The possibility of giving a satisfactory explanation of the function of the organ of Corti must be abandoned at the outset. The rods of Corti apparently serve as a supporting mechanism for the sensory epithelium. It has been supposed that they serve to pick up and magnify vibrations of the basilar fibres, and, through the medium of the reticulate membrane, transmit such irritations to the hairs of Corti's cells. There is no doubt that the ciliated "cells of Corti" are the special, and probably the only, peripheral sense organs of the auditory nerve. The cilia springing from their free ends are usually regarded as the sensory structures upon which the vibrations immediately act. If Ayers is correct in his opinion that the *membrana tectoria*, instead of being a damper for the vibrations for the organ of Corti, is really a mass of cilia or hairs torn off from the ends of the hair cells, great strength would be given to that view according to which the hairs themselves are the structures set into sympathetic vibration by the waves of the endolymph, not that their stimulation depends upon movements indirectly transmitted from the basilar membrane. In considering this view, it is significant that the scala vestibuli, the vibrations of whose perilymph it would seem should be more powerful than those within the scala tympani, adjoins the canalis cochlearis on the side next the free ends of the hair cells and away from the basilar membrane. Finally, Rutherford * has proposed the theory that the auditory nerve filaments simply transmit to the brain without analysis vibrations applied to them, much as a motor nerve carries to its muscle the impulses generated by induction currents. The basilar membrane, according to this view, vibrates as a whole, and has somewhat the relation to the nerve that a telephone plate has to the conducting wire of the instrument.

Functions of the Vestibular Sacs and of the Semicircular Canals.—Experiments upon the lower animals and the results of aural disease in man have rendered it extremely probable that the semicircular canals are peripheral organs for the complex *sense of equilibrium*, and that they give rise to perception of the movements of the head. There is reason for believing that the sensory cells of the *saccule* and *utricle* also serve as equilibrating organs, giving rise to sensations determined not so much by movements of rotation as by those in a straight line, and to some extent determining the position of the head while at rest. It is thought that the *otoliths* resting upon the hairs of the sensory cells, by their weight and inertia, aid or arouse the excitement of these cells according to the position of the head (see article on *Equilibrium*).

In the ears of fishes the cochlea is wanting, but the vestibular sacs, and especially the masses of otoliths in them, are well developed. But fishes respond to vibrations which may be supposed to arouse auditory sensation just as well when the labyrinth is removed as when it is present, probably through some cutaneous sense.† Such considerations indicate that sounds excite in these creatures other sensations than those of audition as we understand it. It is worth observing that the vestibular branch of the auditory nerve, that supplying the cristæ and maculæ, differs in its characters, in its development, and in its central connections from the cochlear branch of the same nerve. Some have supposed that the sensory cells of the maculæ are excited by the heterogeneous vibrations which we recognize as noises, while musical sounds need the cochlear organ for their interpretation.

Comparison of Visual and Auditory Sensations.—No definite relation can be shown to exist between visual and auditory sensations as such, because they are different in quality. A man born blind may describe the blare of a trumpet as having the color scarlet, but such a statement is evidently only a metaphor expressing the relations of the psychical effect of the trumpet's note and the blind man's inference as to the associations suggested by the color. It is an interesting fact that the language of visual sensation is continually employed in illustrating peculiarities of sound, as in indicating the *quality* as the *color* of the note. In the same way other sensory impressions are used to illustrate visual description, as "warm" and "cold" colors. The intimate association of sound with color in certain persons is an interesting fact of psychology.

Both the auditory and the visual sensory cells are brought into functional activity by physical vibrations, in the one case of ether and in the other of labyrinthine fluid. That continuous sensation shall be aroused these vibrations must be repeated at a definite rate. We have found (p. 612) that the lowest rate which is recognized as sound represents a vibration rate of 16 to 24 per second, while the highest note which is still audible varies in different individuals from 16,000 to 40,000 per second. In musical execution and in the ordinary uses of life the auditory range embraces about seven octaves, though the extreme range of hearing may be eleven octaves. Visual impressions, as those from alternating black and white sections of a rotating disc, fuse together when the different sensations succeed one another at an interval varying from one-tenth to one-fiftieth of a second, the interval being shorter with stronger illumination. But the ear is able to distinguish apart vibrations recurring as "beats" at the rate of 132 per second. The rate of succession of air waves falling upon the ear is marked in consciousness as a particular pitch. When separate luminous impressions, as those of a series of electric sparks, succeed one another with sufficient rapidity, the effect is that of a steady light; there is nothing analogous to musical pitch produced by increasing the rate of stimulation. Ether waves must represent a certain rate of vibration in order to excite visual sensation. The fastest vibration represented in the visible spectrum is less than twice the rate of the slowest; so that the range of vibration in the visual spectrum is included within a single octave. Difference of vibration rate, or of the factor usually considered the *wave length*, in ether, produces that peculiar variety of visual sensation known as color.

