This action occurs in whispering and it can not properly be called vocal. It is difficult to make any considerable variations in the pitch of a whisper, and articulation in this way may be produced in inspiration as well as in expiration, although the act in expiration is more natural and easy. The character of a whisper may be readily distinguished from that of the faintest audible sound involving vibration of the vocal chords. In aphonia from simple paralysis of the vocal muscles of the larynx, patients can articulate distinctly in whispering; but in cases of chronic bulbar paralysis (glosso-labio-laryngeal paralysis), speech is entirely lost.

The Phonograph.—In 1877, a remarkable invention was made in this country, by Mr. Thomas A. Edison, which possesses considerable physiological importance. Mr. Edison constructed a very simple instrument, called the phonograph, which will repeat, with a certain degree of accuracy, the peculiar characters of the human voice both in speaking and singing, as well as the pitch and quality of musical instruments. This demonstrates conclusively the fact that the qualities of vocal sounds depend upon the form of the sonorous vibrations. The following are the main features in the construction of this instrument: It consists of a cylinder of iron provided with very fine, shallow grooves in the form of an exceedingly close spiral. Upon the cylinder, a sheet of tin-foil is accurately fitted. Bearing upon the tin-foil, is a steel-point connected with a vibrating plate of mica or of thin iron. The vibrating plate is connected with a mouth-piece which receives the vibrations of the voice or of a musical instrument. The cylinder is turned with a crank, and at the same time, the plate is thrown into vibration by speaking into the mouth-piece. As the disk vibrates in consonance with the voice, the vibrations are marked by little indentations upon the tin-foil. When this has been done, the cylinder is moved back to the starting point and is turned again at the same rate as before. As the steel-point passes over the indentations in the tin-foil, the plate is thrown into vibration, and the sound of the voice is actually repeated, although much diminished in intensity and distinctness. The improvements that have lately been made in the phonograph do not involve any modifications in the principles of its construction.

CHAPTER XVI.

PHYSIOLOGICAL DIVISIONS, STRUCTURE AND GENERAL PROPERTIES OF THE NERVOUS SYSTEM.

Divisions and structure of the nervous tissue—Medullated nerve-fibres—Simple, or non-medullated nerve-fibres—Gelatinous nerve-fibres (fibres of Remak)—Accessory anatomical elements of the nerves—Termination of the nerves in the muscular tissue—Termination of the nerves in glands—Modes of termination of the sensory nerves—Corpuscles of Vater, or of Pacini—Tactile corpuscles—End-bulbs—Structure of the nerve-centres—Nerve-cells—Connection of the cells with the fibres and with each other—Accessory anatomical elements of the nerve-centres—Composition of the nervous substance—Degeneration and regeneration of the nerves—Motor and sensory nerves—Mode of action of the motor nerves—Associated movements—Mode of action of the sensory nerves—Physiological differences between motor and sensory nerve-fibres—Nervous excitability—Different means employed for exciting the nerves—Rapidity of nervous conduction—Personal equation—Action of electricity upon the nerves—Law of contraction—Induced muscular contraction—Electrotonus, anelectrotonus and catelectrotonus—Negative variation.

THE nervous system is anatomically and physiologically distinct from all other systems and organs in the body. It receives impressions made upon the terminal branches of its sensory portion and it conveys stimulus to parts, determining and regulating their actions; but its physiological properties are inherent, and it gives to no tissue or organ its special excitability or the power of performing its particular office in the economy. The nervous system connects into a co-ordinated organism all parts of the body. It is the medium through which all impressions are received. It animates or regulates all movements, voluntary and involuntary. It regulates secretion, nutrition, calorification and all the processes of organic life.

In addition to its action as a medium of conduction and communication, the nervous system, in certain of its parts, is capable of receiving impressions and of generating a stimulating influence, or force, peculiar to itself. As there can be no physiological connection or co-ordination of different parts of the organism without nerves, there can be no unconscious reception of impressions giving rise to involuntary movements, no appreciation of impressions, general, as in ordinary sensation, or special, as in sight, smell, taste or hearing, no instinct, volition, thought or even knowledge of existence, without nerve-centres.

DIVISIONS AND STRUCTURE OF THE NERVOUS TISSUE.

