1. As a condition preliminary to coagulation, there is either an increase in the formation of fibrin-ferment or an appearance of ferment in the blood, due to changes in certain of the leucocytes. The red corpuscles are probably not directly concerned in coagulation, and there is nothing definite known of the action of the blood-plaques in this process.

2. The fibrin-ferment unites with fibrinogen and forms fibrin, which is the coagulating substance. Paraglobuline (or metalbumin) is little if at all concerned in this process.

3. The processes described as incident to the coagulation of blood take place also in the coagulation of lymph and chyle.

In accordance with the views stated in connection with the composition of blood-plasma, paraglobuline, or metalbumin, fibrinogen and, finally, fibrin are products of decomposition, are abnormal formations, and are not normal constituents of the blood.

It is possible that the statement just given of the mechanism of the coagulation of the blood may be modified in the future in accordance with the most recent views of Schmidt, who claims that all the so-called fibrin-factors result from decomposition of the leucocytes, a great number of which, it is said, are dissolved soon after blood is drawn from the vessels. There are, indeed, many experimental and pathological facts in support of this view; but it can not be adopted without reserve, until the experiments of Schmidt shall have been supplemented by more extended observations. Schmidt maintains that in certain classes of animals, dissolved red corpuscles are also concerned in the production of fibrin-factors.

Leech-drawn blood remains fluid in the body of the animal. Richardson has observed, also, that the blood flowing from a leech-bite presents the same persistent fluidity, which explains the well-known fact that the insignificant wound gives rise to considerable hæmorrhage.

The existence of projections into the caliber of vessels, or the passage of a fine thread through an artery or vein, will determine the formation of a small coagulum upon the foreign substance, while the circulation is neither interrupted nor retarded. In the present state of knowledge, explanation of these facts is difficult if not impossible. The process, under these conditions, can not be subjected to direct experiment as in the case of blood coagulating out of the body.

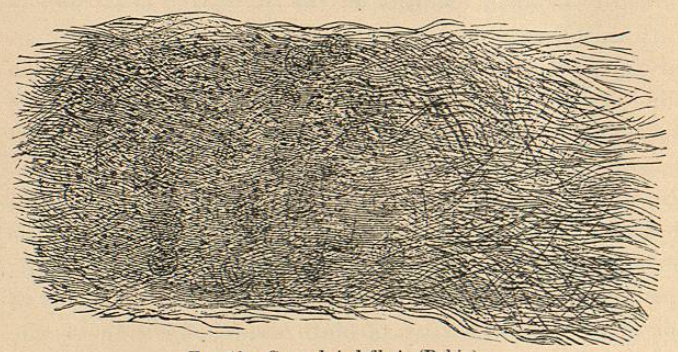

FIG. 10.—*Coagulated fibrin* (Robin).
Fibrinous clot, without red corpuscles, and containing leucocytes, thrown off in the form of a whitish pseudo-membrane in a case of ulceration of the neck of the uterus with hæmorrhage.

During coagulation, fibrin assumes a filamentous form, presenting, under the microscope, the appearance of rectilinear fibrillæ. These fibrillæ gradually increase in number, and as contraction of the clot occurs, they become irregularly crossed. They are always straight, however, and never assume the wavy appearance characteristic of true fibrous tissue.

The blood of the renal and hepatic veins, capillary blood and the blood which passes from the capillary system into the veins after death generally does not coagulate or coagulates very imperfectly; in other words, these varieties of blood do not readily form fibrin. The reason of this peculiarity is not known; but the fact affords a partial explanation of the normal fluidity of the blood; for this fluid, passing over the entire course of the circulation in about thirty seconds, seems to be constantly losing its coagulability in its passage through the liver, kidneys and the general capillary system, as fast as its coagulability is increased in the other parts. Taking into consideration the rapidity of the circulation, it is evident that coagulation can not take place while the normal circulation is maintained and while the blood is undergoing the constant changes incident to general nutrition.

CHAPTER II.

CIRCULATION OF THE BLOOD—ACTION OF THE HEART.

Discovery of the circulation—Physiological anatomy of the heart—Valves of the heart—Movements of the heart—Impulse of the heart—Succession of the movements of the heart—Force of the heart—Action of the valves—Sounds of the heart—Causes of the sounds of the heart—Frequency of the heart's action—Influence of age and sex—Influence of digestion—Influence of posture and muscular exertion—Influence of exercise etc.—Influence of temperature—Influence of respiration on the action of the heart—Cause of the rhythmical contractions of the heart—Accelerator nerves—Direct inhibition of the heart—Reflex inhibition of the heart—Summary of certain causes of arrest of the action of the heart.