The important visual phenomenon of fatigue finds its analogue in auditory sensation. For if a simple musical tone is sounded and immediately thereafter a composite note of which that tone is an upper partial, the note will be found to differ from its normal quality because it falls upon an ear disproportionately fatigued for one of its component tones.

Judgments of Direction and Distance. Ventriloquism.—The direction and distance from which sounds come to the ear are not perceived directly, but our estimate of them is a judgment based on the loudness and quality of the sound sensation, combined with a power of reasoning from past experience. Thus, in seeking to discover the direction whence a sound comes, it is usual for an observer to turn the head to the position in which the sound is heard loudest, and thus to form an opinion as to its source. Errors of judgment as to direction are frequent, owing to the sound reflected from some object appearing louder than that coming in a direct line from its source. It is said that when there is total deafness in one ear, every sound seems to have its origin on the side of the healthy ear.

When the eyes are closed and the head is unmoved, sounds produced anywhere in the median plane of the head are very imperfectly localized. There is a tendency to refer such sounds in a direction above and in front, no doubt because this is the space from which most sounds noticed come to us.

The quality as well as the loudness of a sound varies according to the distance of its source. Thus, the lower tones of a composite note die away earliest as a sound recedes, bringing the overtones into undue prominence. The art of the ventriloquist consists largely in altering the quality of the sounds he produces to imitate the quality they would naturally have if arising under the conditions which he would lead his hearers to believe to be their origin. A comparatively feeble sound near at

* Rutherford, W.: "A New Theory of Hearing." Journ. Anat. and Phys., xxi., 166. (Quoted in Hermann's Jahresbericht d. Physiologie, Bd. xv., S. 108.

† M. Foster: "Text-Book of Physiology," pt. iv., p. 1494, 1900.

hand may have the same quality as a very loud one heard at a distance; thus a frog croaking in an adjoining room was once mistaken by the writer for a large dog barking outside the building.

Acuteness of hearing differs greatly in normal individuals, and tests frequently show disparity in the sensitiveness of the two ears. The hearing ability of children is said to improve up to the age of twelve years. There is no functional relation between keenness of hearing and sensibility to pitch.*

Albino animals and also white cats and dogs with blue eyes are usually deaf. Rawitz † has found the cochlear sense organ degenerated in such cases.

It seems probable that congenital deafness, at least, is inheritable, and that Graham Bell's prediction as to the establishment of a race of deaf mutes from the intermarriage of such unfortunates may be verified.

(In the foregoing pages the author has made some use of his article on Hearing in the "American Text Book of Physiology.") *Henry Sewall.*

AUDITORY CANAL, ANATOMY AND PHYSIOLOGY OF.—The external auditory canal, or meatus auditorius externus, extends from the bottom of the concha to the tympanic membrane, and serves to convey sound vibrations to the middle ear.

It develops in the embryo from the persistent portion of the first outer visceral furrow, making its appearance during the fourth week of fetal development.

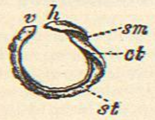

FIG. 410.—Annulus Tympanicus of the Left Side, as Seen from the Inside of the Tympanum. (After Gruber.) *h*, Anterior, *v*, posterior upper end; *sm*, sulcus malleolaris; *ct*, crista tympanica; *st*, sulcus tympanicus.

The centre of ossification shows itself during the third month in the lower wall of the membranous canal.

At birth this bone development has assumed the shape of an incomplete ring, *the annulus tympanicus.* This ring presents a slight groove along its concave border for the attachment of the tympanic membrane, the deficiency upward and backward forming the so-called Rivinian fissure or notch.

At birth the auditory canal is a partially collapsed tube, the roof and floor being in contact throughout a considerable portion of its extent and containing small masses of broken-down epithelial scales and vernix caseosa.

