowd together, in order to accommodate themselves to the diminished calibre of the cone interiorly.

2ndly. The common fibres posteriorly (*g*) pass from the left to the right ventricle, and dip or bend in at the track for the anterior coronary artery, to become continuous with fibres having a similar direction on the septum (*m*).

3rdly. On account of the great preponderance of the internal fibres, and the projecting of the musculi papillares into the interior, the appearance of the ventricular cavities is considerably changed. Thus the left ventricular cavity (*b*) is triangular—the right ventricular one (*l*) being concavo-convex, and having two constrictions init caused by the anterior (h') and posterior (*h*) musculi papillares.

4thly. The thickness of the septum ($c'd'$) is nearly one-sixth greater than that of the left ventricular wall (*c d*), between the papillary muscles (*x y*), the thickness of the right ventricular wall ($c''d''$) being only half that of the latter.

5thly. The thickness of the ventricular walls is greater in this section than in any other.

When a transverse section is made about two inches and a quarter from the base (Plate XV. fig. 51), the thickness of the ventricular walls (*c d*, $c'd'$, $c''d''$) is found to have diminished slightly. The peculiarities of this section are these:—

1st. The preponderance of the internal ($d\, d''$) over the external ($c\, c''$) fibres, especially in the left ventricle, is more marked than in the two preceding sections.

2ndly. The circular nature of the more central fibres is also better defined ($e\, e'$), the fibres being observed to cross each other (*f*).

3rdly. The musculi papillares (*x y*) of the left ventricle (*b*) are very prominent, the left ventricular cavity (*b*) from this circumstance being more triangular in shape than in the second section (Plate XV. fig. 50).

4thly. The right ventricular cavity (*l*), from its proximity to the right apex, is moreover greatly reduced in size.

In a transverse section three and a half inches from the base, and fully half an inch from the left apex (Plate XV. fig. 52)—the right apex is now removed—the subjoined results are obtained:—

1st. The preponderance of the internal ($d\ d'$) over the external ($c\ c'$) fibres is still more marked, illustrating the necessity for the internal fibres overlapping and crowding on their appearance in the interior, more especially at the apex, where the cavity is greatly reduced.

2ndly. The circular nature of the more central fibres ($e\ e'$) is still better defined, many of the external fibres at this point reversing their direction to become internal.

3rdly. The musculi papillares are very prominent, the external fibres which have just entered the interior being seen to curve into them (*x y*).

4thly. The left ventricular cavity (*b*), from the comparatively large dimensions of the musculi papillares, is greatly diminished *; and the form of the left ventricular cavity is more or less bayonet-shaped.

In a transverse section a quarter of an inch from the extremity of the left apex (Plate XV. fig. 53), the peculiarities of the preceding section (fig. 52) are found exaggerated. Thus the quantity of the internal as compared with the external fibres is increased—the more central fibres ($e\ e'$), from the great number of external ones which at the apex change their direction to become internal, curving round in a regular whorl, many of them entering directly into the composition of the musculi papillares (*x y*); the left ventricular cavity is now all but closed.

Casts of the interior of the right and left ventricles (Mammal).

When casts of the interior of the ventricles are taken, the left ventricular cavity (Plate XII. fig. 17), as has been stated, yields a highly symmetrical conical screw whose spiral runs from left to right downwards, the right ventricular cavity (Plate XII. fig. 16) yielding a more unsymmetrical one—unsymmetrical in this sense, that it is flattened out and applied to or round the left. The amount of spiral made by the left ventricular cavity is rather over a turn and a half; that made by the right ventricular cavity rather under a turn.

* In this and the following section, the cavity of the left ventricle, towards the apex, would be at once obliterated by a slight approximation of the musculi papillares—this approximation of the papillary muscles being effected by the contraction of the spiral nearly circular fibres which constitute the apex. By this arrangement, the apex, which is the weak part of the ventricle, can be readily converted into a solid muscular wall capable of resisting any amount of pressure.

Shape of the right and left ventricular cavities, as shown by casts and transverse sections.

As it is difficult to obtain a correct idea of the shape of the ventricular cavities, a detailed description of them may prove not unacceptable. The left ventricular cavity in the fresh heart of the deer, at the extreme base (if the aortic opening is not included), is more or less circular in form (Plate XII. fig. 17, *b*). Half an inch or so from the base (Plate XV. fig. 49, *b*) it changes from the circular to the oval, and is slightly increased in size from the fact of the left ventricular cavity tapering from its middle third towards the base (Plate XII. fig. 17, *b*). In this portion of the left ventricular cavity (Plate XV. fig. 49), the chordæ tendineæ and the segments of the bicuspid valve hang loosely.

Receding from the base to the extent of fully an inch (Plate XV. fig. 50, *b*), the appearance of the left ventricular cavity again changes—the change in this instance being caused by the projection into it of the flattened oblique heads of the papillary muscles (*x*, *y*), which convert it from an oval shape into an irregularly triangular one (Plate XII. fig. 17, *w*).

Proceeding an inch or so nearer the apex, the left ventricular cavity (Plate XV. fig. 51, *b*) becomes smaller and more decidedly triangular, and is, from the prominence of the carneæ columnæ and musculi papillares (Plates XII. & XV. figs. 17 & 51, *x y*), somewhat bayonet-shaped. The bayonet-shaped appearance of the cavity becomes better defined as the extreme apex is reached (Plate XV. figs. 52 & 53, *b*), the cavity itself becoming smaller and smaller until it terminates in a point (Plate XII. fig. 17, *z*).

The right ventricular cavity (Plates XII. & XV. figs. 16 & 49, *l*), which is as it were applied to or round the left one (Plates XII. & XV. figs. 17 & 49), is also conical-shaped (Plate XII. fig. 16). It agrees with the left in having nearly the same vertical measurement, but differs from it in having a considerably greater antero-posterior measurement, and a decidedly less transverse one (Plate XV. compare *b* and *l* of fig. 49). Its shape at the extreme base, owing to the spindle-shaped constriction (fleshy pons) which separates it from the opening for the pulmonary artery, is oval * (Plate XV. fig. 46, *l*). Half an inch from the base it is concavo-convex (Plate XV. fig. 49, *l*), and, from the protruding of the carneæ columnæ and musculi papillares (*h*) at this point, more or less irregular. The chordæ tendineæ and the segments of the tricuspid valve hang loosely in this portion of the right ventricular cavity.

Receding from the base in the direction of the right apex an inch and a half or so (Plate XV. fig. 50), the shape of the right ventricular cavity (*l*) is still concavo-convex; it is moreover slightly diminished in its antero-posterior and transverse diameters, in conformity with its conical nature (Plate XII. fig. 16). Proceeding to within a quarter of an inch of the right apex, the right ventricular cavity (Plate XII. fig. 12, *m*, and Plate XV. fig. 51, *l*) is seen to maintain its concavo-convex shape, and to taper gradually until it terminates in a blunted extremity (Plate XII. fig. 16, *m*).

* In this description the infundibulum, or conus arteriosus, is regarded as projecting beyond what is commonly regarded as the base.

The comparative size of the right and left ventricular cavities has been the subject of considerable discussion, and is not likely soon to be set at rest, from the yielding nature of the ventricular parietes.

Inference deduced from a consideration of the Arrangement of the Fibres in the Ventricles of the Bird and Mammal.

Without presuming dogmatically to assert that the ultimate arrangement of the fibres of the ventricles of the bird and mammal is reducible to any known mathematical law, I cannot omit mentioning the fact that the arrangement in question can be so thoroughly imitated, even in its details, by certain mechanical contrivances about to be explained, that I would consider the present communication incomplete, were I not shortly to direct attention to them.

If a sheet of paper, parchment, or any flexible material * whose length is twice that of its breadth, be taken, and parallel lines drawn on either side of it in the direction of the length, to represent the course of the fibres (Plate XV. diag. 1), all that requires to be done, in order to convert it into a literal transcript of one-half of the left or typical ventricle, is to lay it out lengthwise across a table, and, catching it by the right-hand distant corner, to roll or turn in towards one's self a conical-shaped portion (C), and continue the rolling process in the direction of the opposite or oblique corner (U), until three and a half turns of the sheet have been made and a hollow cone produced, as shown at diagrams 4 & 5, Plate XVI. If the sheet be so manipulated, it will be found that every line in it is converted into a double conical spiral,—the one-half of the spiral being external to the other half, and running from base to apex and from left to right (Plate XVI. diag. 3, A B), precisely as in the left ventricle (Plate XII. compare with the direction of the fibres in figs. 1 & 9); the remaining half, which is internal, running from apex to base, and from right to left (Plate XVI. diag. 3, D E; Plate XII. compare with the direction of the fibres in figs. 7 & 8). Tracing the external spirals to the apex, they are seen to turn abruptly upon themselves at this point (Plate XVI. diagrams 3 & 4, C, diagrams 8 & 13, D; Plate XII. compare with apex of fig. 10), to reverse their direction and enter the interior, where they are continuous with the internal spirals (Plate XVI. diagrams 4 & 6, D E E′; Plate XII. compare with the fibres marked *k* of fig. 4); and if the corners of the sheet be folded out at the base, as has been done at Plate XVI. diagrams 3, 4, 5, & 6, and the internal spirals traced from the apex, or from below upwards (Plate XVI. diag. 3, H I J), they will be seen again to reverse their direction to become continuous with the external spirals (F G H),—an arrangement coinciding in

* Very beautiful transparent models of the left ventricle may be made, by employing sheets of net of a large pattern, with threads of wool drawn through the interstices at intervals of an inch or so. Sheets of this nature have been photographed to illustrate this part of the paper. Very convenient opaque models may be constructed by employing portions of newspapers, the reading of which represents the parallel lines. The author strongly recommends the use of these models, as a few minutes with such aids will throw more light on the course and direction of the fibres than hours of abstract reasoning without them.