The nervous tissue presents two great divisions, each with distinct anatomical as well as physiological differences. One of these divisions is composed of fibres or tubes. This kind of nervous matter is incapable of generating a force or stimulus, and it serves only as a conductor. The other division is composed of cells, and this kind of nervous matter, while it may act as a conductor, is capable of generating the so-called nerve-force.

The nerve-fibres and cells are also divided into two great systems, as follows:

1. The cerebro-spinal system, composed of the brain and spinal cord with the nerves directly connected with these centres. This system is specially connected with the functions of relation, or of animal life. The centres pre-

side over general sensation, the special senses, voluntary and some involuntary movements, intellection, and, in short, all of the functions that characterize the animal. The nerves serve as the conductors of impressions known as general or special sensations and of the stimulus that gives rise to voluntary and certain involuntary movements, the latter being the automatic movements connected with animal life.

2. The sympathetic, or organic system. This system is specially connected with the functions relating to nutrition, operations which have their analogue in the vegetable kingdom and are sometimes called the functions of vegetative life. Although this system presides over functions entirely distinct from those characteristic of and peculiar to animals, the centres of this system all have an anatomical and physiological connection with the cerebro-spinal nerves.

The cerebro-spinal system is subdivided into centres presiding over movements and ordinary sensation, and centres capable of receiving impressions connected with the special senses, such as sight, audition, olfaction and gustation. The nerves which receive these special impressions and convey them to the appropriate centres are more or less insensible to ordinary impressions. The organs to which these special nerves are distributed are generally of a complex and peculiar structure, and they present accessory parts which are important and essential in the transmission of the special impressions to the terminal branches of the nerves.

The physiological division of the nervous system into nerves and nerve-centres is carried out as regards the anatomical structure of these parts. The two great divisions of the system, anatomically considered, are into nerve-cells and nerve-fibres.

The cells of the nerve-centres, while they may transmit impressions and impulses, are the only parts capable, under any circumstances, of generating the nerve-force; and as a rule, they do not receive impressions in any other way than through the nerve-fibres. There are, however, many exceptions to this rule, as in the case of movements following direct stimulation of the sympathetic ganglia and certain centres in the brain and spinal cord; but the cells of many of the ganglia belonging to the cerebro-spinal axis are insensible to direct stimulation and can receive only impressions conducted to them by the nerves.

The nerve-fibres act only as conductors and are incapable of generating nerve-force. There is no exception to this rule, but there are differences in the properties of certain fibres. The nerves generally, for example, receive direct impressions, the motor filaments conducting these to the muscles and the sensory filaments conveying the impressions to the centres. These fibres also conduct the force generated by the nerve-centres; but there are many fibres, such as those composing the white matter of the encephalon and the spinal cord, that are insensible to direct irritation, while they convey to the centres impressions conveyed to them by sensory nerves and conduct to the motor nerves the stimulus generated by nerve-cells.

In the most natural classification of the nerve-fibres, they are divided into

two groups; one embracing those fibres which have the conducting element alone, and the other presenting this anatomical element surrounded by certain accessory structures. In the course of the nerves, the simple fibres are the exception, and the other variety is the rule; but as the nerves are followed to their terminations in muscles or sensitive parts or are traced to their origin in the nerve-centres, they lose one or another of their coverings. These two varieties are designated as medullated and non-medullated fibres.

Medullated Nerve-fibres.—These fibres are so called because, in addition to the axis-cylinder, or conducting element, they contain, enclosed in a tubular sheath, a soft substance called medulla. This substance is strongly refractive and gives the nerves a peculiar appearance under the microscope, from which they are sometimes called dark-bordered nerve-fibres. As the whole substance of the fibre is enclosed in a tubular membrane, these are frequently called nerve-tubes.

If the nerves be examined while perfectly fresh and unchanged, their anatomical elements appear in the form of simple fibres with strongly accentuated borders. The diameter of these fibres is $\frac{1}{2500}$ to $\frac{1}{1700}$ of an inch (10 to 15 μ). In a very short time the borders become darker and the fibres assume an entirely different appearance. By the use of certain reagents, it can be demonstrated that a medullated nerve-fibre is composed of three distinct portions; viz., a homogeneous sheath, a semi-fluid matter contained in the sheath, and a delicate, central band.