During the first few years of life we find proportionately little difference in the length of the canal when compared with that of the adult, 20 mm. being about the average length at birth. The calibre of the canal is smaller and more oval in shape. The general direction is straighter, passing inward with a decided downward inclination, so that when examining the membrana tympani in the child the speculum can be used to more advantage if the external ear be pulled downward and outward.

The fully developed adult canal is made up of an inner bony portion and an outer cartilaginous and membranous portion. The bone formation extends from the annulus tympanicus outward in the membranous canal, forming the anterior, inferior, and a portion of the posterior bony wall of the perfected canal. The roof is formed by the horizontal plate of the squama and the root of the zygoma; the posterior wall by the annulus, squama, and mastoid prominence.

The outer portion of the canal is a continuation inward of the cartilage of the auricle, the cartilaginous elements being absent in the upper and posterior portion, this gap being filled in by fibrous membrane. The amount of cartilage making up the canal is found to lessen as it extends inward; at its commencement two-thirds of the circumference is composed of cartilage, at its attachment to the bony canal it represents less than one-third of the lower front wall. The cartilaginous portion is attached to the roughened edge of the tympanic ring—now developed into the bony external auditory canal—by fibrous tissue. The fibrous portions of the upper and back wall become merged into the periosteum of the mastoid and squamous portions of the bony canal.

The length, size, and shape of the canal varies according to age, race, and the form of cranial development.

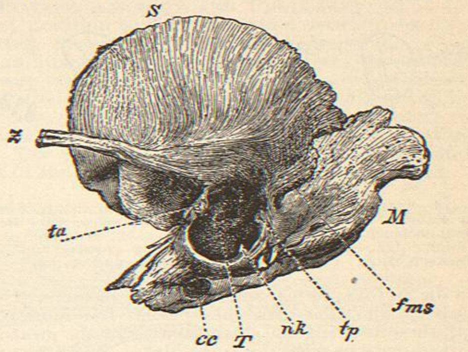

FIG. 411.—Temporal Bone of New-Born Infant. (After Gruber.) *S*, Upper part of squamous portion; *M*, mastoid portion; *Z*, zygomatic process; *T*, tympanic cavity; *fms*, fissura mastoides squamosa; *cc*, foramen caroticum; *ta*, *nk*, *tp*, bony processes representing the beginnings of growth outward on the part of the annulus tympanicus.

The length of the canal is stated variously by different authors, depending on the points from which the measurements are taken; the average length from the bottom of the concha being about 24 mm., of which 16 mm. are found to be bone and 8 mm. cartilage.

Von Troeltsch has given the most complete measurements of the different walls. Starting from a plane drawn from the posterior wall at right angles to the axis of the canal, he found the following measurements: Anterior wall, 27 mm.—9 mm. cartilage, 18 mm. bone; inferior wall, 26 mm.—10 mm. cartilage and 16 mm. bone; posterior wall, 22 mm.—7 mm. cartilage, 15 mm. bone; superior wall, 21 mm.—7 mm. cartilage, 14 mm. bone; the variations in the length of the different walls being due to the oblique position of the tympanic membrane at the inner end of the canal. The shape of the canal at the external orifice is somewhat oval, the long axis inclining slightly backward from the vertical.

Ostman, from a study of 2,302 skulls, found that with the dolichocephalic skull the canal was shorter and more circular, while in the brachycephalic skull the canal was longer and more oval. It is a clinical fact that in the negro race the canal is more circular and straighter, making it often unnecessary to resort to the speculum in order to view the tympanic membrane.

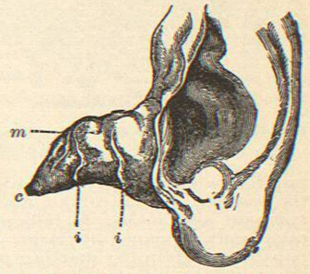

FIG. 412.—*m*, Cartilaginous meatus; *c*, inner extremity of the cartilaginous meatus; *ii*, fissuræ Santorini.

The smallest diameters of the canal are near the end of the cartilaginous portion, and in the bony canal close to the inner third. The following diagrams show the shape and size of the canal at different parts of its course, as found by Bezold from a study of casts of the cavity.

The direction of the canal is sigmoid. In its outer third it is inclined somewhat forward and ascends very

* Seashore: Studies in "Psychology," Bull. Univ., Iowa, vol. ii., 1899.