the most perfect manner with the structure exhibited in the left ventricle (Plate XII. compare the fibres marked ff' of fig. 1 with those marked $o\,o'\,o''$ of fig. 8). Nor does the coincidence stop here. If the cone composed of the spiral lines constructed as above (Plate XVI. diagram 4) be examined in a direction from without inwards, it will be seen that its walls on the one aspect consist of four distinct layers—two external (A A′, B, compare with the direction of the fibres in Plate XII. figs. 1 & 3) and two internal (D, E E′, compare with the direction of the fibres in Plate XII. figs. 5 & 8); and on the other (Plate XVI. diagram 5) of three—one external (B B′, compare with the direction of the fibres in Plate XII. fig. 2), one internal (D D′, compare with the direction of the fibres in Plate XII. fig. 6), and one central (C C′ C″, compare with the direction of the fibres in Plate XII. fig. 4); and, what is remarkable, that the lines entering into the formation of the external layers run in different directions, and cross those forming the internal layers as in the ventricle itself (Plate XII., compare the direction of the external fibres in figs. 1, 2, & 3 with that of the internal fibres in figs. 5, 6, & 7). Another point of resemblance, deserving of particular attention, is the regional distribution of the layers themselves, that side of the cone which is composed of four layers (Plate XVI. diagram 4) showing how one layer enters into the formation of the extreme apex (C), two into the extreme base (A E′) and the portion of the ventricular wall immediately above the apex (B D), three into the portion of the wall immediately below the base, and four into the upper and more central portion (B′ D′),—the other or remaining side which is composed of three layers (Plate XVI. diagram 5), showing that one layer enters into the extreme apex (C), two into the extreme base (R), and three into the upper and central portion (C′ C″). This arrangement proves, curiously enough, that the model ventricular wall, like the true one, tapers in two directions, viz. towards the base (Plate XII. compare with *s* of figs. 13, 14, & 15) and towards the apex (Plate XII. compare with *s′* of figs. 13, 14, & 15). There are other points of resemblance. If the marginal line* (Plate XVI. diagram 3, A B C D E) of the sheet rolled up as described (and which may be taken to represent the first and seventh layers of the left ventricle) be traced, it will be found to proceed in a spiral nearly vertical direction, and to run from the extreme base (A) to the extreme apex (C), at which point it reverses its course and enters the interior, after which it returns to the extreme base, making one turn and a half of a spiral in either direction, as in Plate XII. figs. 1 & 8. It in this manner embraces in its convolutions all the other lines, the initial letters of which are H M R V, in the same way that the first layer and its internal continuation, the seventh layer, overlaps or embraces all the deeper layers (Plate XII. *vide* figs. 2, 3, 4, 5, and 6), all of which are included within and embraced by figs. 1 and 7). If, on the other hand, a second line a little removed from the marginal line (Plate XV. diagram 1, F G H I J),

* I have chosen to speak of individual lines, as admitting of more precise description; but it would be equally correct to speak of the lines confined to any particular portion of the sheet, for it is the aggregate of the lines in certain portions of it which constitutes the layers. Thus the lines composing one-third of the sheet go to form the first external layer and the last internal (Plate XVI. diagram 4, A A′ & E E′).

and which when the sheet is rolled up represents two deeper layers (Plate XVI. diagram 3, F G H I J), be taken, it will be found to pursue a similar though slightly more oblique course, and to extend from the extreme base (F) to a point somewhat short of the extreme apex (H), where it turns abruptly upon itself at a much wider part of the cone, to change its direction and enter the interior; after which, like the other, it gradually regains the base (J),—an arrangement which proves that the apex of the artifical cone or ventricle is opened into or enlarged by the removal of successive lines, precisely in the same way that the apex of the left ventricle is opened into, or enlarged, by the removal of successive layers (Plate XII. compare *f g*, *e d*, of fig. 9 with *k l* of fig. 11). It further shows that many of the lines, like the fibres themselves, return to points not wide of those from which they started. If another line, about the middle of the sheet (Plates XV. & XVI. diagrams 1 & 3, K L M N O), be taken, and traced in the same manner, it will be seen to proceed from the extreme base K (Plate XII. compare with fibres marked *f* in fig. 3), and to turn upon itself or reverse its direction and enter the interior at a still wider portion of the cone M (Plate XII. compare with fibres marked *k* in fig. 3)—*i. e.* at a point still further removed from the original apex (C)—and so on until the opposite marginal line (Plates XV. & XVI. diagrams 1 & 3, U V W) is reached, which confines itself entirely to the base, or upper portion of the cone (Plate XII. compare with fibres marked *f g*, *d' e*, fig. 4), and makes only one turn of a spiral. This disposition of the lines reveals what to me is a very interesting fact, viz. that certain lines, like certain layers, are confined to certain localities or regions. (The first layer of the left ventricle, as was pointed out, extends from the extreme base to the extreme apex (Plate XII. fig. 1), while the fourth layer does not quite extend to either (Plate XII. fig. 4). It further shows, what is scarcely less important, that, of the lines originally of the same length, some, from the fact of their winding very partially round the base or wider portion of the cone (Plate XVI. diagram 3, A) while they twist rapidly round the apex or narrow part (B C), make one turn and a half of a spiral, whereas others, which are confined to and wind round the base or wider portion of the cone, make only one turn of a spiral (Plate XVI. diagram 3, U V W)—an arrangement which, as I endeavoured to point out (see p. 456), prevails also in the left ventricle. When the interior of the cone, fashioned as recommended, is examined, the marginal lines are observed to twist out of the apex (Plate XVI. diagram 9, Y) and assume a more or less vertical direction (Plate XVI. diagram 6, E E', and diagram 8, Y), in a manner which wonderfully accords with the direction of the fibres composing one or other of the musculi papillares (Plate XVI. compare Y of diagram 9 with *y* of figs. 12 & 13, Plate XII.).

Having constructed one half of the typical ventricle, it is necessary, to complete the other, to lay a second sheet upon the original one, at a slight angle, as represented in diagram 2, Plate XV.*, after which the sheets are rolled up (the one within the

* In the diagram adverted to, it will be observed I have represented on the corners of the sheets two imaginary papillary muscles (X, Y), for the purpose of showing the positions they occupy in the interior of the cone when the sheets are rolled up.

other), as was recommended when manipulating the single sheet. The additional sheet, which is thus made to pass through the same changes as the first, in nowise complicates the arrangement, and has the effect of doubling the layers, while it does not increase the number of spiral turns made by the lines composing them *. The object of having two sheets set at an angle is to ensure that the lines will enter the apex, and issue from the base, in two places, so as to render the cone bilaterally symmetrical, as it exists in the undissected left ventricle; forit is found that, if only one sheet is employed, the apex of the cone, from its being composed of spiral lines, is lopsided, or like the barrel of a pen cut slantingly (Plate XVI. diagram 6, D). This difficulty is at once obviated by the employment of the second sheet; for the one sheet being made by the angle of difference to wind from behind forwards (Plate XVI. diagram 10, C D), and the lines to enter the apex anteriorly (E), while the other winds from before backwards (A B), the lines entering the apex posteriorly (F), the apex, as every other portion of the cone, is rendered bilaterally symmetrical (Plate XVI. compare *a b e* with *c d f* of fig. 55; Plate XII. compare also *f g* and *e d* of figs. 9, 10, and *x y* of figs. 12, 13, & 14). When sheets adjusted as represented in Plate XV. diagram 2 are rolled up into a cone, as may be closely and conveniently imitated by placing the cone marked 5, Plate XVI., inside of that marked 4 †, it will be found that a cone bilaterally symmetrical (Plate XVI. diagrams 7, 10, 11, 12 & 14), having a symmetrical apex (diagrams 7, 10, & 12, E F, diagram 11, X Y, and diagram 14, D K) with walls consisting of seven layers, each having a different direction (Plate XVI. diagram 4, A, B, D, E, and diagram 5, B C D), is at once produced. Of these layers three are external, three internal, and one central, precisely as in the left ventricle itself (Plate XII. compare with figs. from 1 to 8 inclusive).

If the foregoing arrangement were reduced to a principle and applied to the fibres of the left ventricle of the bird and mammal, it would be stated in something like the following terms.

By a simple process of *involution* and *evolution*, the external fibres become internal at the apex, and the internal ones external at the base; so that whether they be traced from without inwards, or from within outwards, they always return to points not wide of those from which they started. The fourfold set of fibres, viz. the two external sets and the two internal, being spirally arranged round a cone, and running in two diametrically opposite directions, it follows that, in order to involute and evolute, certain preliminary changes are necessary. Thus the two sets of external fibres, which wind from the base of the cone to the apex in a direction from left to right downwards, make

* Another effect produced by the two sheets being set at an angle and rolled within each other, which finds a counterpart in the ventricle itself, is the following. The lines composing the several anterior layers are relatively more vertical than those composing the posterior ones.

† Strictly speaking the sheet composing the one cone should be rolled within that composing the other, so that, when the unwinding of the cones takes place, alternate coils or layers from either cone are removed in constant succession.

smaller and smaller curves as they approach the apex, where they *involute or turn in*; whereas the two sets of internal ones, which wind from the apex of the cone to the base in a direction from right to left upwards, make larger and larger curves as they approach the base, where they *evolute or turn out*. The external and internal fibres have therefore different directions in different parts of their respective courses; and as the spirals formed by the external and internal sets cross and overlap at every half turn of their progress, we are in this way furnished not only with fibres having different degrees of obliquity, but also with different layers or strata of fibres.

Since the artificial ventricle, constructed as described, presents all the peculiarities of the typical or left ventricle, it is obvious that if, beginning a little above its apex, a portion of the anterior wall is pushed in (Plate XVI. diagram 15, A; Plate XV. compare with *m* of fig. 50, and with *o l*, *p n* of fig. 45) until it touches the posterior one (Plate XVI. diagram 15, B; Plate XV. compare with *g* of fig. 50), and allowance made for the passing through and blending of the lines posteriorly (Plate XVI. diagram 16, G) and septally (Plate XVI. diagrams 16, H K; also diagrams 17 & 18, H E), as recommended at page 464, and indicated by the division of the primary tube in the embryo, two ventricles (C & D) would be produced, resembling the true ventricles (compare with *b l* of figs. 49, 50, & 51, and *o p* of fig. 45, Plate XV. more particularly; also with *o* of fig. 23, Plate XIII.) as closely as the artificial single ventricle resembles the left or typical ventricle. This is so evident that further explanation is unnecessary.