HARVEY "set forth for the first time his discovery of the circulation," in his public lectures in 1616, and in 1628 published the "*Exercitatio Anatomica de Motu Cordis et Sanguinis in Animalibus.*" This discovery, from the isolated facts bearing upon it which were observed by anatomists to its culmination in the experiments of Harvey, so fully illustrates the gradual development of most physiological truths, that it does not seem out of place to begin the study of the circulation with a brief sketch of its history.

The facts bearing upon the circulation developed before the time of Harvey were chiefly anatomical. The writings of Hippocrates are very indefinite upon all points connected with the circulatory system; and no clear and positive statements are to be found in ancient works before the time of Aristotle. The work of Aristotle most frequently quoted by physiologists is his "History of Animals;" and in this occurs a passage which seems to indicate that he thought that air passed from the lungs to the heart; but in his work, *De Partibus Animalium*, it is stated that there are two great blood-vessels, the vena cava and aorta, arising from the heart, and that the aorta and its branches carry blood. Galen, however, demonstrated experimentally the presence of blood in the arteries, by including a portion of one of these vessels between two ligatures, in a living animal; but his ideas of the communication between the arteries and veins were erroneous, for he believed in the existence of small orifices in the septum between the ventricles of the heart, a mistake that was corrected by Vesalius, at about the middle of the sixteenth century.

In 1553, Michael Servetus, who is generally regarded as the discoverer of the passage of the blood through the lungs, or the pulmonary circulation, described in a work on theology the course of the blood through the lungs, from the right to the left side of the heart. This description, complete as it is, was merely incidental to the development of a theory with regard to the formation of the soul and the development of what were called animal and vital spirits (*spiritus*).

A few years later, Colombo, professor of anatomy at Padua, and Cesalpinus, of Pisa, described the passage of the blood through the lungs, though probably without any knowledge of what had been written by Servetus. To Cesalpinus is attributed the first use of the expression circulation of the blood; and he also remarked that after ligature or compression of veins, the swelling is always below the point of obstruction.

The history of the discovery of the valves in the veins is quite obscure, although priority of observation is almost universally conceded to Fabricius. As regards this point, only the dates of published memoirs are to be considered, notwithstanding the assertion of Fabricius that he had seen the valves in 1574. In 1545, Étienne described, in branches of the portal vein, "valves, which he called apophyses, and which he compared to the valves of the heart." In 1551, Amatus Lusitanus published a letter from Cannanus, in which it is stated that he had found valves in certain of the veins. In 1563, Eustachius published an account of the valves of the coronary vein. In 1586, a clear account, by Piccolhominus, of the valves of the veins was published. Fabricius gave the most accurate descriptions and delineations of the valves, and his first publication is said to have appeared in 1603. He demonstrated the valves to Harvey, at Padua; and it is probable that this was the origin of the first speculations by Harvey on the mechanism of the circulation.

In the work of Harvey are described, first the movements of the heart, which he exposed and studied in living animals. He described minutely all the phenomena which accompany its action; its diastole, when it is filled with blood, and its systole, when the fibres of which the ventricles are composed contract simultaneously, and "by an admirable adjustment all the internal surfaces are drawn together, as if with cords, and so is the charge of blood expelled with force." From the description of the action of the ventricles, he passed to the auricles, and showed how these, by their contraction, filled the ventricles with blood. By experiments upon serpents and fishes, he proved that the blood fills the heart from the veins and is sent out into the arteries. Exposing the heart and great vessels in these animals, he applied a ligature to the veins, which had the effect of cutting off the supply from the heart so that it became pale and flaccid; and by removing the ligature the blood could be seen flowing into the organ. When, on the contrary, a ligature was applied to the artery, the heart became unusually distended, which continued so long as the obstruction remained. When the ligature was removed, the heart soon returned to its normal condition. Harvey completed his description of the circulation, by experiments showing the course of the blood in the arteries and veins and the uses of the valves of the veins.

By these simple experiments, the chain of evidence establishing the fact of the circulation of the blood was completed. Truly it is said that here began an epoch in the study of physiology; for then scientific observers began to emancipate themselves from the ideas of the ancients, which had controlled opinions for two centuries, and to study Nature for themselves by means of experiments.