† Rawitz: Zoölogischer Jahresbericht, 1896, Arch. f. Anat. u. Physiol., 1897.

slightly. It then turns sharply backward and is horizontal near the middle third, where it again changes its course, the inner portion curving forward and decidedly downward.

In the cartilaginous floor of the canal are found one small and two large fissures running in a circular manner, called the fissures of Santorini. These spaces are filled

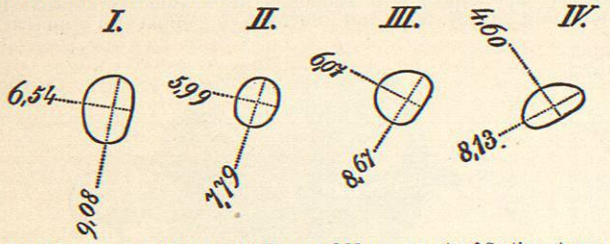

FIG. 413.—Diagram Showing the Form and Measurements of Sections Across the External Auditory Meatus. (From Schaefer, after Bezold.) *I.*, At commencement of cartilaginous portion; *II.*, near end of cartilaginous portion; *III.*, near beginning of osseous portion; *IV.*, near end of osseous portion. (The measurements are in millimetres.)

in with fibrous tissue and allow the passage of blood-vessels; at the same time they permit free motion of the canal, thus favoring the straightening of the meatus during examinations with the speculum. These fissures are sometimes the channel through which an abscess in the parotid gland may find its exit.

The canal is lined by a continuation of the cutaneous covering of the auricle. In the cartilaginous portion the skin is 1 to 2 mm. in thickness and loosely attached to the perichondrium. In the bony canal it is thinner and firmly united to the periosteum.

Kaufman describes a number of ridges or vascular

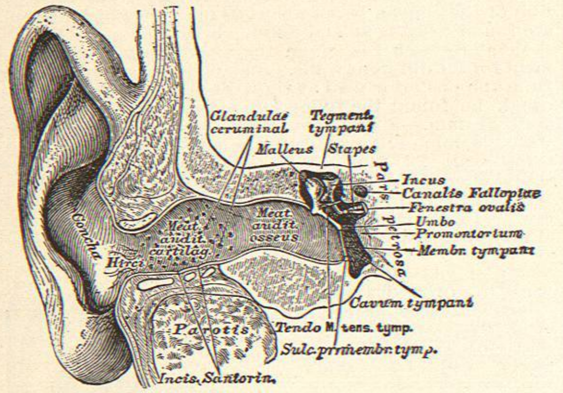

FIG. 414.—Vertical Section of the External Auditory Canal and Tympanic Cavity. (After Heitzmann.)

papillæ which occupy a circular position in the skin of the osseous portion of the canal, close to the membrana tympani, and which, in inflammatory conditions of the canal, may become quite large. Politzer states that these papillæ are often the starting point for polypi. At the inner end the skin continues over the membrana tympani and forms its outer layer.

Throughout the cartilaginous part, and extending in a triangular manner into the upper and back wall of the osseous canal, are found numerous hairs and sebaceous glands, and in addition, large oval, convoluted tubular glands resembling in form and structure the sweat gland —the *Glandulæ Ceruminosæ*. These glands secrete the cerumen or ear wax, and are found opening into and around the hair follicles. The hair development is sometimes abundant. The sebaceous glands secrete a small quantity of oily material for lubrication of the skin. The secretion from the ceruminous glands when first discharged is of a yellowish brown color and soft in consistency, but in a short time evaporation of the watery elements causes the mass to thicken and it becomes darker. Often it becomes inspissated, and by blocking the canal gives rise to much temporary discomfort. The function of the cerumen is probably to protect the ear from the entrance of insects and foreign particles that may get into the canal.

Röhrer found a number of organisms to exist in plugs of ear wax. It is of a pungent, bitter taste, and chemically, in addition to oil from the sebaceous glands, is made up of a dry material not soluble in water, alcohol, or ether, and of potash, stearin, a trace of soda and lime, and 0.1 per cent. water, mixed with numbers of broken-down epidermic exfoliations and loose hairs.