The tubular sheath of the nerve-fibres, the neurilemma, is a somewhat elastic, homogeneous membrane, never striated or fibrillated, and generally presenting oval nuclei with their long diameter in the direction of the tube. This is sometimes called the sheath of Schwann. In its chemical and general properties this membrane resembles the sarcolemma, although it is less elastic and resisting. It exists in all the medullated nerve-fibres, large and small, except those in the white portions of the encephalon and spinal cord. It is not certain that it does not exist in the small, non-medullated fibres, although its presence here has never been satisfactorily demonstrated.

The medullary substance fills the tube and surrounds the central band. This is called by various names, as myeline, white substance of Schwann, medullary sheath, nervous medulla etc. It does not exist either at the origin of the nerves in the gray substance of the nerve-centres or at the peripheral termination of the nerves, and it is probably not an essential conducting element. When the nerves are perfectly fresh, this substance is transparent, homogeneous, and strongly refracting, like oil; but as the nerves become altered by desiccation, the action of water, acetic acid and various other reagents, it coagulates into an opaque, granular mass. In the white substance of the encephalon and spinal cord, the neurilemma is wanting and the fibres present only the axis-cylinder surrounded with the white substance of Schwann. As a post-mortem condition, these fibres present, under the microscope, varicosities at irregular intervals, which give them a peculiar and characteristic appearance.

The medullated nerve-fibres do not have regular outlines, but present constrictions at various points in their length, called the constrictions or nodes of Ranvier. At these nodes the medullary substance is wanting and the neurilemma is in contact with the axis-cylinder. It is at these points that the transverse lines of Fromann, produced by the action of silver nitrate upon the axis-cylinder, are particularly prominent.

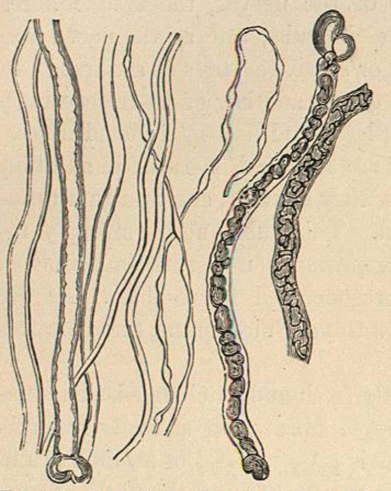

Fig. 172.—*Nerve-fibres from the human subject; magnified* 350 *diameters* (Kölliker).

Four small fibres of which two are varicose, one medium-sized fibre with borders of single contour, and four large fibres. Of the latter, two have a double contour, and two contain granular matter.

When a medullated nerve-fibre is slightly stretched, a number of oblique cuts are observed running across the fibre and extending to the axis-cylinder, called incisures. These involve the medullary substance only, and are best observed when this substance has been stained with osmic acid. It is not known that they possess any physiological importance.

The axis-cylinder, which occupies one-fifth to one-fourth of the diameter of the nerve-tube, is probably the conducting portion of the nerve. In the ordinary medullated fibres, the axis-cylinder can not be seen in the natural condition, because it refracts in the same manner as the medullary substance; and it can not easily be demonstrated afterward, on account of the opacity of the coagulated matter. If a fresh nerve, however, be treated with strong acetic acid, the divided ends of the fibres retract, leaving the axis-cylinder, which latter is but slightly affected by reagents. It then presents itself in the form of a pale, slightly flattened band, with outlines tolerably regular, though slightly varicose at intervals. It is somewhat granular and very finely striated in a longitudinal direction. This band is elastic but not very resisting. What serves to distinguish it from all other portions of the nerve-fibre is its insolubility in most of the reagents employed in anatomical investigations. It is slightly swollen by acetic acid but is dissolved after prolonged boiling. If nerve-tissue be treated with a solution of carmine, the axis-cylinder only is colored. It has been observed that the nerve-fibres treated with silver nitrate present in the axis-cylinder well marked, transverse striations (Fromann); and some anatomists regard both the nerve-cells and the axes of the fibres as composed of two substances, the limits of which are marked by the regular striæ thus developed. This, however, is a point of purely anatomical interest. The presence of regular and well marked striæ in the axis-cylinder after the addition of a solution of silver nitrate and the action of light can not be doubted; but it has not yet been determined whether these markings be entirely artificial or whether the axis-cylinder be really composed of two kinds of substance.

