plain its rapid and feeble action in certain cases of anæmia. The heart, therefore, although capable of independent action, is excited to contraction by the blood as it passes through its cavities. A glance at the succession of its movements, particularly in cold-blooded animals—in which they are so slow that the phenomena can be easily observed—will show how these contractions are produced. There is first a distention of the auricle, and this is immediately followed by a contraction filling the ventricle, which in its turn contracts. Undoubtedly, the tension of the fibres, as well as the contact of blood in its interior, acts as a stimulus; and as all the fibres of each cavity are put on the stretch at the same instant, they contract simultaneously. The successive and regular distention of each cavity thus produces rhythmical and forcible contractions; and the mere fact that the action of the heart alternately empties and dilates its cavities insures regular pulsations, so long as blood is supplied and no disturbing influences are in operation.

The intermittent contraction and successive action of the fibres of the heart, when the organ has been removed from the body, are dependent, to a great extent, upon sympathetic ganglia situated near its base. If the ventricle of a frog's heart be divided transversely at the upper third, the lower two-thirds will no longer contract spontaneously, while the auricles and the upper third of the ventricle continue to pulsate. If a stimulus be then applied to the lower two-thirds of the ventricle, this is usually followed by a single contraction, and not by a series of more or less regular pulsations. It has been observed, also, that small, detached pieces of the auricles will pulsate regularly for a time.

In the frog there are three ganglia closely connected with the heart; one at an expansion of the inferior vena cava just before it enters the auricle, called the venous sinus (Remak), another between the left auricle and the ventricle (Bidder), and a third between the two auricles (Ludwig). According to Robert Meade Smith, the first two ganglia communicate the motor impulse to the muscular fibres of the heart. The third is the inhibitory ganglion, and this regulates, through its action upon the motor ganglia, the transmission of motor impulses. "As regards the manner in which these ganglia produce the *rhythmical* contraction of the heart, little is known; but that they are the prime factors in producing not only the rhythm of the cardiac revolutions, with its various modifications, but also the starting point of each individual contraction, is one of the best established facts in physiology."

In man and in most warm-blooded animals, collections of sympathetic ganglia are found attached to the nerves at the line of junction of the auricles with the ventricles.

Nearly all of the experiments just referred to were made upon the hearts of cold-blooded animals, particularly the frog; but in all animals, under normal conditions, the contractions of the heart seem to start from the auricles. The fact, however, that the ventricles will contract regularly in a living animal, after the excitability of the auricles has been exhausted by

repeated stimulations and they have ceased to pulsate, shows that the so-called pulsating wave coming from the auricles is not absolutely essential to the contraction of the ventricles.

Finally, in view especially of the results of experiments upon the cold-blooded animals, it may be stated that the muscular fibres of the auricles and of the upper third of the ventricles have the property of intermittent and regular contraction, which is dependent, to a great extent, upon the influence of the so-called motor ganglia of the heart; and that the wave of contraction is transmitted to the lower two-thirds of the ventricles, the fibres of which do not seem to possess the property of independent contraction. The muscular tissue of the heart, however, may be thrown into contraction during diastole by the application of a stimulus, a property which is observed in all musular fibres. The excitability manifested in this way is much more marked in the interior than on the exterior of the organ. Blood in contact with the lining membrane of the heart acts as a stimulus in a remarkable degree and is even capable of restoring excitability after it has become extinct. The passage of blood through the heart is the natural stimulus of the organ and is an important element in the production of regular pulsations, although it by no means endows the fibres with their contractile properties.

Accelerator Nerves.—Experiments on the influence of the sympathetic nerves upon the heart have not been entirely satisfactory. It has been observed that the action of the heart is immediately arrested by destroying the cardiac plexus; but with regard to this, the difficulty of making the operation and the disturbance of the heart consequent upon the necessary manipulations must be taken into account. It has been shown, however, that stimulation of the sympathetic in the neck has the effect of accelerating the cardiac movements.

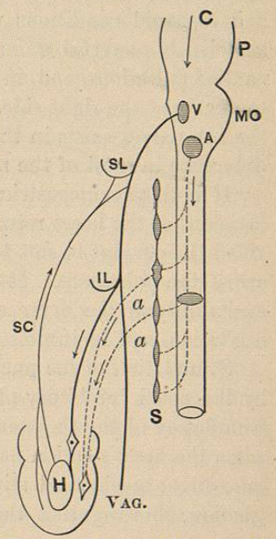

FIG. 22.—*Scheme of the course of the accelerans fibres* (Stirling).
P, pons; MO, medulla oblongata; V, inhibitory centre for the heart; A, accelerans centre; VAG., vagus; SL, superior, IL, inferior laryngeal; SC, superior cardiac; H, heart; C, cerebral impulse; S, cervical sympathetic; *a*, *a*, accelerans fibres.

According to Stricker, there exists in the medulla oblongata a centre, stimulation of which increases the rapidity of the heart's action; and from this centre, fibres descend in the substance of the spinal cord, pass out with the communicating branches of the lower cervical and upper dorsal nerves to the sympathetic, and go to the cardiac plexus. In the cat, the accelerator fibres pass through the first thoracic sympathetic ganglion. Taking all precautions to eliminate the influence of variations in the blood pressure, it has been shown that after division of the pneumogastric, stimulation of the accelerator fibres increases the number of beats of the heart. This action is direct and not reflex.