Although Harvey described so perfectly the course of the blood and left no doubt as to the communication between the arteries and veins, it was left to others to actually see the blood in movement and follow it from one system of vessels to the other. In 1661, Malpighi saw the blood circulating in the vessels of the lung of a living frog, examining it with magnifying glasses; and a little later, Leeuwenhoek saw the circulation in the wing of a bat. These observations completed the discovery of the circulation.

In man and in the warm-blooded animals, the organism requires blood that has been oxygenated in the lungs, and to meet this demand fully, the circulatory system is divided into pulmonic and systemic. The heart is double, having a right side and a left side, which are entirely distinct from each other. The right heart receives the blood as it is brought from the general system by the veins and sends it to the lungs; the left heart receives the blood from the lungs and sends it to the general system. It must be borne in mind, however, that although the two sides of the heart are distinct from each other, their action is simultaneous; and in studying the motions of the heart, it will be found that the blood is sent simultaneously from the right side to the lungs and from the left side to the system. It will not be necessary, therefore, to separate the two circulations in the study of their mechanism; for the simultaneous action of both sides of the heart renders it possible to study its action as a single organ, and the constitution and operations of the two kinds of vessels do not present any material differences.

For convenience of study, the circulatory system may be divided into heart and vessels, the latter being of three kinds: the arteries, which carry blood from the heart to the general system; the capillaries, which distribute the blood more or less abundantly in different parts of the general system; and the veins, which return the blood from the general system to the heart. The three kinds of blood-vessels present certain anatomical as well as physiological distinctions, which will be noted in connection with the description of the vascular system.

Physiological Anatomy of the Heart.

The heart of the human subject is a pear-shaped, muscular organ, situated in the thoracic cavity, with its base in the median line and its apex at the fifth intercostal space, three inches (7·6 centimetres) to the left of the median line, or one inch (2·5 centimetres) within the line of the left nipple.

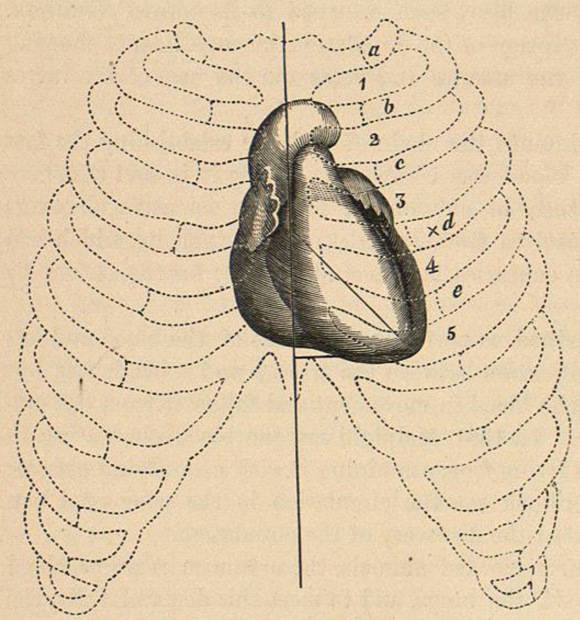

Fig. 11.—*Heart in situ* (Dalton, in Flint, "on the heart").
a, b, c etc., ribs ; 1, 2, 3 etc., intercostal spaces ; vertical line, median line; triangle, superficial cardiac region ; × on the fourth rib, nipple.

Its weight is eight to ten ounces (227 to 283 grammes) in the female, and ten to twelve ounces (283 to 340 grammes) in the male. It has four distinct cavities; a right and a left auricle, and a right and a left ventricle. Of these, the ventricles are the more capacious. The heart is held in place by the attachment of the great vessels to the posterior wall of the thorax; while the apex is free and capable of a certain degree of motion. The whole organ is enveloped in a fibrous sac called the pericardium. This sac is lined by a serous membrane, which is attached to the great vessels at the base and reflected over its surface. The membrane is lubricated by about a drachm (3·7 c. c.) of fluid, so that the movements of the heart are normally accomplished without any friction. The serous pericardium does not present any differences from serous membranes in other situations. The cavities of the heart are lined by a smooth membrane called the endocardium, which is continuous with the lining membrane of the blood-vessels.