With these remarks I finish the description of an avowedly difficult structure; and, in taking leave of the subject, I trust I may not be charged with forcing analogies and instituting resemblances where none exist. Having no theory to serve, my sole aim throughout the investigation has been the elucidation of truth; but where that is so cunningly, and, it may be added, so successfully concealed, it has often been exceedingly difficult to arrange the materials with which my numerous dissections supplied me, so as to preserve a sequence in the description while I at the same time contrasted the direction of the fibres composing the several layers with each other. The method employed in demonstrating the ventricles in the present instance, viz. by consecutive layers, while it is by far the most natural yet proposed, is, I believe, the best calculated to afford intelligible results; for as layers or strata of fibres unquestionably exist, and these intersect each other at various angles, and are found at different depths from the surface, it follows that all attempts to display in any individual heart, what can only be shown in a series of hearts, must prove abortive. The great advantage of conducting the dissection from without inwards by the removal of consecutive layers consists in its preserving the relation of the several layers to each other, and in showing how the fibres of each are continuous at the base and at the apex. This is well seen in the first seven figures of Plate XII., where the layers of the left ventricle are exposed posteriorly; for by placing fig. 7 within 6, figs. 7 & 6 within 5, and so on until all the figures are placed within fig. 1, not only are the relations of the several layers to each other maintained, but the ventricle is as it were rendered transparent, so that one may trace in imagination, or by the aid of diagrams 4 & 5, the fibres of figs. 8 & 7 crossing those of fig. 1, the fibres of fig. 6 crossing those of fig. 2, and those of fig. 5 crossing those of fig. 3. The minutely reticulated structure to which this disposition of the fibres gives rise, although very simple when the layers are regarded separately or apart from each other, becomes very perplexing when they are placed in apposition or as they occur in the undissected ventricle; and to the partial dissection of the layers perhaps more than to any other cause, is to be attributed that numerous class of complicated diagrams which represent the fibres of the ventricles as running in all directions without either law or order. In those diagrams that beautiful gradation in direction by which the fibres diverge from an imaginary vertical, and gradually return to it after having intersected each other in all directions, finds no place. In conclusion, the scheme of the course and direction of the fibres as summed up, while it greatly facilitates the comprehension of the general principle involved in the ultimate structure of the ventricles, harmonizes in the most perfect manner with all that is at present known of the heart's movements—those movements apparently so simple, and yet so difficult of analysis.

Explanation of the Plates.

In the engravings the same letters have been employed, as far as possible, to designate corresponding portions of the ventricles. The description of the figures in Plate XIII. from 22 to 29 inclusive does not follow in strictly numerical order. Thus the description of fig. 24 follows the description of fig. 22, and precedes that of figs. 25, 27, & 28; while the description of fig. 23 follows that of fig. 28, and precedes that of fig. 26. The object of this arrangement is to ensure that the description may be read as a connected narrative. In the figures of the right ventricle some of the layers have not been represented, from a desire to curtail the number of figures. This, however, can occasion no difficulty, as portions of the unrepresented layers may be seen in other figures. A portion of the second external layer of the right ventricle (one of the omitted layers) is seen at f' of fig. 22, while the greater portions of the two other unrepresented layers, viz. layers four and seven, are seen at Plate XIII. fig. 23, *p*, *q*, and Plate XIV. fig. 43, *o*, *h*.

PLATE XII.

Fig. 1. Left ventricle of the sheep's heart, seen posteriorly. Shows the superficial or first external layer. See pages 454, 455, & 456.

Fig. 2. Left ventricle of the sheep's heart, seen posteriorly. Shows the second layer. See pages 456 & 457.

Fig. 3. Left ventricle of the sheep's heart, seen posteriorly. Shows the third layer. See page 458.

Fig. 4. Left ventricle of the sheep's heart, seen posteriorly. Shows the fourth or transverse layer, which occupies a central position in the ventricular wall, and divides the external from the internal layers. The fibres of this layer are in the act of doubling or turning upon themselves. See pages 458 & 459.

Fig. 5. Left ventricle of the sheep's heart, seen posteriorly. Shows the fifth layer. See page 459.

Fig. 6. Left ventricle of the sheep's heart, seen posteriorly. Shows the sixth layer. See pages 459 & 460.

Figs. 7 & 8. Left ventricle of the sheep's heart, seen posteriorly. Show the seventh or last internal layer, the fibres composing which extend from the extreme base to the extreme apex. See pages 460, 461, & 462.

Fig. 9. Left ventricle of the sheep's heart, as seen posteriorly from above. Shows the course pursued by the two sets of fibres constituting the superficial or first external layer. See pages 454, 455, & 456.

f g. Posterior set of fibres of first layer, winding in a spiral direction from base to apex to enter the apex anteriorly.

e d. Anterior set of fibres of the first layer, winding in a spiral direction from base to apex to enter the apex posteriorly. As the convexity of the posterior set of fibres fits accurately into the concavity of the anterior set, they are linked or twisted into each other so as completely to close the apex and render it bilaterally symmetrical. The internal continuations of the major portions of the two sets of fibres forming the first layer are seen at *x* and *y* of figs. 12, 13, 14, & 15, where they appear as the anterior and posterior musculi papillares.

Fig. 10. Bird's-eye view of the apex of the left ventricle of the sheep's heart. Shows the two sets of fibres constituting the superficial or first external layer, separated from each other, and entering the left apex to become internal without breach of continuity. See pages 454, 455, & 456.

e d. The anterior set of fibres, curving or twisting into or round the posterior set.

f g. The posterior set of fibres, curving or twisting into or round the anterior set.

Fig. 11. Bird's-eye view of the apex of the left ventricle of the sheep's heart. Shows the appearance presented by the left apex when the two sets of fibres composing the first layer have been removed. See pages 456 & 457.

f g. Undissected portion of the anterior set of fibres of the first layer.

l. Anterior set of fibres of the second layer, preparing to enter the left apex posteriorly.

k. Posterior set of fibres of the second layer, preparing to enter the apex anteriorly.

Fig. 12. Transverse section of the left ventricle of the sheep's heart, half an inch above

the apex. Shows the anterior and posterior sets of fibres forming the seventh or last internal layer, twisting out of the interior of the left apex, in an opposite direction to that by which the anterior and posterior sets of fibres forming the first layer (with which they are continuous) entered. See pages 460, 461, & 462.

y. Anterior musculus papillaris, cut across.

x. Posterior musculus papillaris, cut across.

m. Right apex. Shows comparative absence of spiral twist in the fibres composing it.

Fig. 13. Left ventricle of the heart of a deer, opened anteriorly. Shows the anterior and posterior musculi papillares *in situ*. See pages 460, 461, & 462.

y. The anterior musculus papillaris, winding in a spiral nearly vertical direction from the apex to within a short distance of the base, where it terminates in a more or less flattened uneven head, the irregular surface being occasioned by muscular prominences which give off chordæ tendineæ to be inserted into the segments of the bicuspid valve.

x. The posterior musculus papillaris, twisting from behind the anterior one, and winding in a spiral nearly vertical direction from the apex to within a short distance of the base, where it terminates like the anterior, in a flattened uneven head.

s. Vertical section of the left ventricle, showing how the ventricular wall tapers towards the apex and the base.

r. Fibrous stay connecting the posterior musculus papillaris with the septal side of the left ventricular cavity.

Fig. 14. Left ventricle of the heifer's heart, opened laterally. Shows the musculi papillares and the bicuspid valve as usually displayed, the spiral twist peculiar to the musculi papillares being inadvertently destroyed. See pages 460 & 461.

v. Anterior or outer segment of the bicuspid valve, with the chordæ tendineæ (*t*) which proceed from each musculus papillaris terminating in it.

s s'. Vertical section of ventricular wall, tapering towards the apex and the base.

w. Termination of the spiral groove which forms one of the two hollows found between the spiral musculi papillares. This groove, or rather the cast taken from it, is seen throughout its entire extent at *z w b* of fig. 17.

r. Fibrous stays connecting the anterior and posterior musculi papillares with the septal side of the ventricular cavity.

z. Reticulated arrangement of the fibres lining the interior of the ventricle and forming the carneæ columnæ.

Fig. 15. Left ventricle of a human heart, opened laterally. Shows a tendency on the part of the fascicular bundles forming the musculi papillares to remain separate, also the highly developed nature of the carneæ columnæ. See page 461.

a. Aorta.

v. Posterior and inner segment of the bicuspid valve, attached by its chordæ tendineæ to the musculi papillares.

y y'. The anterior musculus papillaris, consisting in this instance of two portions, from the fibres composing it never having fully united.

x. Posterior musculus papillaris, likewise terminating in muscular processes.

z. Carneæ columnæ, forming a rich network which lines the interior of the ventricle.

s s'. Vertical section of the ventricular wall, showing how it tapers towards the base and the apex.

Fig. 16. Wax cast of the interior of the right ventricle of a deer's heart, seen anteriorly. Shows the spiral nature of the cavity. See page 482.

l. Right auriculo-ventricular opening.

k. Conical-shaped spiral infundibulum or conus arteriosus, with the spiral grooves occasioned by the projection of the carneæ columnæ into it. These grooves facilitate the passage of the blood towards the pulmonary artery during the systole.

h. Depression caused by the head of the right anterior musculus papillaris.

m. Right apex, the peculiarity of which consists in its being more blunted, and less distinctly spiral, than that of the left apex.

Fig. 17. Wax cast of the interior of the left ventricle of a deer's heart. Shows the peculiar spiral twist of the left ventricular cavity, and how, like the wall, it tapers towards the base and the apex. See pages 462 & 482.

b. Left auriculo-ventricular opening.

x. Spiral track of the posterior musculus papillaris.

y. Spiral track of the anterior musculus papillaris.

z w b. Projecting spiral ridge, corresponding to one of the spiral grooves or hollows found between the spiral musculi papillares.

z. Left apex, twisting rapidly upon itself and terminating in a point. The left ventricular cavity is widest at the upper part of its middle third (*w*), and the amount of spiral made by it rather exceeds a turn and a half.

Note.—Figs. 16 & 17 give the exact shape of the ventricular cavities, and consequently the precise form assumed by the blood, prior to the systole.

PLATE XIII.

Fig. 18. Right and left ventricles of the sheep's heart, seen posteriorly. Shows the superficial or first external layer of both ventricles. See pages 467 & 468.

Fig. 19. Right and left ventricles of the sheep's heart, seen posteriorly, the right ventricular wall being divided and separated to expose the septum. Shows how the direction of the fibres of the first layer of the septum corresponds with the direction of the fibres of the first layer of the right and left ventricles. See pages 468 & 469.

Fig. 20. Right and left ventricles of the sheep's heart, seen anteriorly. Shows the direction of the fibres of the superficial or first external layer of both ventricles, the track for the anterior coronary artery, &c. See page 468.

Fig. 21. Right and left ventricles of the sheep's heart, seen posteriorly. Shows the direction of the fibres of the second layer of the right and left ventricles. See pages 475 & 476.