Direct Inhibition of the Heart.—Division of the pneumogastric nerves in the neck increases the frequency and diminishes the force of the contractions of the heart. To anticipate a little of the history of the pneumogastric nerves, it may be stated that while they are exclusively sensory at their origin, they receive, after having emerged from the cranial cavity, a number of filaments from various motor nerves. That they influence certain muscles, is shown by the paralysis of these muscles after division of the nerves in the neck, as, for example, the arrest of the movements of the glottis.

A moderate Faradic current passed through both pneumogastrics arrests the action of the heart in diastole (Ed. Weber). This observation has been made upon living animals, both with and without exposure of the heart; and this kind of action is known as inhibitory, or restraining. Its nervous mechanism is direct and not reflex; and the inhibitory influence is conveyed to the heart through filaments in the pneumogastric which are derived from the spinal accessory.

It is said that direct stimulation of the medulla oblongata will have the same effect upon the heart as stimulation of the pneumogastrics; but it must be very difficult to limit the stimulation to a particular point in the medulla and to avoid conditions which would complicate such an experiment. A sufficiently powerful stimulus applied to one pneumogastric will arrest the cardiac pulsations, and in some animals the inhibitory action is confined to the nerve of the right side. It is not known that any such difference between the two nerves exists in the human subject, and certainly there is no marked difference in most of the mammalia.

If both pneumogastrics be Faradized for two or three minutes, the contractions of the heart return, even though the stimulation be continued, provided the current be not too powerful but of sufficient strength to promptly arrest the pulsations. It is probable that this is due to the fact that the excitability of the nerve after a time becomes exhausted by the prolonged excitation, and its inhibitory influence is for the time destroyed.

Stimulation of the pneumogastrics in any part of their course is followed by the usual inhibitory phenomena, and the same results sometimes follow stimulation of the thoracic cardiac branches. It has also been observed that when the heart's action has been arrested and the organ is quiescent in diastole, direct mechanical stimulation of the heart is followed by a single contraction, showing that the excitability of the fibres has not been entirely suspended.

After section of both pneumogastrics in the neck, digitalis fails to diminish the number of beats of the heart (Traube); showing that separation of the heart from its connections with the cerebro-spinal nerves removes the organ from the characteristic and peculiar effects of the poison.

Feeble stimulation of one or both pneumogastrics, when it produces any effect, almost always slows the action of the heart. In some animals, however, the pneumogastrics contain a few accelerator fibres, and feeble excitation sometimes is followed by a slight increase in the rapidity of the cardiac pulsations, but this is unusual.

Reflex Inhibition of the Heart.—Like most of the direct operations of nerves that can be imitated by electric stimulation, the inhibitory action of the pneumogastrics can be produced by reflex action. The action of the heart may be arrested in the frog by sharply tapping the exposed intestines (Goltz). The same effect has been produced by stimulation of the splanchnic nerves or the cervical sympathetic. In some animals, if one pneumogastric be divided in the neck, the other being left intact, stimulation of the central end of the divided nerve will produce inhibition of the heart, by an action induced in the undivided nerve. In all of these instances, the inhibition is reflex. The stimulation is carried by the afferent fibres of the nerves stimulated, to the inhibitory centre in the medulla oblongata, and is reflected to the heart through the efferent fibres of the pneumogastric.

While moderate stimulation of ordinary sensory nerves is sometimes followed by inhibition of the heart, very powerful stimulation arrests the cardio-inhibitory action of the pneumogastrics, as well as certain other reflexes.

The inhibitory fibres of the pneumogastrics undoubtedly have an important office in connection with the regulation of the rapidity and force of the cardiac pulsations. It is important, of course, that the heart should act at all times with nearly the same force and frequency. It has been seen that the inherent properties of its fibres and the action, probably, of the cardiac ganglia are competent to make it contract, and the necessary intermittent dilatation of its cavities makes these contractions assume a certain regularity; but the quantity and density of the blood are subject to very considerable variations within the limits of health, which, without some regulating influence, would undoubtedly cause variations in the heart's action, so considerable as to be injurious. This is shown by the palpitating and irregular action of the heart when the pneumogastrics have been divided. These nerves convey to the heart a constant influence, which may be compared to the insensible tonicity imparted to voluntary muscles by the general motor system. When a set of muscles on one side is paralyzed, as in facial palsy, their tonicity is lost, they become flaccid, and the muscles on the other side, without any effort of the will, distort the features. An exaggeration of this force may be imitated by a feeble Faradic current, which renders the pulsations of the heart less frequent and more powerful, or it may be still farther exaggerated by a more powerful current, which arrests the action of the heart. Phemonena are not wanting in the human subject to verify these views. Causes which operate through the nervous system frequently produce palpitation and irregular action of the heart. Cases are not uncommon in which palpitation habitually occurs after a full meal. There are instances on record of death from arrest of the heart's action as a consequence of fright, anger, grief or other severe mental emotions. Syncope from these causes is by no means uncommon. In the latter instance, when the heart resumes its contractions, the nervous shock carried along the pneumogastrics is only sufficient to arrest its action temporarily. When death takes place, the shock is so great that the heart never recovers from its effects.