The right auricle receives the blood from the venæ cavæ and empties it into the right ventricle. The auricle presents a principal cavity, or sinus, as it is called, with a little appendix, called, from its resemblance to the ear of a dog, the auricular appendix. It has two large openings for the vena cava ascendens and the vena cava descendens respectively, with a small opening for the coronary vein which brings the blood from the substance of the heart itself. It has, also, another large opening, called the auriculo-ventricular opening, by which the blood flows into the ventricle. The walls of this cavity are quite thin as compared with the ventricles, measuring about one line (2·1 mm.). They are composed of muscular fibres arranged in two layers,

one of which, the external, is common to both auricles, and the other, the internal, is proper to each. These muscular fibres, although involuntary in their action, belong to the striated variety, and are similar in structure to the fibres of the ventricles. The fibres of the auricles are much fewer than those of the ventricles. Some of them are looped, arising from a cartilaginous ring which separates the auricles and ventricles and passing over the auricles; and others are circular, surrounding the auricular appendages and the openings of the veins, extending, also, a short distance along the course of these vessels. One or two valvular folds are found at the orifice of the coronary vein, preventing a reflux of blood, but there are no valves at the orifices of the venæ cavæ.

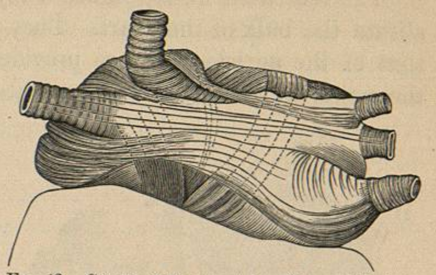

Fig. 12.—*Course of the muscular fibres of the left auricle* (Landois).

The left auricle receives the blood which comes from the lungs by the pulmonary veins. It does not differ materially in its anatomy from the right. It is a little smaller, and its walls are thicker, measuring about a line and a half (3·15 mm.). It has four openings by which it receives the blood from the four pulmonary veins. These openings are not provided with valves. Like the right auricle, it has a large opening by which blood flows into the corresponding ventricle. The arrangement of the muscular fibres is essentially the same as in the right auricle. In adult life, the cavities of the auricles are entirely distinct from each other. Before birth, they communicate by a large opening, the foramen ovale, and the orifice of the inferior vena cava is provided with a mem-

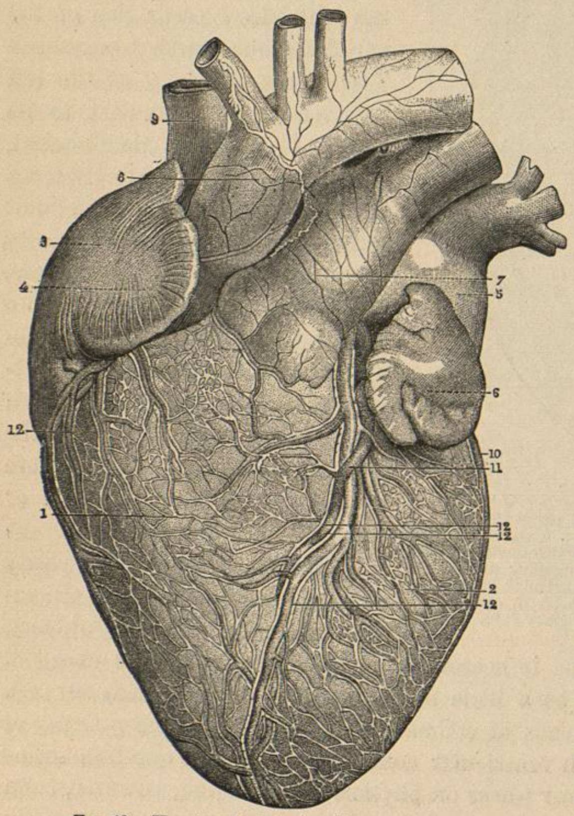

Fig. 13.—*Heart, anterior view* (Bonamy and Beau).
1, *right ventricle* ; 2, *left ventricle* ; 3, 4, *right auricle* ; 5, 6, *left auricle* ; 7, pulmonary artery; 8, aorta; 9, superior vena cava ; 10, anterior coronary artery ; 11, branch of the coronary vein ; 12, 12, 12, lymphatic vessels.

branous fold, the Eustachian valve, which serves to direct the blood from the lower part of the body through the opening into the left auricle. After birth, the foramen ovale is closed and the Eustachian valve gradually disappears.