Fig. 22. Right and left ventricles of the sheep's heart with the septum exposed, seen posteriorly. Shows how the fibres of the second layer of the septum correspond in direction with those of the second layer of the right and left ventricles generally. See page 476.

Fig. 24. Right and left ventricles of the sheep's heart, seen posteriorly. Shows the direction of the fibres of the third layer of the right and left ventricles. See pages 476 & 477.

Fig. 25. Right and left ventricles of the sheep's heart with the septum exposed, seen posteriorly. Shows how the direction of the fibres of the third layer of the septum corresponds with the direction of the fibres of the third layer of the right and left ventricles generally. See pages 476 & 477.

Fig. 27. Right and left ventricles of the sheep's heart, seen posteriorly. Shows the fourth or central layer of the left ventricle, and the fifth layer of the right one. The fourth layer of the right ventricle is seen at $p\,q$ of fig. 23. See pages 477, 478, & 479.

Fig. 28. Right and left ventricles of the sheep's heart with the septum exposed, seen posteriorly. Shows that the direction of the fibres on the septum corresponds with that of the deeper fibres of the fourth or central layer of the left ventricle. See pages 477 & 478.

Fig. 23. Right and left ventricles of the sheep's heart, seen anteriorly. Shows the direction of the fibres of the fourth or central layer of the right ventricle ($p\,q$), as compared with the direction of the fibres of the undissected left ventricle ($d\,d''$). They run at nearly right angles. See pages 477 & 478.

Fig. 26. Right and left ventricles of the sheep's heart, seen anteriorly. Shows the direction of the fibres of the fifth layer of the right ventricle ($p\,q$) as compared with the direction of the fibres of the third layer of the left one ($d\,d'$). See pages 478 & 479.

Fig. 29. Right and left ventricles of the sheep's heart, seen anteriorly. Shows the direction of the fibres of the sixth layer of the right ventricle ($p\,q$) as compared with the direction of the fibres of the fourth layer of the left one ($d\,d'$). See page 479.

PLATE XIV.

Fig. 30. Right ventricle of the sheep's heart. Shows the bone of the heart (c) *in situ*, direction of the fibres of the first layer, &c. See pages 467, 468, 474, & 475.

Fig. 31. Right ventricle of the sheep's heart. Shows the bone of the heart *in situ*, the direction of the fibres of the third external layer, &c. See page 476.

Note.—The fourth or central layer of the right ventricle is seen at *p q* of fig. 23, Plate XIII.

Fig. 32. Right ventricle of the sheep's heart. Shows the direction of the fibres of the fifth layer of the right ventricle, fleshy pons, &c. See pages 478 & 479.

Fig. 33. Right ventricle of the sheep's heart. Shows the direction of the fibres of the sixth layer of the right ventricle. See page 479.

Fig. 34. Right ventricle of the sheep's heart, seen anteriorly and from the left side. Shows the first layer of the septum dissected from within, or from the left side, and how the fibres of the first external layer of the right ventricle bend or double upon themselves to become continuous with fibres having a similar direction on the septum. See page 468.

Note.—The second layer of the right ventricle is omitted. (See $f' d'$ of fig. 22, Plate XIII.)

Fig. 35. Right ventricle of the sheep's heart, seen anteriorly and from the left side. Shows the fibres of the third layer of the septum dissected from within or from the left side, and how the fibres of the third layer of the right ventricle bend or double upon themselves, anteriorly and posteriorly, to become continuous with those on the septum having a similar direction. See page 476.

Note.—The fourth or central layer of the right ventricle is omitted. (See *p q* of fig. 23, Plate XIII.)

Fig. 36. Right ventricle of the sheep's heart, seen anteriorly and from the left side. Shows the fibres of the septum dissected from within or from the left side, as in the two preceding figures, also how the fibres of the fifth layer of the right ventricle are continuous on the septum, anteriorly and posteriorly. See pages 478 & 479.

Fig. 37. Right ventricle of the sheep's heart, seen anteriorly and from the left side. Shows the fibres of the septum dissected from within or from the left side, as in the three preceding figures, also how the fibres of the sixth layer are continuous on the septum, anteriorly and posteriorly. See page 479.

Note.—The seventh or last internal layer is omitted.

Fig. 38. Bird's-eye view of the base of the ventricles of the swan's heart. Shows the right and left auriculo-ventricular openings, with the muscular and bicuspid valves *in situ*. See pages 470, 471, & 472.

Fig. 39. The ventricles of the heart of the swan, seen from the right side. Shows the right side of the septum and the posterior portion of the muscular valve in position (*g*), also how the fibres from the upper third of the septum and left ventricle posteriorly enter into the formation of the inner half of the muscular fold. See pages 470, 471, & 472.

Fig. 40. Right and left ventricles of the turkey's heart, opened anteriorly. Shows the somewhat triangular shape of the muscular valve (*i*) of the right ventricle of the bird, with its spindle-shaped muscular band (*h*), as contrasted with the anterior and inner segment of the bicuspid valve (*v*) of the left ventricle, with its chordæ tendineæ and musculus papillaris (*y*). The spindle-shaped muscular band is to the muscular valve of the right ventricle of the bird what the anterior musculus papillaris and its chordæ tendineæ are to the anterior segment of the bicuspid valve of the left ventricle. See pages 470, 471, & 472.

Fig. 41. Transverse section of the ventricles of the heart of the emu, half an inch from the base, seen from below. Shows the shape of the right and left ventricular cavities, and the appearance presented by the muscular valve (*g i*) when viewed from beneath. See pages 470, 471, & 472.

Fig. 42. The heart of the dugong, seen anteriorly. Shows the peculiar plaited arrangement of the fibres of the ventricles, and the bifid or double apex. See page 448.

a. Aorta.

k. Pulmonary artery opened into, so as to expose the sigmoid or semilunar valves.

c. Left auricle opened into.

d d'. Plicated arrangement of the external fibres.

z. Plicated arrangement of the internal fibres.

i. Segment of the tricuspid valve.

p. Anterior musculus papillaris of the right ventricle.

y. Portion of the left ventricular wall and posterior musculus papillaris with chordæ tendineæ.

m. Right apex.

n. Left apex.

Fig. 43. Right and left ventricles of the heifer's heart, seen posteriorly, the right ventricle being opened into, to show the arrangement of the carneæ columnæ, musculi papillares, &c. See pages 469 & 470.

Fig. 44. Right and left ventricles of the human heart, seen posteriorly, the right ventricular wall being opened into, to show the distribution of the carneæ columnæ and musculi papillares. Shows the comparatively reticulated structure of the carneæ columnæ and the bifid nature of the musculi papillares, &c. See page 470.

PLATE XV.

Fig. 45. Right and left ventricles of the sheep's heart split up or separated from each other anteriorly. Shows how the fibres of the right and left ventricles are continuous with fibres having a similar direction on the septum. See page 466.

k. External fibres of the right ventricle becoming continuous, in the track for the anterior coronary artery (*o o*), with fibres having a similar direction on the septum (*l*) by simply bending upon themselves.

n. Fibres of the septum passing from above downwards to become continuous in the track for the anterior coronary artery (*p p*) with the external fibres of the left ventricle (*m*), these fibres winding in a spiral direction from above downwards to enter the left apex, not by simply bending upon themselves, but by twisting rapidly round in a whorl.

Fig. 46. Base of the ventricles of the heifer's heart, as seen from above, posteriorly. Shows the relative position and shape of the auriculo-ventricular openings and the orifices of the large blood-vessels. It also shows how the external fibres curve out of the former all round. See pages 454, 470, 472, 473, & 483.

Fig. 47. Right and left ventricles of the heifer's heart laid open, seen posteriorly. Shows the position and shape of the musculi papillares and carneæ columnæ. See pages 460, 461, 469, & 470.

Fig. 48. Left ventricle of the heart of the American elk, inverted. Shows the complete absence of carneæ columnæ, and the undeveloped condition of the musculi papillares. See page 461.

Fig. 49. Transverse section of the right and left ventricles of the deer's heart, half an inch from the base. Shows the shape of portions of the right and left ventricular cavities, and how the right ventricular cavity curves round, or is applied to the left. See pages 480 & 481.

Fig. 50. Transverse section of the right and left ventricles of the deer's heart, rather less than an inch and a half from the base. Shows the same as last section, and in addition how the fibres of the right ventricle dip in at the anterior coronary groove (*m*) to become continuous with fibres having a similar direction on the septum (*e*′). See page 481.

Fig. 51. Transverse sections of the right and left ventricles of the deer's heart, two and a half inches from the base. Shows the same as the two preceding sections. See pages 481 & 482.

Fig. 52. Transverse section of the left ventricle of the deer's heart, three and a half inches from the base, and fully half an inch from the apex. See page 482.

Fig. 53. Transverse section of the left ventricle of the deer's heart, a quarter of an inch from the apex. See page 482.

Fig. 54. Left ventricle of the sheep's heart, seen posteriorly. Shows how the fibres composing the inner half of the central layer of the left ventricle (*f*) pass through the septum (*g*). See page 478.

Diagram 1, Plate XV. Sheet of net with threads of wool drawn through it at intervals to represent the fibres, laid out lengthwise or across the body. Shows how by folding in a portion of the sheet (B C) and rolling it obliquely upon itself in the direction of the arrow marked E, until three and a half turns have been made, a cone is produced whose anterior wall consists of four layers (the posterior wall consists of three), the lines composing these layers having different directions, as represented at Plate XVI. diagrams 4 & 5, and at Plate XII. figures from 1 to 8 inclusive. See pages 484, 485, & 486.

Diagram 2, Plate XV. Double sheet of net, the one sheet (F G Y) being laid upon the other (A B X) at a slight angle. Shows how when the two sheets thus arranged are rolled up together the cone produced is bilaterally symmetrical, as might be imitated (Plate XVI.) by placing the cone marked diagram 5 within that marked diagram 4. It also shows how the lines composing the sheets enter the apex in a whorl in two distinct sets (Plate XVI. diagrams 7, 10, & 12, E F), after which they wind from the apex towards the base, likewise in two sets (Plate XVI. diagram 11, X Y). See pages 486 & 487.

G. Point which when the sheets are rolled into a cone corresponds to its apex, that portion of the uppermost sheet marked X assuming the position of the anterior musculus papillaris (Plate XVI. diagrams 8, 9, & 11, Y), that portion of the lower or undermost sheet marked X taking the place of the posterior musculus papillaris (Plate XVI. diagram 11, X).

PLATE XVI.