Summary of Certain Causes of Arrest of the Action of the Heart.

In warm-blooded animals, the heart's action speedily ceases after the organ is deprived of its natural stimulus, the blood. Proof of this is not derived alone from experiments on the inferior animals. It is well known that in profuse hæmorrhage in the human subject, the contractions of the heart are progressively enfeebled, and when the loss of blood has proceeded to a certain extent, are permanently arrested. Cases of transfusion after hæmorrhage show that when blood is introduced the heart may be made to resume its pulsations. The same result takes place in death by asthenia; and cases are on record in which life has been prolonged, as in hæmorrhage, by transfusion of even a small quantity of healthy blood. These facts have been demonstrated on the inferior animals by experiments already cited. The experiment of Haller, in which the action of the right side of the heart of a cat was arrested by emptying it of blood, while the left side, which was filled with blood, continued to pulsate, showed that the absence of blood is competent of itself to arrest contractions of the heart. The experiments of Erichsen, who paralyzed the heart by tying the coronary arteries, and of Schiff, who produced a local paralysis by tying the vessel going to the right ventricle, show that the action of the heart may also be arrested by cutting off the circulation of blood in its substance. Both of these causes must operate in arrest of the heart's action in hæmorrhage.

The mechanical causes of arrest of the heart's action are of considerable pathological importance. The heart, in common with other muscles, may be paralyzed by mechanical injury. A violent blow upon the deltoid paralyzes the arm; a severe strain will paralyze the muscles of an extremity; and in the same way, excessive distention of the cavities of the heart will arrest its pulsations. This is shown by arrest of the circulation in asphyxia; which is due to the fact that the heart is incapable of forcing the unaërated blood through the systemic capillaries. The heart, in asphyxia, finally becomes enormously strained and distended and is consequently paralyzed. The same result follows the application of a ligature to the aorta. This effect may be produced also, in the cold-blooded animals, in which, if the heart be left undisturbed, the pulsations will continue for a long time. The following experiment illustrating this point was performed upon the heart of a large alligator :

The animal was poisoned with curare, and twenty-eight hours after death the heart, which had been exposed and left *in situ*, was pulsating regularly. It was then removed from the body, and after some experiments on the comparative force, etc., of the pulsations when empty and when filled with blood, was filled with water, the valves having been destroyed so as to allow free passage of the fluid through the cavities, and the vessels were tied. The ventricles, still filled with water confined in their cavity, were then firmly compressed with the hand. From that time, the heart entirely ceased its contractions and became hard like a muscle in a state of cadaveric rigidity.

This experiment shows how completely and promptly the heart, even of a cold-blooded animal, may be arrested in its action by mechanical injury (Flint, 1861).

Cases of death from engorgement of the heart are not unusual in practice; and the form of organic disease which most frequently leads to sudden death is that in which the heart is liable to great distention. In other lesions there is not this tendency; but when the aortic orifice is contracted or the valves are insufficient, any great disturbance of the circulation will cause the heart to become engorged, which is liable to produce a fatal result.

Most persons are practically familiar with the distressing sense of suffocation which frequently follows a blow upon the epigastrium; and a few cases are on record of instantaneous death following a comparatively slight concussion in this region. Although these cases are rare, they are well recognized, and the effects are generally attributed to injury of the solar plexus. The distress is precisely what would occur from sudden arrest of the heart's action. It is the blood charged with oxygen which supplies the wants of the tissues, and not the simple entrance of air into the lungs; and arrest of the circulation of arterial blood, from any cause, produces suffocation as completely as though the trachea were tied. It is a question whether the arrest of the heart, if this be the pathological condition, be due to concussion of the nervous centre or to the direct effects of the blow upon the organ itself. Present data do not afford a definite answer to this question, but they sustain, to a certain extent, the opinion that in such accidents, the symptoms are due to direct injury of the heart. An additional argument in favor of this view is founded on what is known of the mode of operation of the sympathetic system. The effects of stimulation or irritation of this system are not instantaneously manifested, as is the case in the cerebro-spinal system, but are developed slowly and gradually.

As far as the results of experiments are concerned, the nervous influences which arrest the action of the heart seem to operate through the pneumogastrics and are derived from the spinal accessory nerves. This action can be closely imitated by electricity. The causes of arrest in this way are many and varied. Among them may be mentioned, sudden and severe bodily pain and severe mental emotions. With the exception of arrest of the heart's action from loss of blood and from distention, from whatever cause it may occur, stoppage of the heart takes place from influences operating through the nervous system. It may be temporary, as in syncope, or it may be permanent; and examples of the latter, though rare, are sufficiently well authenticated.

In an animal just killed, as the pulsations of the heart become slower and slower until they are finally arrested, it is constantly observed that the auricular appendage on the right side continues to contract for some time after the other portions of the heart have ceased their action.