ute to its production." It will be assumed, therefore, that the sounds of the heart have a mechanism that may be summarized as follows:

The first sound of the heart is a compound sound. It is produced by the closure of the auriculo-ventricular valves at the beginning of the ventricular systole, to which are superadded, the muscular sound, due to the contraction of the muscular fibres of the heart, and the impulsion-sound, due to the striking of the heart against the walls of the thorax.

The second sound is a simple sound. It is produced by the sudden closure of the aortic and pulmonic semilunar valves, immediately following the ventricular systole.

It is of importance, with reference to pathology, to have a clear idea of the currents of blood through the heart, with their exact relations to the sounds and intervals. At the beginning of the first sound, the blood is forcibly thrown from the ventricles into the pulmonary artery on the right side and the aorta on the left, and the auriculo-ventricular valves are closed. During the period occupied by this sound, the blood is flowing through the arterial orifices, and the auricles are receiving blood slowly from the venæ cavæ and the pulmonary veins. When the second sound occurs, the ventricles having become relaxed, the recoil of the arterial walls, acting upon the column of blood, immediately closes the semilunar valves upon the two sides. The auricles continue to dilate, and the ventricles are slowly receiving blood. Immediately following the second sound, during the first part of the interval, the auricles become fully dilated; and in the last part of the interval, immediately preceding the first sound, the auricles contract and the ventricles are fully dilated, This completes a single revolution of the heart.

Frequency of the Heart's Action.—The number of pulsations of the heart is not far from seventy per minute in an adult male and is between seventy and eighty in the female. There are individual cases, however, in which the pulse is normally much slower or more frequent than this, a fact which must be remembered when examining the pulse in disease. It is said that the pulse of Napoleon I. was only forty per minute. Dunglison mentioned a case which came under his own observation, in which the pulse presented an average of thirty-six per minute. The same author stated that the pulse of Sir William Congreve was never less than one hundred and twenty-eight per minute, in health. It is by no means unfrequent to find a healthy pulse of a hundred or more a minute; but in the cases reported in which the pulse has been found to be forty or less, it is possible that every alternate beat of the heart was so feeble as to produce no perceptible arterial pulsation. In such instances, the fact may be ascertained by listening to the heart while the finger is placed upon the artery.

Influence of Age and Sex.—In both the male and female, observers have constantly found a great difference in the rapidity of the heart's action at different periods of life. The pulsations of the heart in the fœtus are about 140 per minute. At birth the pulse is 136. It gradually diminishes during the first year to about 128. The second year, the diminution is quite rapid, 107 being the mean frequency at two years of age. After the second year,

the frequency progressively diminishes until adult life, when it is at its minimum, which is about 70 per minute. At the later periods of life the movements of the heart become slightly accelerated, ranging between 75 and 80 (Guy).

During early life there is no marked and constant difference in the rapidity of the pulse in the sexes; but near the age of puberty, the development of the peculiarities relating to sex is accompanied with an acceleration of the heart's action in the female, which continues even into old age.

Influence of Digestion.—The condition of the digestive system has a marked influence on the rapidity of the pulse, and there is generally an increase in the pulse of between five and ten beats per minute after each meal. Prolonged fasting diminishes the frequency of the pulse by about twelve beats. Alcohol first diminishes and afterward accelerates the pulse. Coffee is said to accelerate the pulse in a marked degree. It has been ascertained that the pulse is accelerated to a greater degree by animal than by vegetable food.

Influence of Posture and Muscular Exertion.—It has been observed that the position of the body has a very marked influence upon the rapidity of the pulse. In the male, there is a difference of about ten beats between standing and sitting, and fifteen beats between standing and the recumbent posture. In the female, the variations with position are not so great. The average is, for the male standing, 81; sitting, 71; lying, 66;—for the female: standing, 91; sitting, 84; lying, 80. This is given as the average of a large number of observations. There were a few instances, however, in which there was scarcely any variation with posture, and some in which the variation was much greater than the average. In the inverted posture, the pulse was found to be reduced about fifteen beats (Guy).

The question at once suggests itself whether the acceleration of the pulse in sitting and standing may not be due, in some measure, to the muscular effort required in making the change of posture. This is answered by the experiments of Guy, in which the subjects were placed on a revolving board and the position of the body was changed without any muscular effort. The same results as those cited above were obtained in these experiments, showing that the difference is due to the position of the body alone. In a single observation, the pulse, standing, was 89; lying, 77; difference, 12. With the posture changed without any muscular effort, the results were as follows: standing, 87; lying, 74; difference, 13. Different explanations of these variations have been offered by physilogists; but Guy seems to have settled experimentally the fact that the acceleration is due in part to the muscular effort required to maintain the body in the sitting and standing positions. The following are the results of experiments bearing on this point, in which it is shown that when the body is carefully supported in the erect or sitting posture, so as to be maintained without muscular effort, the pulse is less frequent than when the subject is standing; and farthermore, that the pulse is accelerated, in the recumbent posture, when the body is imperfectly supported:

"1. Difference between the pulse in the erect posture, without support, and leaning in the same posture, in an average of twelve experiments on the writer, 12 beats; and on an average of eight experiments on other healthy males, 8 beats.