Diagram 3. Sheet of net with threads of wool drawn through it at wide intervals, rolled up in a cone as explained, the cone being placed upon its apex. Shows how lines originally of the same length make fewer turns of a spiral from winding round wider portions of the cone. It also shows how the apex of the cone may be enlarged by removing in succession the lines which make the greatest number of spiral turns, and which, curiously enough, overlap the lines which make the fewest number of turns. See pages 484, 485, & 486.

Note.—The lines in this diagram correspond with the lines in diagram 1, Plate XV., bearing similar letters.

Diagrams 4 & 5. Anterior and posterior views of a cone produced by rolling a sheet of net upon itself, similar to that figured in Plate XV. diagram 1. In the cone marked 5, that portion of the sheet which forms the base (R R) has been folded upon itself in an outward direction, to cause the internal lines to reverse their direction and become parallel with the external ones, with which they unite.

Note.—These diagrams show how by one portion of the sheet overlapping another several layers are produced, the lines composing these layers having different directions. They also show how the layers or overlappings are confined to different regions or localities, just as in the left ventricle, and satisfactorily account for the ventricular wall tapering towards the base and the apex respectively. See pages 484, 485, & 486.

A A′, diagram 4. Lines winding in a spiral nearly vertical direction from above downwards, and forming the first layer (Plate XII. fig. 1, compare with the fibres marked *f f′* and *d d′*). These lines are continuous at the base and the apex with the lines forming the seventh or corresponding internal layer E E′ (Plate XII. fig. 8, compare with the fibres marked *o* and *n*).

B B′, diagram 5. Lines winding in a spiral oblique direction from above downwards, and forming the second layer (Plate XII. fig. 2, compare with the fibres marked *f d′*). These lines are continuous at the apex and the base with the lines forming the sixth or corresponding internal layer D D′ (Plate XII. fig. 6, compare with the fibres marked *o n*).

B B′, diagram 4. Lines winding in a spiral very oblique direction from above downwards, and forming the third layer (Plate XII. fig. 3, compare with the fibres marked *f d′*). These lines are continuous at the apex and the base with the lines forming the fifth or corresponding internal layer D D′ (Plate XII. fig. 5, compare with the fibres marked *o n*).

C C′ C″, diagram 5. Lines winding in a circular or transverse direction and forming the fourth or central layer, which divides the three external from the three internal layers (Plate XII. fig. 4, compare with the fibres marked *f d′*). It is in this layer that the three external layers terminate, and the three internal ones (diagram 6, D E E′) begin.

Diagram 6. A cone similar to that figured at diagram 4, with the external layers uncoiled. Shows the fourth, central or transverse layer, and the three internal layers. See pages 484, 485, & 486.

Diagram 7. Symmetrical cone produced by the rolling of portions of two sheets within each other. Shows the double entrance of the lines at the apex, and how closely the position and shape of the musculi papillares may be imitated. The interior of this cone is seen at diagram 11, and should be compared (Plate XII.) with the interior of fig. 13. See pages 486 & 487.

A B. Portion of posterior sheet, the lines composing which enter the apex anteriorly at E, to represent the posterior musculus papillaris X (Plate XII. fig. 14, compare with *y*). See pages 486 & 487.

C D. Portion of anterior sheet, the lines composing which enter the apex posteriorly at F, to represent the anterior musculus papillaris Y (Plate XII. fig. 14, compare with *x*). See pages 486 & 487.

Diagram 8. Symmetrical cone produced by the rolling of two sheets of net within each other, similar to those figured at Plate XV. diagram 2. Shows the position and track of the anterior papillary muscle (Y). See pages 486 & 487.

Diagram 9. Interior of a single sheet of net rolled up as explained. Shows how the spiral almost vertical direction pursued by the anterior musculus papillaris (Y) may be imitated (Plate XII. fig. 13, compare with *y*). See page 484.

Diagram 10. Symmetrical cone produced by rolling two sheets of net within each other. Shows how the symmetry of the cone is maintained by the sheets winding from opposite points, the one, the anterior (A B), winding from before backwards, or from right to left, to enter the apex posteriorly (F), the other, the posterior (C D), winding from behind forwards, or from left to right, to enter the apex anteriorly (E) (Plate XVI. fig. 55, compare with *e f*; Plate XII. fig. 11, compare with *k l*). See pages 486 & 487.

Diagram 11. Interior of symmetrical cone, as seen at diagram 7, formed by the rolling of two sheets of net within each other. Shows how the position and shape of the spiral nearly vertical anterior (Y) and posterior (X) musculi papillares may be imitated (Plate XII. figs. 12 & 13, compare with *y x*). See pages 486 & 487.

Diagram 12. Two sheets of paper with parallel lines drawn upon them, rolled within each other, and then permitted to spring open (seen from above). Imitates the double entrance of the fibres at the left apex. Compare the direction of the lines on the sheet A B E with the direction (Plate XVI. fig. 55) of the fibres *a b e*, and also the direction of the lines in the sheet C D F with the direction of the fibres *c d f* of the same figure.

Diagram 13 represents the course pursued by a single fibre, how it winds from the base to the apex in one direction, and from the apex to the base in another, so as to return to the point from which it set out. It also shows how the fibre is continuous towards the apex and the base. See page 485.

A B C. External portion of the fibre winding from above downward, or from the base to the apex.

D. Point at which the fibre enters the apex and alters its direction.

E F. Internal portion of the fibre winding from below upward, or from the apex to the base, to return to the point A.

Diagram 14 represents the course pursued by two fibres, each of which is similar to that figured at diagram 13. In this diagram the external portion of one of the fibres (A B C) winds from behind forwards and enters the apex anteriorly (D), the external portion of the other fibre (G H I J) winding from before backwards and entering the apex posteriorly (K). The external portions of the fibres are therefore symmetrically disposed with reference to each other. Similar remarks apply to the internal continuations of these fibres (E G H, L A M), which are only partially seen. The external and internal portions of the fibres are continuous, and when seen from above appear to form complete circles. See pages 486 & 487.

Fig. 55. Sheep's heart separated into its bilateral elements. See pages 457, 486, & 487.

a b. Anterior fibres entering the left apex posteriorly (*e*).

c d. Posterior fibres entering the left apex anteriorly (*f*).

Diagram 15 shows how by pushing in the anterior wall (A) of the typical or left ventricle, in imitation of the constructive process in the embryo, a double septum unattached posteriorly (B) is produced, this septum dividing the ventricle into two, a right or rudimentary ventricle (D), and a left or more complete one (C). It also shows how the fibres may be continuous or common to both ventricles posteriorly (B), while anteriorly (A) they dip in at the track for the anterior coronary artery and are to a certain extent independent of each other (Plate XV. fig. 50, compare with *g* and *m*). See pages 464, 465, 466, 467, & 488.

Diagram 16 shows how the posterior fold (G) of the septal duplicature, by passing through the posterior wall (B) until the central layer in either is reached, completely isolates the right ventricle (D) from the left (C), and how, by the atrophy of the right ventricular wall (F) and its share of the septum (K), after birth, to half their original dimensions, the right ventricle (F) is reduced to half the thickness of the left (I); while the septum (H K) is three times as thick as the right, and a third thicker than the left. See pages 465, 466, 467, & 488.

Diagram 17 shows how, by the partial absorption of the posterior fold of the septal duplicature (K), and the passing through and blending of the right half of the reduplication (E) with the left (H), the ventricles are more intimately united, and the septum reduced until it is only a sixth greater than the left ventricle,—an arrangement which very nearly corresponds to the measurement of the actual septum between the musculi papillares at the thickest part (Plate XV. fig. 50, compare $c' d'$ with $c d$). It also shows how the septum is composed of two elements, and how one portion of it (E E) belongs exclusively to the right ventricle, a second portion (H) to the left; while a third portion (J J) belongs partly to the one ventricle, and partly to the other. See pages 465, 466, & 467.

Diagram 18 shows how the right portion of the septum, as seen at E E of diagram 17, may become absorbed, so as to reduce the septum (H) to the thickness of the left ventricular wall (I) and half the thickness of the right (F) (Plate XV. figs. 49 & 51, compare $c d$ with $c' d'$, and $c d$, $c' d'$, with $c'' d''$).

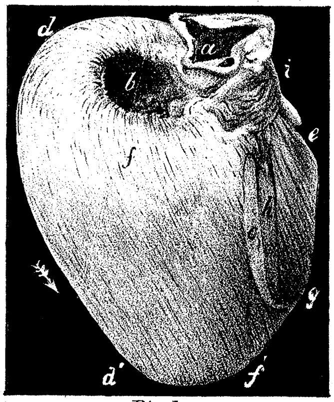


Fig. 1.

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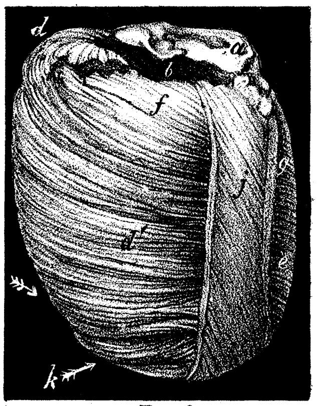
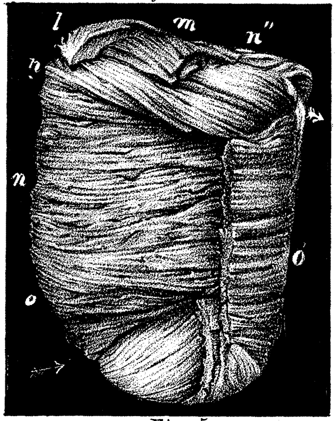


Fig. 3.

Fig. 4.



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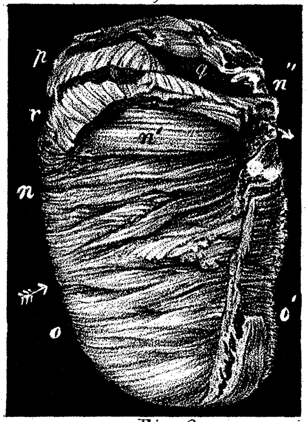
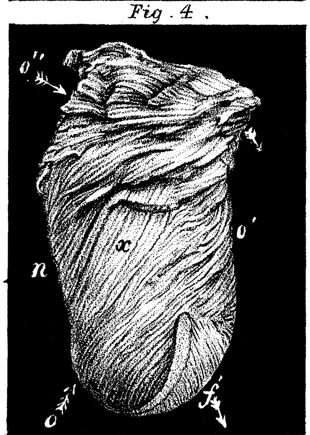


Fig. 6.