Of the very greatest importance to the aural surgeon is the surgical anatomy and relationship of the canal. These differ somewhat in the ear at birth and in the adult. At birth the only portion of the canal found to be bony is the *annulus tympanicus*. This is attached to the squama in front, below and behind to the petro-mastoid portion. Along the external margin of this ring are seen two small tubercles that are the starting points for the future bone development forming the anterior and lower wall of the canal. They do not immediately unite as one process, often leaving a gap until after the fifth or sixth year.

The roof of the canal is formed from the squama. As development takes place the portion below the temporal line assumes a horizontal position and presents two plates of bone containing between them honeycombed spaces. The superior plate forms a part of the floor of the middle cranial fossa and has resting upon it the dura mater. The lower plate, near its inner extremity, suddenly drops down in such a manner as to become wedge-shaped; it forms the outer wall of the attic of the tympanum, called the scutum, and gives attachment to the upper margin of the drum head. The cell spaces contained between the plates of the roof of the canal frequently communicate with the antrum and with the pneumatic spaces found as far forward as the root of the zygomatic process. Clinically these spaces are of importance since they may be the seat of suppuration in conjunction with mastoid diseases, and must not be overlooked in operations in which all the cellular spaces are suspected of containing pus.

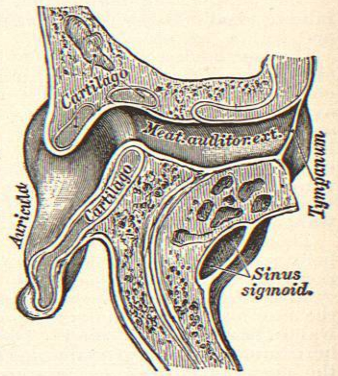

FIG. 415.—Horizontal Section of the Left External Auditory Canal. (After Heitzmann.)

The anterior bony wall of the meatus is the thinnest of the canal. It is slightly convex on the meatal face. Its front surface assists in the formation of the glenoid cavity in which rest the condyle of the lower jaw and part of the parotid gland. Blows on the lower jaw are therefore likely to fracture the wall of the canal. The floor is formed by the bony growth of the tympanic ring. It is thick and compact; toward the meatus the surface is convex except close to the membrana tympani, where a small concavity is found—"the Sinus of Meyer"—in which foreign bodies may lodge. The position of this concavity is such that it is often difficult to detect the presence of these foreign bodies and to remove them.

The posterior wall of the osseous meatus is of much

surgical importance. It is formed by the union of the tympanic ring with the squama, and later with the anterior plate of the developed mastoid, this plate being quite thin and separating the canal from the cell spaces contained in the mastoid. Often the groove for the lateral sinus is in close proximity to this wall.

At the juncture of the upper and the posterior wall the scutum forms a portion of the outer wall of the mastoid antrum. In suppurative diseases of the tympanic cavity often carious tracts (fistulæ) are found in this region; they lead into either the tympanic attic or the antrum of the mastoid, and call for surgical interference. Just external to the upper posterior margin is often found a small bony spine—the supra-meatal spine—which is of value as a surgical landmark in the operation for opening the mastoid antrum.

In the fully developed ear the drum head is placed in an oblique position, the upper and back part forming an obtuse angle of about 135°, while the lower and anterior portion forms an acute angle of about 40°, with the canal wall.

The arterial supply to the auditory canal is quite abundant. The posterior auricular, a branch of the external carotid, sends a branch called the auricular. It passes in at the junction of the cartilaginous with the bony canal, and supplies the back wall of the canal, anastomosing with the anterior auricular, a branch of the temporal, which enters the anterior wall of the canal behind the condyle of the lower jaw. The tympanic branch of the internal maxillary enters the tympanic cavity through the Glaserian fissure, and sends a branch that supplies the skin of the canal adjacent to the membrana tympani. The veins take an irregular course. They empty their blood either directly (and this is the rule) into the external jugular or indirectly by way of the temporal or the internal maxillary vein.

The nerve supply is, first, from the auriculo-temporal branch of the inferior maxillary division of the fifth nerve. Three small branches of this nerve supply the skin on the anterior wall and in the cartilaginous portion. Second, the auricular branch of the pneumogastric — "Arnold's nerve" — enters the back wall of the canal at its junction with the mastoid, and supplies the larger portion of the bony canal and a part of the back wall of the cartilaginous section. Irritation of this nerve by the accumulations of wax, by foreign bodies, or by the speculum when the ear is being examined or cleansed, produces the familiar reflex ear cough.