The ventricles, in the human subject and in warm-blooded animals, constitute the bulk of the heart. They have a capacity somewhat greater than that of the auricles and are provided with thick, muscular walls. It is by the powerful action of this portion of the heart that the blood is forced, on the one hand, to the lungs and back to the left side of the heart, and on the other, through the entire system of the greater circulation, to the right side.

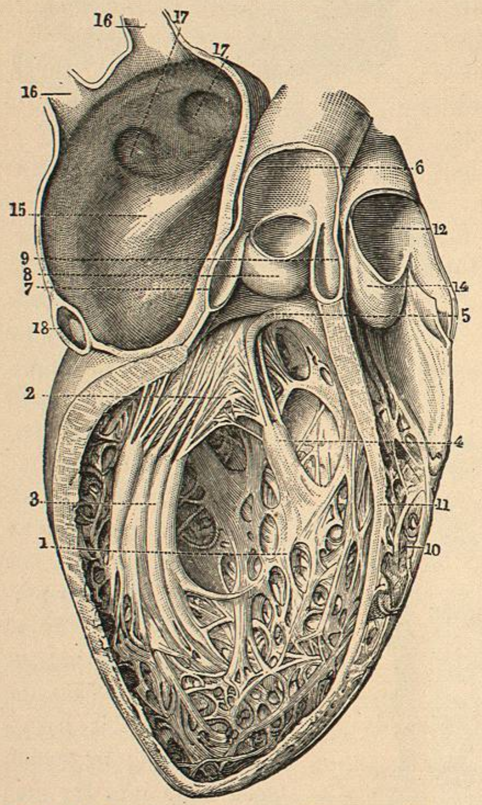

FIG. 14.—*Left cavities of the heart* (Bonamy and Beau.) 1, *left ventricular cavity*; 2, *mitral valve*; 3, 4, *columnæ carneæ*; 5, *aortic opening*; 6, *aorta*; 7, 8, 9, *aortic valves*; 10, right ventricular cavity; 11, interventricular septum; 12, pulmonary artery; 13, 14, pulmonic valves; 15, left auricular cavity; 16, 16, right pulmonary veins, with 17, 17, openings of the veins; 18, section of the coronary vein.

The capacity of the cavities on the right side of the heart is one-tenth to one-eighth greater than that of the corresponding cavities on the left side. The capacity of the ventricles exceeds that of the auricles by one-fourth to one-third. The absolute capacity of the left ventricle, when distended to its utmost (Robin and Hiffelsheim), is 4·8 to 7 ounces (143 to 212 c. c.). This is much greater than most estimates, which place the capacity of each of the various cavities, moderately distended, at about two ounces (59·1 c. c.); but the observations of Robin and Hiffelsheim, upon the human heart, were made evidently with the greatest accuracy, either before cadaveric rigidity had set in or after it had disappeared.

Notwithstanding the disparity in the extreme capacity of the various cavities, the quantity of blood which enters these cavities is necessarily equal to that which is expelled. This has been stated to be a little more than two ounces (about 60 c.c.). There are, however, no means of estimating with exactness the quantity of blood discharged with each ventricular contraction; and the question seems to be rather avoided in many works on physiology. Judging, however, from observations on the heart during its action, it never seems to contain much more than half the quantity in all its cavities that it does when fully distended by injection; but the right cavities are more dilatable than the left,

and probably the ordinary quantity of blood in the left ventricle is four-fifths to five-sixths of its extreme capacity, or five to six ounces (120 to 170 c.c.).

The cavities of the ventricles are triangular or conoidal, the right being broader and shorter than the left, which latter extends to the apex. The inner surface of both cavities is marked by ridges and papillæ, which are called columnæ carneæ. Some of these are fleshy ridges projecting into the cavity; others are columns attached by each extremity and free at the central portion; and others are papillæ giving origin to the chordæ tendineæ, which are attached to the free edges of the auriculo-ventricular valves. These fleshy columns interlace in every direction and give the inner surface of the cavities a reticulated appearance. This arrangement facilitates the complete emptying of the ventricles during their contraction.

The walls of the left ventricle are uniformly much thicker than those of the right side. The average thickness of the right ventricle at the base is two and a half lines (5·25 mm.), and the thickness of the left ventricle at the corresponding part is seven lines (14·7 mm.), or a little more than half an inch (Bouillaud).