Fig. 7.



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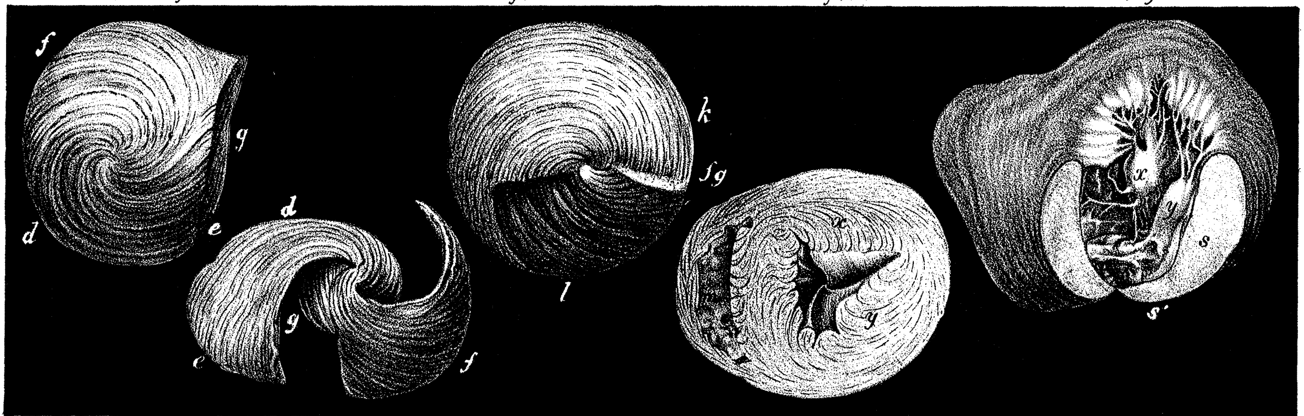
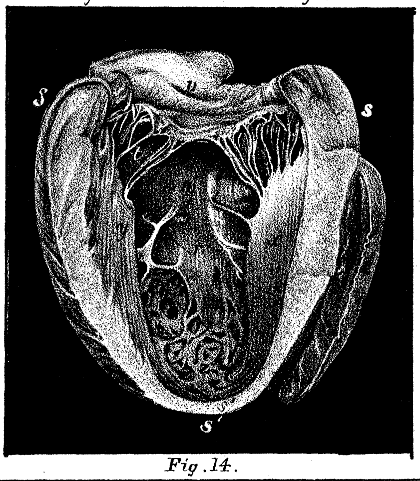


Fig. 9. Fig. 10. Fig. 11. Fig. 12. Fig. 13.



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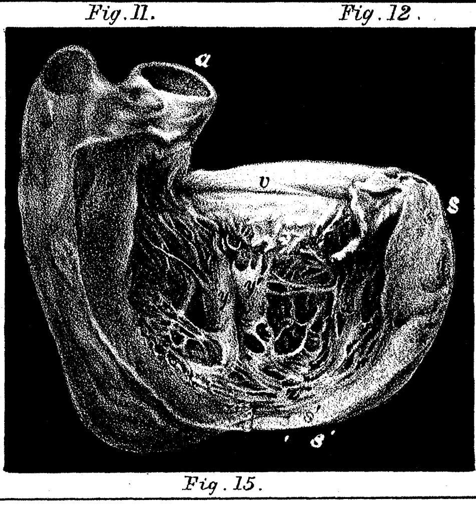

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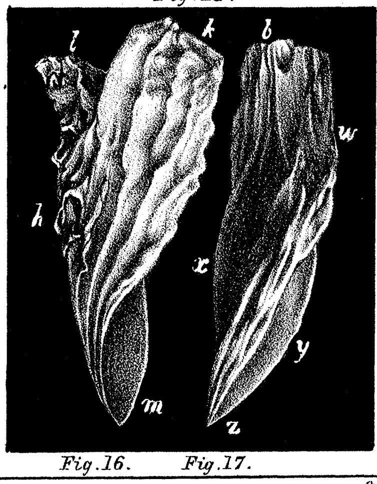

Fig. 16. Fig. 17.