For some time it has been known that the axis-cylinders in the organs of special sense, in the final distribution of sensory nerves and in some other

situations, break up into fibrillæ. A fibrillated appearance, indeed, is often observed in nerves in their course, and it is now the general opinion that the axis-cylinders are composed of fibrillæ held closely together by connective substance. This fibrillated structure of the nerves is quite prominent in some of the lower orders of animals.

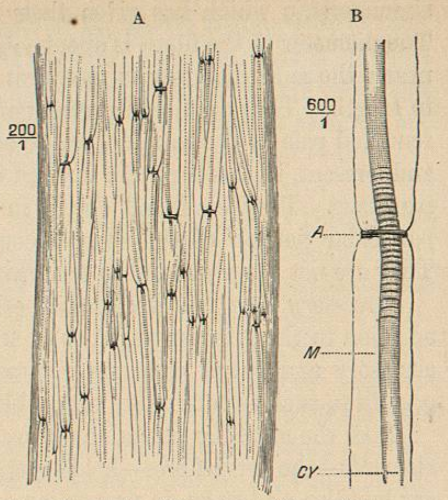

Fig. 173.—*Nodes of Ranvier and lines of Fromann* (Ranvier).

A. Intercostal nerve of the mouse, treated with silver nitrate.

B. Nerve-fibre from the sciatic nerve of a full-grown rabbit. A, node of Ranvier; M, medullary substance rendered transparent by the action of glycerine; CY, axis-cylinder presenting the lines of Fromann, which are very distinct near the node. The lines are less marked at a distance from the node.

The various appearances which the nerve-fibres present under different conditions are represented in Figs. 172 and 173.

Non-medullated Nerve-Fibres.—These fibres, which are largely distributed in the nervous system, appear to be simple prolongations, without alteration, of the axis-cylinders of the medullated fibres. They are found chiefly in the peripheral terminations of the nerves and in the filaments of origin of the fibres from the nerve-cells. Some anatomists think that they have a delicate investing membrane, but this has not been satisfactorily demonstrated.

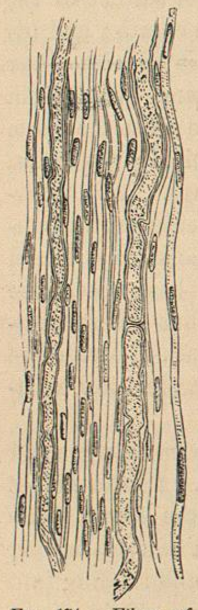

Fig. 174.—*Fibres of Remak; magnified* 300 *diameters* (Robin).

With the gelatinous fibres of Remak, are seen two of the ordinary, dark-bordered nerve-fibres.

Gelatinous Nerve-Fibres (*Fibres of Remak*).—There has been some difference of opinion with regard to the physiology of the so-called gelatinous nerve-fibres. Some anatomists have regarded them simply as elements of connective tissue, and others have described them as axis-cylinders surrounded with a nucleated sheath; but the fibres do not present the lines of Fromann when treated with silver nitrate. While elements of connective tissue may have been mistaken for true nerve-fibres, there are in the nerves, particularly in those belonging to the sympathetic system, fibres resembling the nerve-fibres of the embryon. These are the true, gelatinous nerve-fibres, or fibres of Remak. All the nerves have this structure until about the fifth month of intraüterine life, and in the regeneration of nerves after division or injury, the new elements usually assume this form before they arrive at their full development.

The true, gelatinous nerve-fibres present the following characters: They are flattened, with regular and sharp borders, grayish, pale and always fibrillated, with very fine granulations, and a number of oval, longitudinal nuclei, a characteristic which has given them the name of nucleated nerve-fibres. The diameter of the fibres is about $\frac{1}{8000}$ of an inch (3 μ). The nuclei have nearly the same diameter as the fibres and are about $\frac{1}{1250}$ of an inch (20 μ) in length. They are finely granular and present no nucleoli. The fibres are rendered pale by the action of acetic acid, but they are slightly swollen only, and present, in this regard, a marked contrast with the elements of connective tissue. They are found chiefly in the sympathetic system and in that particular portion of this system connected with involuntary movements. They are not usually found in the white filaments of the sympathetic.