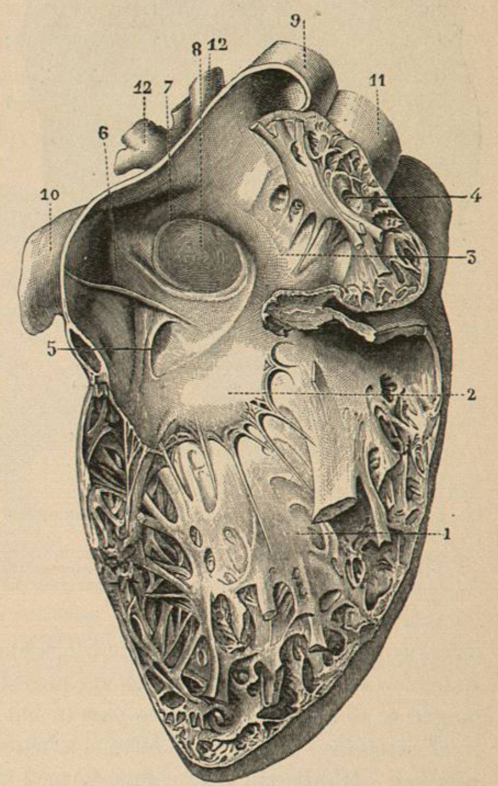

FIG. 15.—*Right cavities of the heart* (Bonamy and Beau). 1, *right ventricular cavity*; 2, *posterior curtain of the tricuspid valve*; 3. *right auricular cavity*; 4, *columnæ carneæ of the right auricle*; 5, section of the coronary vein; 6, Eustachian valve; 7, ring of Vieussens; 8, fossa ovalis; 9. superior vena cava; 10, inferior vena cava; 11, aorta; 12, 12, right pulmonary veins.

The arrangement of the muscular fibres constituting the walls of the ventricles is more regular than in the auricles, and their course affords an explanation of some of the phenomena which accompany the heart's action. The direction of the fibres can not be well made out unless the heart have been boiled for a number of hours, when part of the intermuscular tissue is dissolved out, and the fibres can be easily separated and followed. Without entering into a minute description of their direction, it is sufficient to state, in this connection, that they present two principal layers; a superficial layer common to both ventricles, and a deep layer proper to each ventricle. The superficial fibres pass obliquely from right to left from the base to the apex; here they take a spiral course, become deep, and pass into the interior of the organ, to form the columnæ carneæ. These fibres envelop both ventricles. They may be said to arise from cartilaginous rings which surround the auriculo-ventricular orifices. The external surface of the heart is marked by a little groove which indicates the division between the two ventricles. The deep fibres are circular, or transverse, and surround each ventricle separately.

The muscular tissue of the heart is of a deep-red color and resembles, in its gross characters, the tissue of ordinary voluntary muscles; but as already intimated, it presents certain peculiarities in its minute anatomy. The fibres are considerably smaller and more granular than those of ordinary muscles. They are, moreover, connected with each other by short, inosculating branches. (See Fig. 17.) The muscular fibres of the heart have no sarcolemma. These peculiarities, particularly the inosculation of the fibres, favor the contraction of the ventricular walls in every direction and the complete expulsion of the contents of the cavities with each systole.

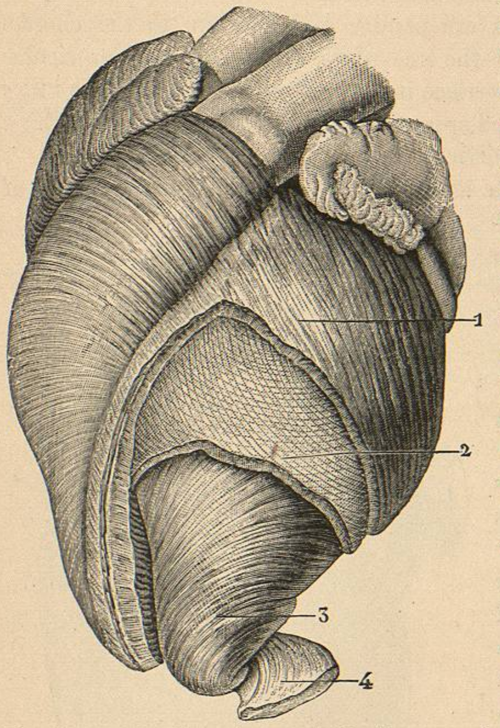

FIG. 16.—*Muscular fibres of the ventricles* (Bonamy and Beau).
1, superficial fibres common to both ventricles; 2, fibres of the left ventricle; 3, deep fibres passing upward toward the base of the heart; 4, fibres penetrating the left ventricle.