"2. Difference in the frequency of the pulse in the recumbent posture, the body fully supported, and partially supported, 14 beats on an average of five experiments.

"3. Sitting posture (mean of ten experiments on the writer), back supported, 80; unsupported, 87; difference, 7 beats.

"4. Sitting posture with the legs raised at right angles with the body (average of twenty experiments on the writer), back unsupported, 86; supported, 68; difference, 18 beats. An average of fifteen experiments of the same kind on other healthy males gave the following numbers: back unsupported, 80; supported, 68; a difference of 12 beats."

Influence of Exercise etc.—Muscular exertion increases the frequency of the pulsations of the heart; and the experiments just cited show that the difference in rapidity, which is by some attributed to change in posture—some positions, it is fancied, offering fewer obstacles to the current of blood than others—is mainly due to muscular exertion. According to Bryan Robinson (1734), a man in the recumbent position has 64 pulsations per minute; sitting, 68; after a slow walk, 78; after walking four miles in an hour, 100; and 140 to 150 after running as fast as he could. This general statement, which has been repeatedly verified, shows the important influence of the muscular system on the heart.

The influence of sleep upon the action of the heart reduces itself almost entirely to the proposition that during this condition, there is usually entire absence of muscular effort, and consequently the number of beats is less than when the individual is aroused. It has been found that there is no difference in the pulse between sleep and perfect quiet in the recumbent posture. This fact obtains in the adult male; but there is a marked difference in females and young children, the pulse being always slower during sleep (Quetelet).

Influence of Temperature.—The influence of extremes of temperature upon the heart is very decided. The pulse may be doubled by remaining a very few minutes exposed to extreme heat. Bence Jones and Dickinson have ascertained that the pulse may be very much reduced in frequency, for a short time, by the cold douche. It has also been remarked that the pulse is habitually more rapid in warm than in cold climates.

Although many circumstances materially affect the rapidity of the heart's action, they do not complicate, to any great extent, examinations of the pulse in disease. In cases which present considerable febrile movement, the patient is generally in the recumbent posture. The variations induced by violent exercise are easily recognized, while those dependent upon temperature, the condition of the digestive system, etc., are so slight that they may practically be disregarded. It is necessary to bear in mind, however, the variations which exist in the sexes and at different periods of life, as well as the

possibility of individual peculiarities, when the action of the heart is extraordinarily rapid or slow.

Influence of Respiration upon the Action of the Heart.—The relations between the circulation and respiration are very intimate and one process can not go on without the other. If circulation be arrested, the muscles, being no longer supplied with fresh blood, soon lose their contractile power, and respiration ceases. Circulation, also, is impossible if respiration be permanently arrested. When respiration is imperfectly performed, the action of the heart is slow and labored. The effects of arrest of respiration are marked in all parts of the circulatory system, arteries, capillaries and veins; but the disturbances thus produced all react upon the heart.

If the heart be exposed in a living animal and artificial respiration be kept up, although the pulsations are increased in frequency and diminished in force, after a time they become perfectly regular and continue thus so long as air is adequately supplied to the lungs. Under these conditions, respiration is entirely under control and the effects of its arrest upon the heart can easily be studied. If respiration be interrupted, the following changes in the action of the heart are observed: For a few seconds pulsations go on as usual, but in about a minute they begin to diminish in frequency. At the same time, the heart becomes engorged with blood and the distention of its cavities rapidly increases. For a time its contractions are competent to discharge the entire contents of the left ventricle into the arterial system, and a cardiometer applied to an artery will indicate a great increase in the pressure of blood. A corresponding increase in the movements of the mercury will be noted at each contraction of the heart, indicating that the organ is acting with abnormal vigor. If respiration be still interrupted, the engorgement becomes intense, the heart at each diastole being distended to its utmost capacity. It now becomes incapable of emptying itself, the contractions become very unfrequent, perhaps three or four in a minute, and are progressively enfeebled. The organ is dark, almost black, owing to the circulation of venous blood in its substance. If respiration be not resumed, this distention continues, the contractions become less frequent and more feeble, and in a few minutes they cease.

The arrest of the action of the heart, under these conditions, is chiefly mechanical. The unaërated blood passes with difficulty through the capillaries of the system, and as the heart is constantly at work, the arteries become largely distended. This is shown by the great increase in the arterial pressure while these vessels are full of black blood. If, now, the heart and great vessels be closely examined, the order in which they become distended is readily observed. These phenomena show that in asphyxia the obstruction to the circulation begins, not in the lungs, as is commonly supposed, but in the capillaries of the system, and is propagated backward to the heart through the arteries (Dalton). The distention of the heart in asphyxia is therefore due to the fact that unaërated blood can not circulate freely in the systemic capillaries. When thus distended, the heart becomes paralyzed, like any muscle after a severe strain.