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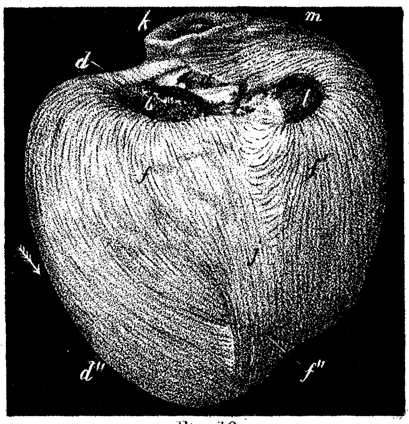
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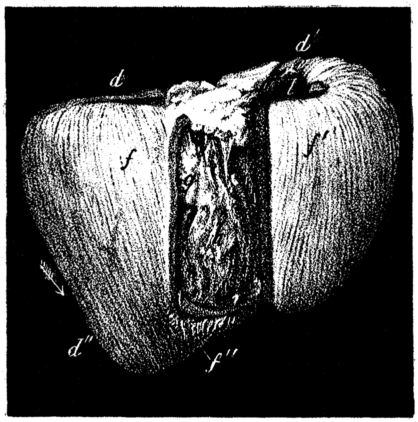
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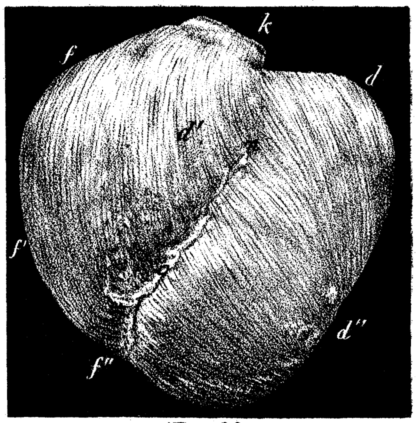
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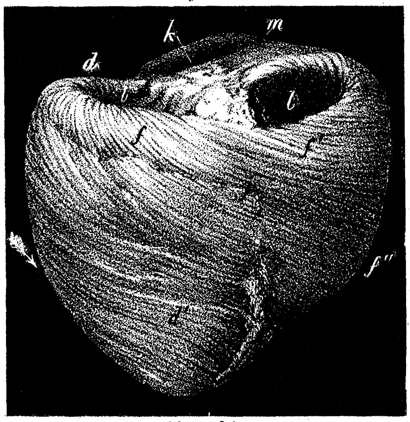
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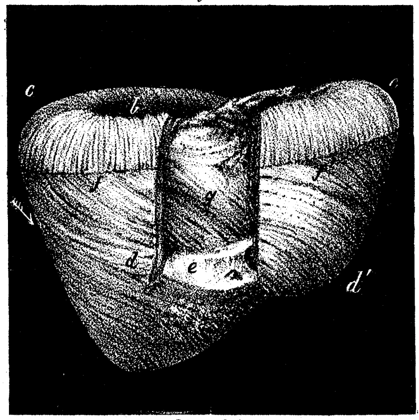
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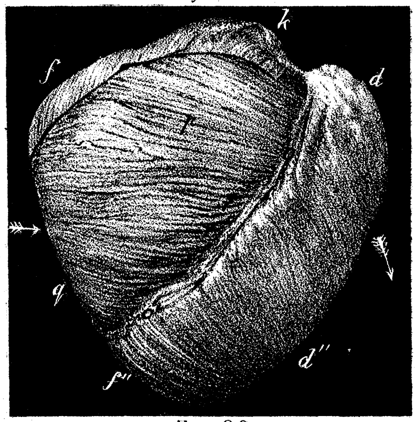
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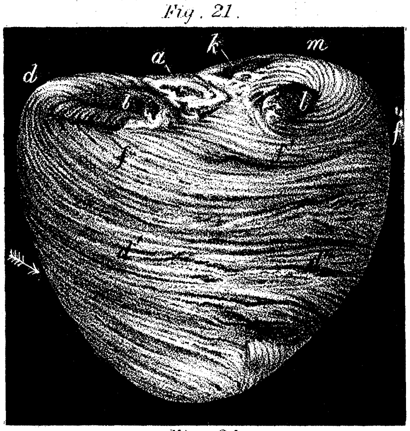
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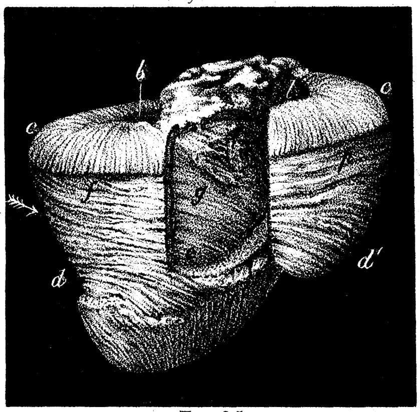
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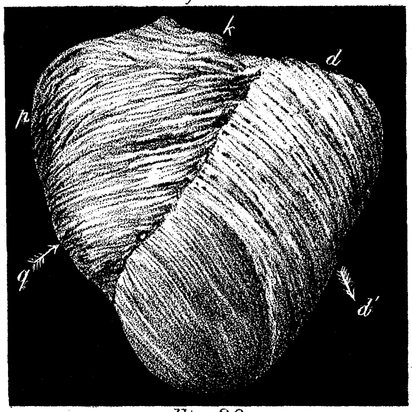
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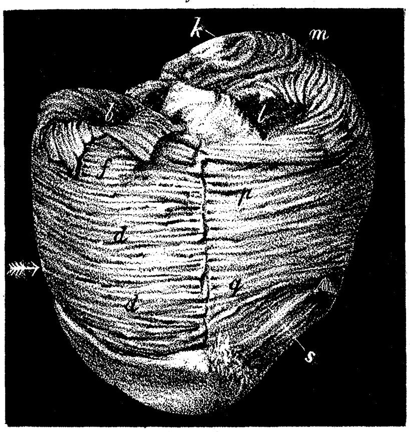
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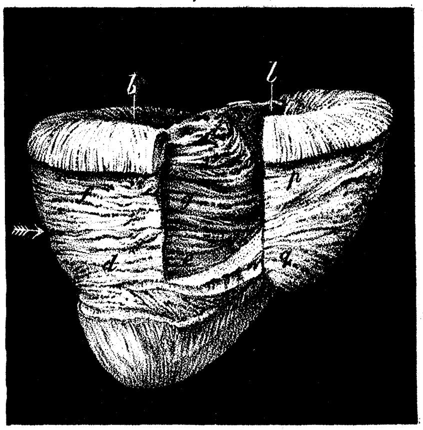
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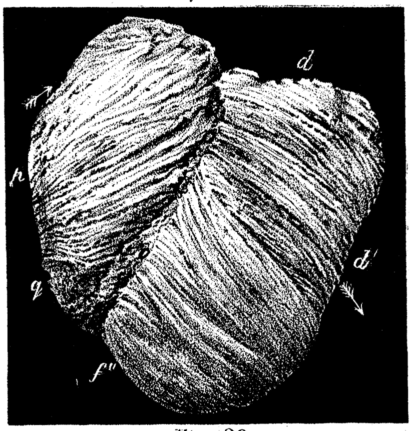
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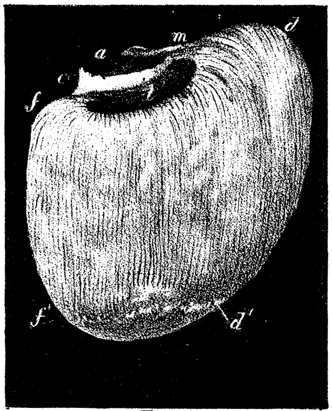
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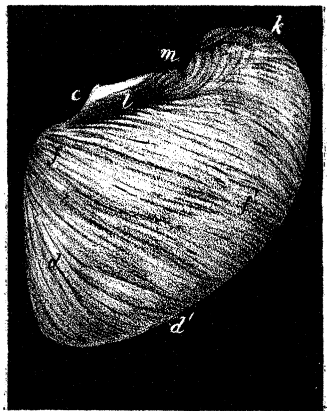
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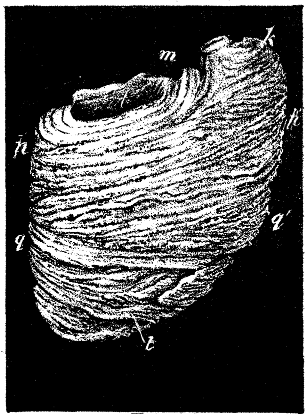
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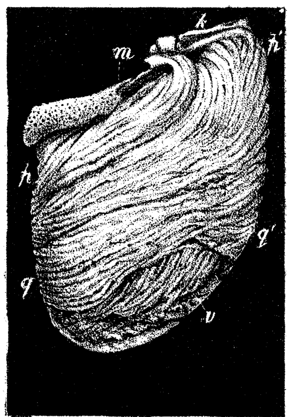
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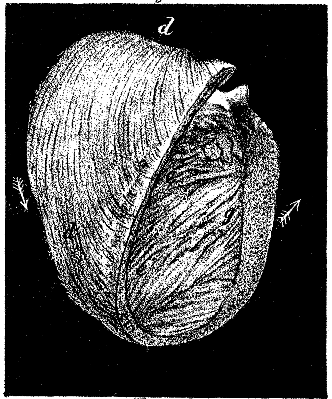
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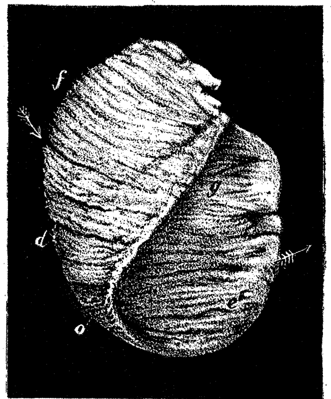
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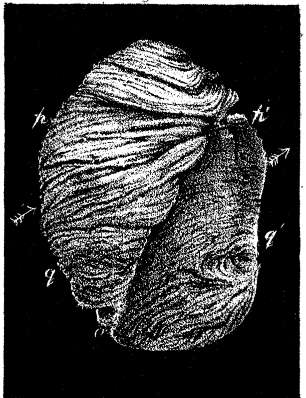
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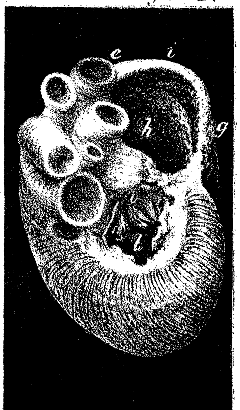
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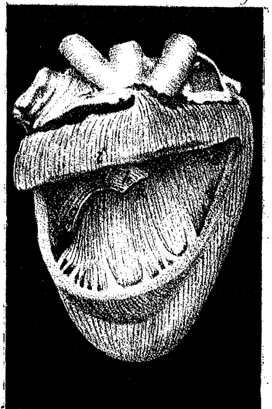
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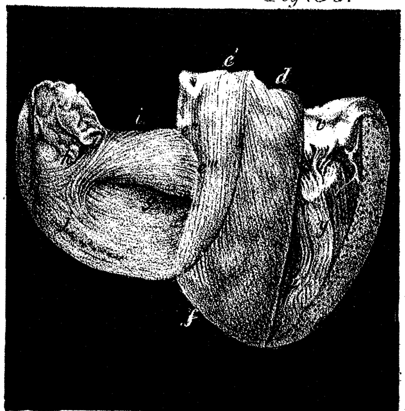
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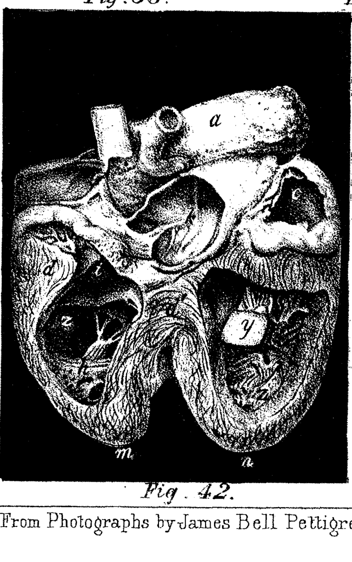
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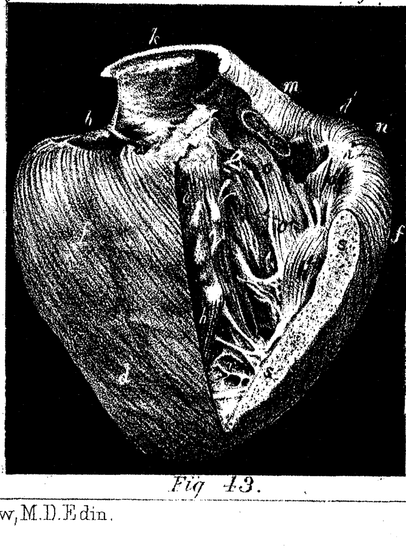
Fig. 43.


Fig. 44.

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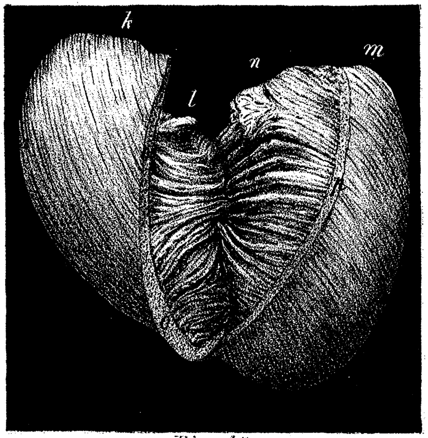

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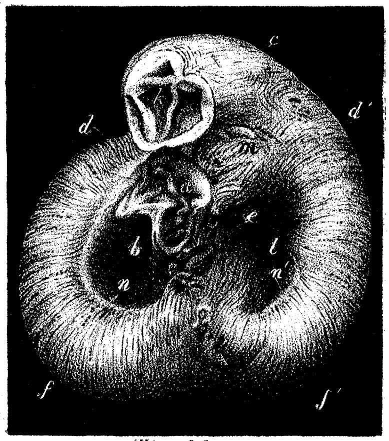

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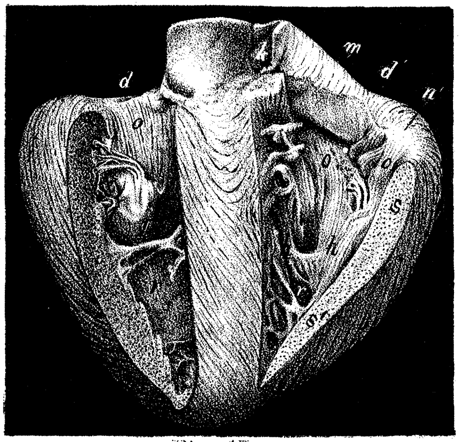

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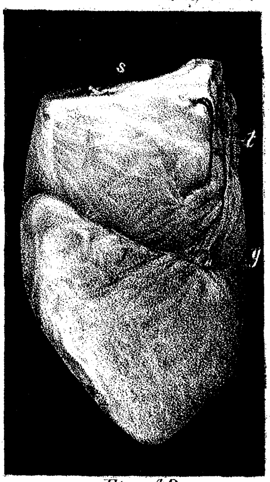

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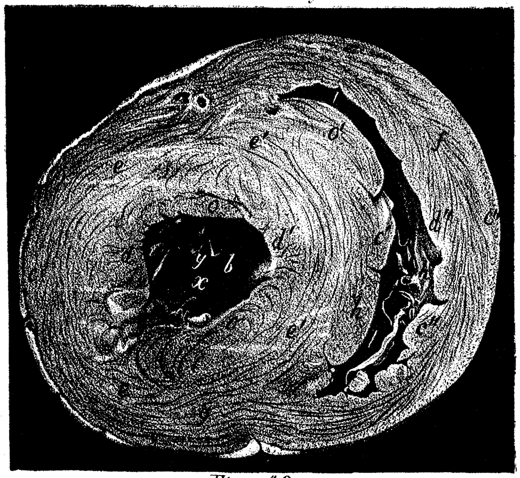

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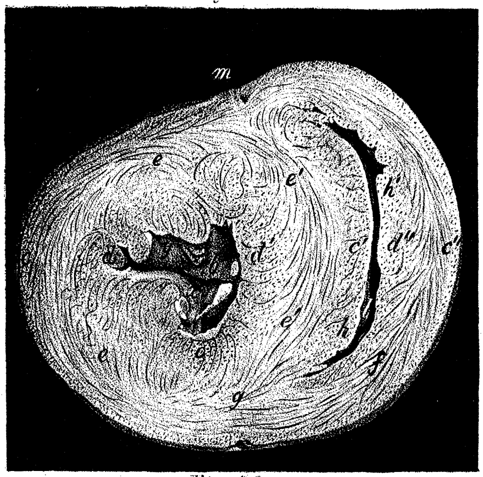

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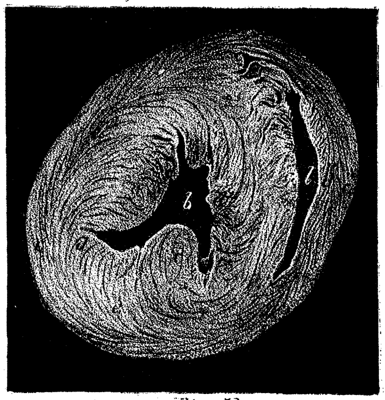

Fig. 51.