The distribution of the nerves to the heart and the arrangement of the ganglia and nerve-terminations in its substance will be described in connection with the influence of the nervous system upon the circulation.

Each ventricle has two orifices; one by which it receives the blood from the auricle, and the other by which the blood passes from the right side to the lungs and from the left side to the general system. All of these openings are provided with valves, which are so arranged as to allow the blood to pass in but one direction.

Tricuspid Valve.—This valve is situated at the right auriculo-ventricular opening. It has three curtains, formed of a thin but resisting membrane, which are attached around the opening. The free borders are attached to the chordæ tendineæ, some of which arise from the papillæ on the inner surface of the ventricle, and others, directly from the walls of the ventricle. When the organ is empty, these curtains are applied to the walls of the ventricle, leaving the auriculo-ventricular opening free; but when the ventricle is completely filled and the fibres contract, they are forced up, their free edges become applied to each other, and the opening is closed.

Pulmonic Valves.—These valves, also called the semilunar, or sigmoid valves of the right side, are situated at the orifice of the pulmonary artery. They are strong, membranous pouches, with their convexities, when closed, looking toward the ventricle. They are attached around the orifice of the pulmonary artery and are applied very nearly to the walls of the vessel when the blood passes in from the ventricle; but at other times their free edges meet in the centre, opposing the regurgitation of blood. At the centre of the free edge of each valve is a little corpuscle called the corpuscle of Arantius; and just above the margins of attachment of the valves, the artery presents three little dilatations, or sinuses, called the sinuses of Valsalva. The corpuscles of Arantius probably aid in the adaptation of the valves to each other and in the effectual closure of the orifice.

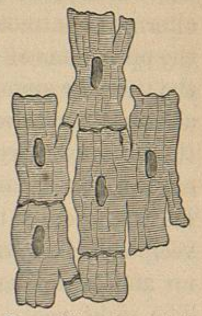

FIG. 17. — *Branched muscular fibres from the heart of a mammal* (Landois).

Mitral Valve.—This valve, sometimes called the bicuspid, is situated at the left auriculo-ventricular orifice. It is called mitral from its resemblance, when open, to a bishop's mitre. It is attached to the edges of the auriculo-ventricular opening, and its free borders are held in place, when closed, by the chordæ tendineæ of the left side. It presents no material difference from the tricuspid valve, with the exception that it is divided into two curtains instead of three.

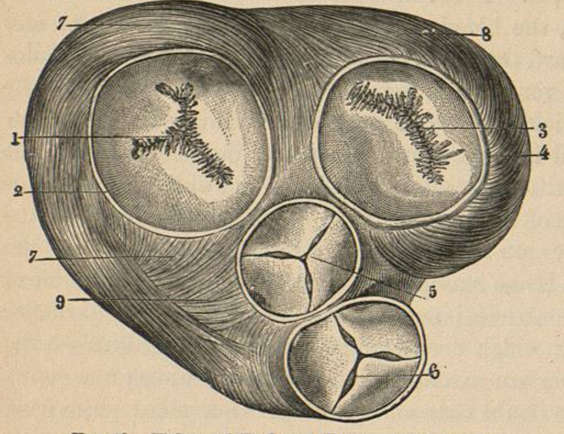

FIG. 18.—*Valves of the heart* (Bonamy and Beau).
1, right auriculo-ventricular orifice, closed by the tricuspid valve; 2, fibrinous ring; 3, left auriculo-ventricular orifice, closed by the mitral valve; 4, fibrinous ring; 5, aortic orifice and valves; 6, pulmonic orifice and valves; 7, 8, 9, muscular fibres.

Aortic Valves.—These valves, also called the semilunar, or sigmoid valves of the left side, present no difference from the valves at the orifice of the pulmonary artery. They are situated at the aortic orifice.

MOVEMENTS OF THE HEART.

The dilatation of the cavities of the heart is called the diastole, and the contraction of the heart, the systole. When these terms are used without any qualification, they are understood as referring to the ventricles; but they are also applied to the action of the auricles, as the auricular diastole and systole, which are distinct from the action of the ventricles.

A complete revolution of the heart consists in the filling and emptying of all its cavities, during which they present an alternation of repose and activity. As these phenomena occupy, in many warm-blooded animals, a period of time