Accessory Anatomical Elements of the Nerves.—The nerves present, in addition to the different varieties of true nerve-fibres just described, certain accessory anatomical elements common to nearly all of the tissues of the organism, such as connective tissue, blood-vessels and lymphatics.

Like the muscular tissue, the nerves are made up of their true anatomical elements—the nerve-fibres—held together into primitive, secondary and tertiary bundles, and so on, in proportion to the size of the nerve. The primitive fasciculi are surrounded with a delicate membrane, described by Robin, under the name of *périnèvre*, but which had been already noted by other anatomists, under different names, and is now frequently called the sheath of Henle. This membrane is homogeneous or very finely granular, sometimes marked with longitudinal striæ, and possessing elongated, granular nuclei. According to Ranvier, there are three kinds of nuclei either attached to or situated near the sheath. These are (1) nuclei attached to the inner surface of the sheath; (2) nuclei belonging to the nerve-fibres within the sheath; and (3) nuclei of connective-tissue elements near the sheath. Treated with silver nitrate, the sheath presents the borders of a lining endothelium. The sheath of Henle begins at the point where the nerve-fibres emerge from the white portion of the nervous centres, and it extends to their terminal extremities, being interrupted by the ganglia in the course of the nerves. This membrane generally envelops a primitive fasciculus of fibres, branching as the bundles divide and pass from one trunk to another, and is sometimes found surrounding single fibres. It usually is not penetrated by blood-vessels, the smallest capillaries of the nerves ramifying in its substance but seldom passing through to the individual nerve-fibres. Within the sheath of Henle are sometimes found elements of connective tissue, with very rarely a few capillary blood-vessels in the largest fasciculi.

The quantity of fibrous tissue in the different nerves is very variable and depends upon the conditions to which they are subjected. In the nerves within the bony cavities, where they are entirely protected, the fibrous tissue is very scanty; but in the nerves between muscles, there is a tolerably strong investing membrane or sheath surrounding the whole nerve and sending into its interior processes which envelop smaller bundles of fibres. This sheath is formed of ordinary fibrous tissue, with small elastic fibres and nucleated connective-tissue cells. These latter may be distinguished from the gelatinous nerve-fibres by the action of acetic acid, which swells and finally dissolves them, while the nerve-fibres are but slightly affected.

The greatest part of the fibrous sheath of the nerves is composed of bundles of white inelastic tissue, interlacing in every direction; but it contains also many elastic fibres, adipose tissue, a net-work of arteries and veins, and "nervi nervorum," which are to these structures what the vasa vasorum are to the blood-vessels. The adipose tissue is constant, being found even in extremely emaciated persons (Sappey).

The vascular supply to most of the nerves is rather scanty. The arteries break up into a plexus of very fine capillaries, arranged in oblong, longitudinal meshes surrounding the fasciculi of fibres; but they rarely penetrate the sheath of Henle, and they do not usually come in contact with the ultimate nervous elements. The veins are rather more voluminous and follow the arrangement of the arteries. Lymph-spaces, lined by delicate endothelium, are found in the connective-tissue sheaths of the bundles of fibres.

Branching and Course of the Nerves.—The ultimate nerve-fibres in the course of the nerves have no connection with each other by branching or inosculation. A bundle of fibres frequently sends branches to other nerves and receives branches in the same way; but this is simply the passage of fibres from one sheath to another, the ultimate fibres themselves maintaining throughout their course their individual physiological properties. The nerve-fibres do not branch or inosculate except near their termination. When there is branching of medullated fibres, it is always at the site of one of the nodes of Ranvier. The branching and inosculation of the ultimate nerve-fibres will be fully described in connection with their final distribution to muscles and sensitive parts.