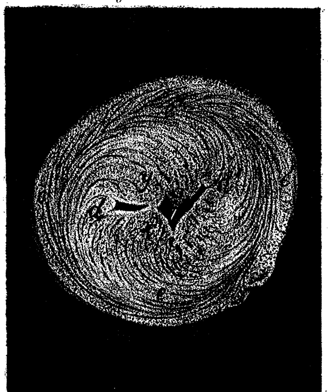

Fig. 52.

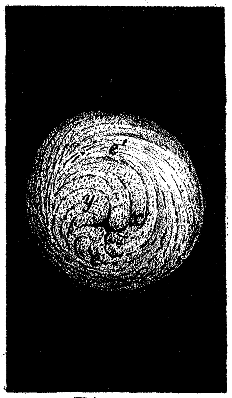

Fig. 53.

Fig. 54.

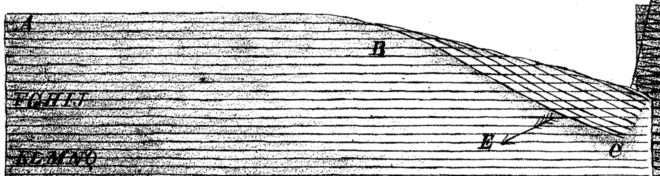

Diagram. 1.

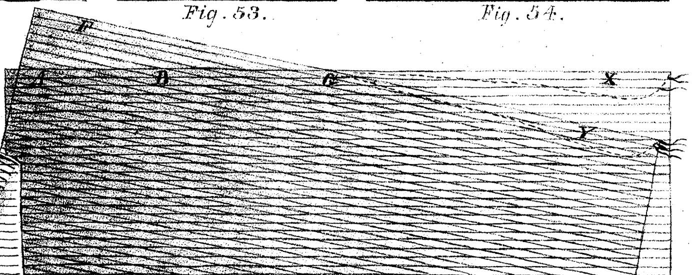

Diagram. 2.

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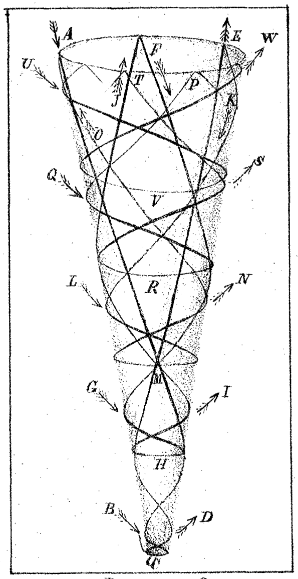

Diagram. 3.

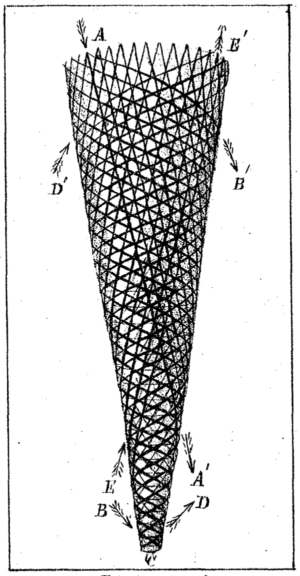

Diagram. 4.

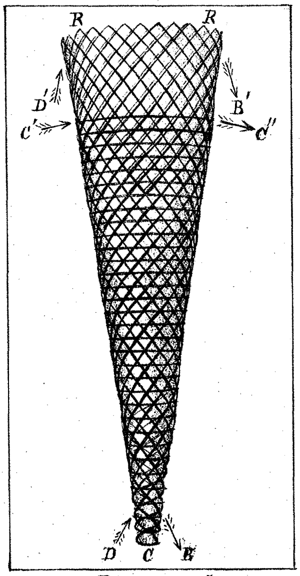

Diagram. 5.

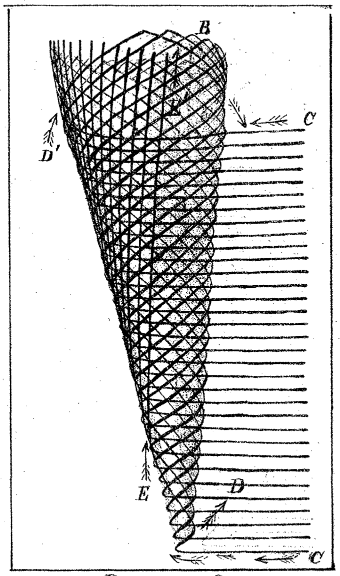

Diagram. 6.

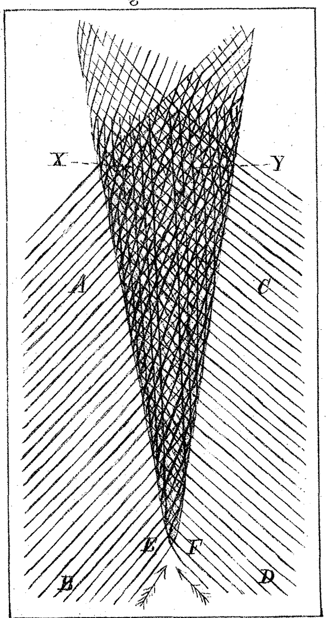

Diagram. 7.

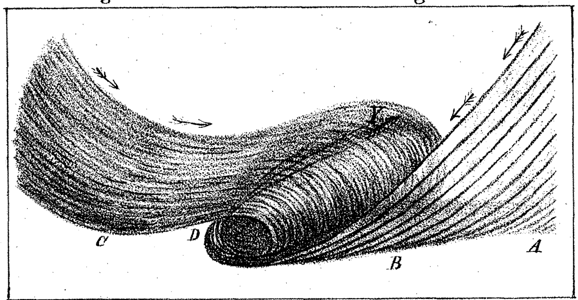

Diagram. 8.

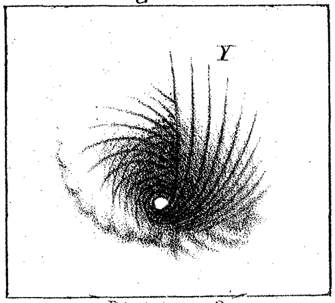

Diagram. 9.

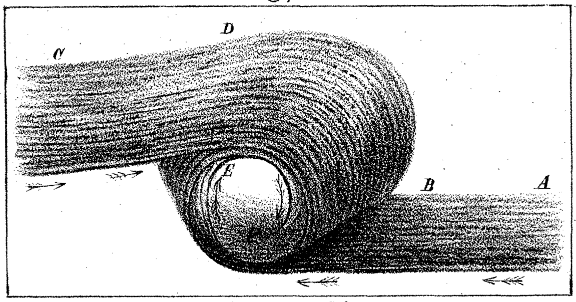

Diagram. 10.

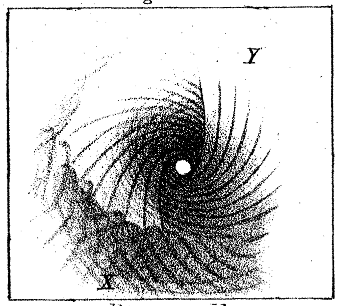

Diagram. 11.

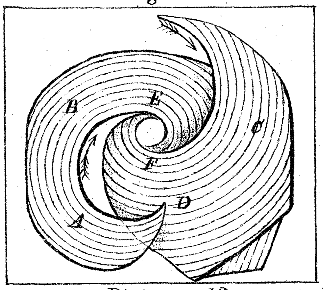

Diagram. 12.

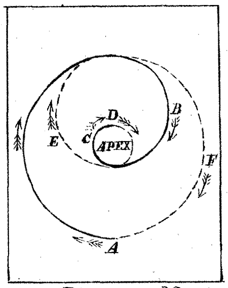

Diagram. 13.

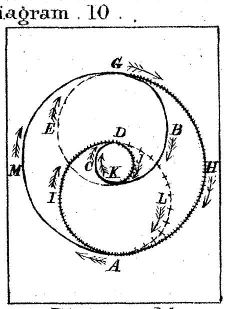

Diagram. 14.

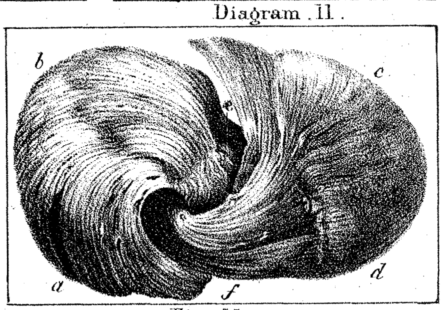

Fig. 55

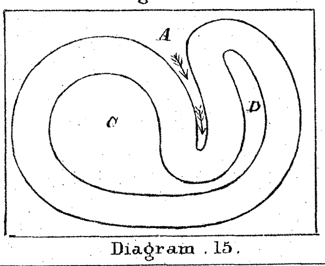

Diagram. 15.

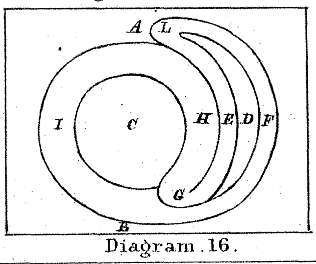

Diagram. 16.

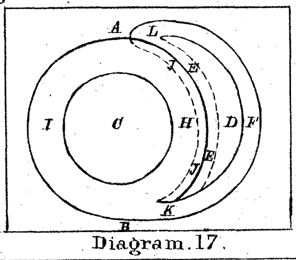

Diagram. 17.

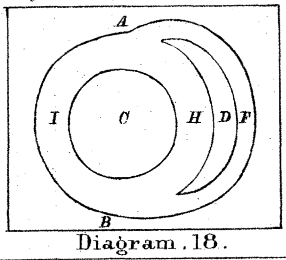

Diagram. 18.

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