But little seems to be known regarding the lymphatic vessels contained in the walls of the external canal. Politzer states that they are probably connected with the lymphatic glands overlying the parotid, by way of the fissures of Santorini, since it is a matter of clinical observation that swelling of the lateral cervical glands often occurs in inflammatory conditions affecting the meatus.

The skin lining the auditory canal maintains all the histological characteristics of the skin in other parts of the body, although that part which lines the bony canal becomes very firmly united to the periosteum and altered in color. In its development there is a gradual growth outward of the skin, thus producing a constant tendency for the ear wax to move outward, this being further facilitated by the pressure of the condyle of the jaw, which in mastication constantly pushes the parotid gland against the anterior wall of the canal and somewhat influences its lumen.

The sinuous course of the canal is such that sound waves do not strike the membrana tympani directly, but are reflected from the walls of the canal and are thus modified in their intensity. Politzer states that the two most important points where this reflection takes place are on the back wall of the cartilaginous canal and on the anterior inferior portion of the bony canal.

The size of the canal plays no influence in the acuteness of hearing, although Burnett observes that large straight canals are more likely to be found in those possessing a so-called ear for music. *J. Morrison Ray.*

AUDITORY NERVE AND ITS END ORGANS.—COMPARATIVE ANATOMY AND PHYLOGENY.—The functions of audition and equilibration seem to be closely associated throughout the animal kingdom. The so-called auditory organs, or otocysts, of the invertebrates, if we may trust the results of most recent experimental studies, are in the majority of cases concerned largely, if not wholly, with equilibrium, though in some cases (notably among insects) true auditory organs undoubtedly exist. The structure of these organs is usually similar to that of the organs in the labyrinth of vertebrates.

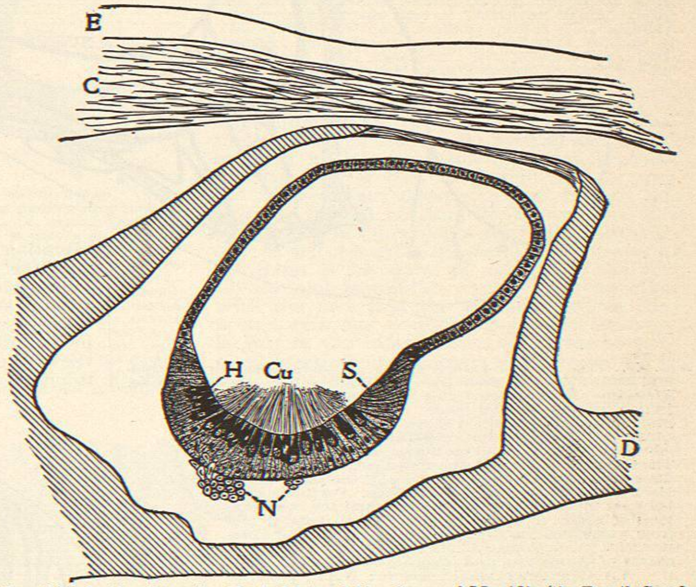

FIG. 416.—Section through a Typical Lateral-Line Organ of *Menidia* (the Fourth Canal Organ of the Mandibular Line of Fig. 417). *C*, Corium; *Cu*, cupula, composed of hairs from the hair cells matted together and more or less gelatinized; *D*, dentary bone; *E*, epidermis; *H*, hair cells, or specific sensory cells; *N*, nerve fibres supplying the latter; *S*, supporting cells.

For the proper morphological comprehension of the eighth nerve and its terminal organs we must look far back to the early phylogenetic stages of its development in the vertebrates. The fishes possess a system of cutaneous and subcutaneous sense organs, the so-called lateral-line organs (Fig. 416), widely distributed over the head and trunk. Part of these are in canals (the lateral-line or "mucous" canals), and part are variously distributed over the skin, either naked or sunken in separate pits (the pit organs of ganoids and ampullæ of elasmobranchs); but all closely resemble structurally the maculæ and cristæ of the internal ear, and all are innervated by nerves which arise with the auditory nerve from the tuberculum acusticum. These lateral-line nerves go out with the vagus and facial roots and are conventionally associated with these nerves. They have, however, really nothing to do with them, but are more logically associated with the auditory nerve to comprise the "acustico-lateralis" system of nerves (*cf. Cranial Nerves*). The peripheral distribution of this component in a typical fish is expressed in the accompanying diagram (Fig. 417).