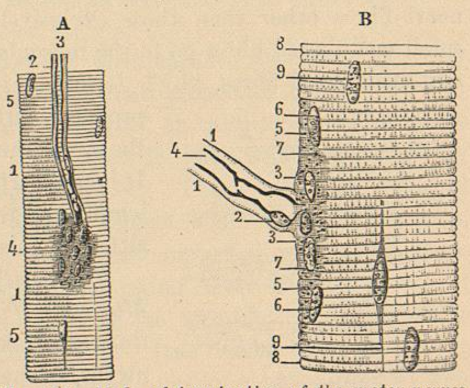

FIG. 175.—*Mode of termination of the motor nerves* (Rouget).

A, primitive fasciculus of the thyro-hyoid muscle of the human subject, and its nerve-tube: 1, 1, primitive muscular fasciculus; 2, nerve-tube; 3, medullary substance of the tube, which is seen extending to the terminal plate, where it disappears; 4, terminal plate situated beneath the sarcolemma, that is to say, between it and the elementary fibrillæ; 5, 5, sarcolemma.

B, primitive fasciculus of the intercostal muscle of the lizard, in which a nerve-tube terminates: 1, 1, sheath of the nerve-tube; 2, nucleus of the sheath; 3, 3, sarcolemma becoming continuous with the sheath; 4, medullary substance of the nerve-tube, ceasing abruptly at the site of the terminal plate; 5, 5, terminal plate; 6, 6, nuclei of the plate; 7, 7, granular substance which forms the principal element of the terminal plate and which is continuous with the axis-cylinder; 8, 8, undulations of the sarcolemma reproducing those of the fibrillæ; 9, 9, nuclei of the sarcolemma.

Termination of Nerves in Voluntary Muscles.—The mode of termination of motor nerves in voluntary muscles was indicated by Doyère, in 1840, was quite fully described by Rouget, in 1862, and has since been studied by anatomists, who have extended and elaborated these researches. It is the general opinion that but one nerve-ending exists in each muscular fibre in the mammalia, while several exist in cold-blooded animals. In man and in the warm-blooded animals generally, the medullated nerve-fibres divide dichotomously near their endings in the muscular fibres, each division always taking place at a node of Ranvier. The fibres finally resulting from these divisions pass to the sarcolemma and terminate in a rather prominent mass called an end-plate, with six to twelve or sometimes sixteen nuclei which are distinct from the nuclei of the muscular fibre. The tubular membrane of the nerve-fibre here fuses with the sarcolemma (Rouget) and the medullary substance is lost. By the action of gold chloride, it has been shown that fibrils arise from the under surface of the end-plates, which pass into the substance of the muscular fibres, between the muscular fibrillæ.

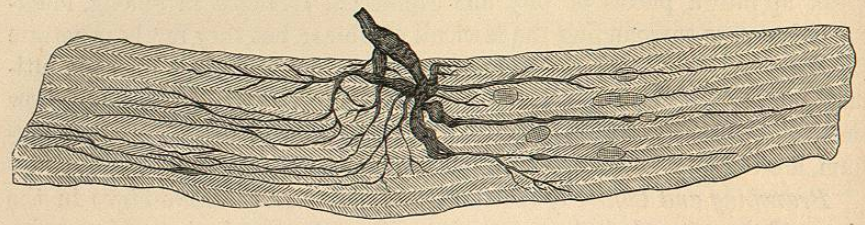

FIG. 176.—*Intrafibrillar terminations of a motor nerve in striated muscle, stained with gold chloride* (Landois).

These fibrils probably are connected with the axis-cylinders, but their exact mode of termination in the muscular substance has not been satisfactorily demonstrated.

Although the sensibility of the muscles is slight as compared with that of the skin and mucous membranes, they are not insensible and they possess nerve-fibres other than those exclusively motor. According to Kölliker, small medullated fibres go to the muscular tissue and here give off very fine non-medullated fibres, which terminate in fibres of the same appearance but provided with nuclei. These form a plexus on the sarcolemma and surround the muscular fibres. It is not certain that they penetrate the sarcolemma and terminate in the muscular substance, although this view has been advanced.

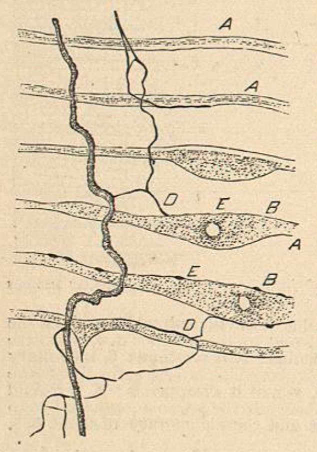

FIG. 177.—*Termination of nerves in non-striated muscle* (Cadiat).