If respiration be resumed before the heart's action has entirely ceased, the organ in a few moments will resume its contractions. There is observed first a change from the dusky hue it had assumed, to a vivid red, which is owing to the circulation of arterial blood in its capillaries. The distention then becomes gradually relieved, and for a few moments, the pulsations are abnormally frequent. The arteries will then be found to contain red blood. An instrument applied to an artery will show a diminution in arterial pressure and in the force of the heart's action, if the arrest of respiration have been carried only far enough to moderately distend the heart; or there is an increase in the pressure and force of the heart, if its action have been nearly arrested. A few moments of regular insufflation will cause the pulsations to resume their normal character and frequency.

In the human subject, the effects of temporary or permanent arrest of respiration on the heart are undoubtedly the same as those observed in experiments upon the warm-blooded animals. In the same way, also, it is possible to restore the normal action of the organ, if respiration be not too long suspended, by the regular introduction of fresh air into the lungs. Examples of animation restored by artificial respiration, in drowning etc., are evidence of this fact. In cases of asphyxia, those measures by which artificial respiration is most effectually maintained have been found most efficient.

Cause of the Rhythmical Contractions of the Heart.

The question of the actual cause of the rhythmical contractions of the heart is one of great importance and has long engaged the attention of physiologists. While researches have resulted in much positive information with regard to influences which regulate or modify this action, there seems to be little known, even now, concerning the main question, why the fibres of the heart, unlike the ordinary muscular fibres, seem to contract spontaneously.

The heart in its structure resembles the voluntary muscles; but it has a constant office to perform and seems to act without any palpable excitation, while the latter act only under the influence of a natural stimulus, like the nervous impulse, or under artificial excitation. The movements of the heart are not the only examples of what seems to be spontaneous action. The ciliated epithelium is in motion from the beginning to the end of life, and will continue for a certain time, even after the cells are detached from the organism. This motion can not be explained, unless it be called an explanation to say that it is dependent upon vital properties; but if the actual cause of the rhythmical contraction of the heart be unknown, physiologists are acquainted with certain influences which render its action regular, powerful and sufficient for the purposes of the economy.

The action of the heart is involuntary. Its pulsations can be neither arrested, retarded nor accelerated by an effort of the will, excepting, of course, examples of arrest by stoppage of respiration or acceleration by violent muscular exercise etc. In this respect the heart differs from certain muscles, like the muscles of respiration, which act automatically, but the movements of which may be temporarily arrested or accelerated by a direct voluntary effort. The last-mentioned fact illustrates the difference between the heart and all other striated muscles. All of them, in order to contract, must receive a stimulus, either natural or artificial. The natural stimulus comes from the nerve-centres and is conducted by the nerves. If the nerves going to any of the respiratory muscles, for example, be divided, the muscle is paralyzed and will not contract without some kind of stimulation. Connection with the central nervous system does not seem necessary to the action of the heart, for it will contract, especially in the cold-blooded animals, some time after its removal from the body. If the supply of blood be cut off from the substance of the heart, especially in the warm-blooded animals, the organ soon loses its contractility.

Erichsen, after exposing the heart in a warm-blooded animal and keeping up artificial respiration, tied the coronary arteries, thus cutting off the greatest part of the supply of blood to the muscular fibres. He found, as the mean of six experiments, that the heart ceased pulsating, although artificial respiration was continued, in twenty-three and a half minutes. After the pulsations had ceased, they could be restored by removing the ligatures and allowing the blood to circulate again in the substance of the heart.

The regular and powerful contractions of the heart are promoted by the circulation of the blood through its cavities. Although the heart, removed from the body, will contract for a time without a stimulus, it can be made to contract during the intervals of repose by an irritant, such as the point of a needle or a feeble electric current. For a certain time after the heart has ceased to contract spontaneously, contractions may be produced in this way. This can easily be demonstrated in the heart of any animal, warm-blooded or cold-blooded. This excitability, which is manifested, under these conditions, in the same way as in ordinary muscles, is different in degree in different parts of the organ. Haller and others have shown that it is greater in the cavities than on the surface; for long after stimulation applied to the exterior fails to excite contraction, the organ will respond to a stimulus applied to its interior. The experiments of Haller also show that fluids in the cavities of the heart have an influence in exciting and keeping up its contractions. This observation is important, as showing that the presence of blood is necessary to the natural and regular action of the heart. Schiff succeeded in restoring the pulsations in the heart of a frog, which had ceased after it had been emptied, by introducing a few drops of blood into the auricle. Experiments upon alligators and turtles show that when the heart is removed from the body and emptied of blood, the pulsations are feeble, rapid and irregular; but when filled with blood, the valves being destroyed so as to allow free passage in both directions between the auricles and ventricle, the contractions become powerful and regular. In these experiments, when water was introduced instead of blood, the pulsations were more frequent and not so powerful as when blood was used (Flint, 1861). These experiments show, also, that the action of the heart may be affected by the character, particularly the density, of the fluid which passes through its cavities, which may ex-