Termination of Nerves in the Involuntary Muscular Tissue.—According to the observations of Frakenhaeuser upon the nerves of the uterus, the nerve-fibres form a plexus in the connective tissue surrounding the involuntary muscles and then send small fibres into the sheets or layers of muscular-fibre cells, which branch and finally go into the nucleoli of these structures. Arnold has confirmed these observations and has shown farther that in many instances, the fine, terminal nerve-fibres branch and go into the nuclei of the muscular fibres and afterward pass out to join with other fibres and form a plexus.

Termination of the Nerves in Glands.—The researches of Pflüger upon the salivary glands leave no doubt of the fact that medullated nerve-fibres pass to the cells of these organs and there abruptly terminate, at least as dark-bordered fibres. This author believes, however, that having formed a

more or less branching plexus, non-medullated fibres pass directly into the glandular cells and terminate in the nucleoli. The same observer has described and figured multipolar cells, mixed with the glandular cells, in which some of the nerve-fibres terminate. These, however, are not found in the parotid. These nerve-fibres are regarded as glandular nerves, and they are distinct from the vaso-motor nerves.

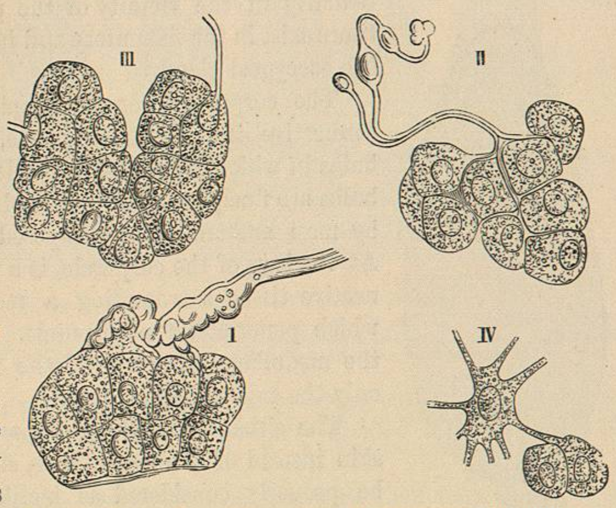

FIG. 178.—*Termination of the nerves in the salivary glands* (Pflüger). I, II, branching of the nerves between the glandular cells; III, terminations of the nerves in the nuclei of the cells; IV, multipolar nerve-cell.

Modes of Termination of the Sensory Nerves.—There undoubtedly are several modes of termination of the sensory nerves in integument and in mucous membranes, some of which have been quite accurately described, while others are still somewhat uncertain. In the first place, anatomists now recognize three varieties of corpuscular terminations, differing in their structure, probably, according to the different properties connected with sensation, with which the parts are endowed. In addition it is probable that sensory nerves are connected with the hair-follicles, which are so largely distributed throughout the cutaneous surface. There are, also, terminal filaments not connected with any special organs, some of them, perhaps, ending simply in free extremities, and some connected with epithelium. There are still differences of opinion concerning these various modes of termination of the nerves, but with regard to the terminal corpuscles, these differences relate mainly to anatomical points. It is not proposed, therefore, to enter fully into the discussions upon these questions, but simply to present what seem to be the most reliable anatomical views.

Corpuscles of Vater or of Pacini.—These bodies were called corpuscles of Pacini, until it was shown that they had been seen about a century and a half ago by Vater. In man, they are oval or egg-shaped and measure $\frac{1}{25}$ to $\frac{1}{6}$ of an inch (1 to 4 mm.) in length. They are always found in the subcutaneous layer on the palms of the hands and the soles of the feet, and are most abundant on the palmar surfaces of the fingers and toes, particularly the third phalanges. In the entire hand there are about six hundred, and about the same number on the feet. They are sometimes, but not constantly, found in the following situations: the dorsal surfaces of the hands and feet, on the cutaneous nerves of the arm, the forearm and the neck, the internal pudic nerve, the intercostal nerves, all of the articular nerves of the extremi-