ously with the cochlea. The cerebellum has been mentioned as a secondary end station for the acustico-lateral system of nerves. As the organ of equilibration (and of the static senses in general) for the body, this was

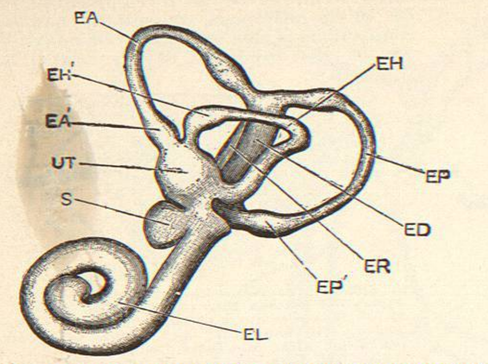


FIG. 424.—The Left Auditory Vesicle of a Human Embryo of the Eighth Week, Seen from the Left Side. (After W. His, Jr., from Marshall's "Embryology." × 17. *EA*, Anterior vertical semicircular canal; *EA'*, ampulla of anterior vertical semicircular canal; *ED*, common stem of the two vertical semicircular canals; *EH*, horizontal semicircular canal; *EH'*, ampulla of horizontal semicircular canal; *EL*, cochlea; *EP*, posterior vertical semicircular canal; *EP'*, ampulla of posterior vertical semicircular canal; *ER*, recessus labyrinthi; *S*, sacculus; *UT*, utriculus.

probably its primary connection. But these static functions are served by all of the other senses as well (except, perhaps, the olfactory), so that the terminal nuclei of the other sensory nerves have also effected secondary connections with the cerebellum.

The middle and external ear do not appear in the fishes, the vibrations of the surrounding medium being transferred to the labyrinth through the tissues of the head. But air-breathing vertebrates require some intermediary mechanism to intensify the more feeble aërial vibrations. Accordingly, the middle ear, with its contained auditory ossicles, is seen for the first time in the Amphibia. The phylogeny of the auditory ossicles has been the subject of endless investigation, and there is still no agreement upon the details of this history. The internal ear in the lower fishes clearly lies in the hyoid segment of the head. With the gradual enlargement of the brain case in the higher animals, the greater portion of the facial skeleton of the fishes is absorbed into the cranium. According to the most recently published research (Kingsley, 1900), the derivation of the auditory ossicles is as follows: The malleus from the articulare (in part), the incus from the quadrate, and the stapes from the hyomandibulare, the first two being derived from the mandibular arch, the last from the hyoidean.

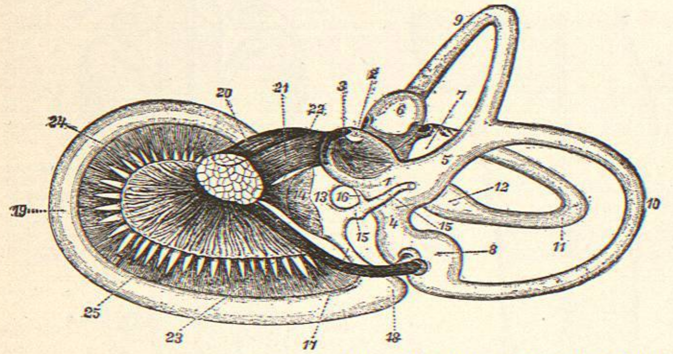


FIG. 425.—The Membranous Labyrinth of the Right Internal Ear of a Human Embryo at the Fifth Month, Seen from the Medial Side. (After Retzius, from Barker's text-book.) 1–5, Utriculus; 2, recessus utriculi; 3, macula acustica utriculi; 4, sinus posterior; 5, sinus superior; 6, ampulla membranacea superior; 7, ampulla membranacea lateralis; 8, ampulla membranacea posterior; 9, ductus semicircularis superior; 10, ductus semicircularis posterior; 11, ductus semicircularis lateralis; 12, widened mouth of crus simplex of the lateral semicircular canal opening into the utriculus; 13, sacculus; 14, macula acustica sacculi; 15, ductus endolymphaticus; 16, ductus utriculo-saccularis; 17, ductus reuniens; 18, cæcum vestibulare of ductus cochlearis; 19, ductus cochlearis; 20, nervus facialis; 21–24, N. acusticus; 21, N. vestibuli; 22, N. saccularis; 23, N. ampullaris inferior; 24, N. cochleæ; 25, distribution of N. cochleæ within the lamina spiralis ossea.

The Eustachian tube is now quite generally regarded as the derivative of the spiracular canal, a rudimentary gill cleft present in some of the lower fishes between the hyoid and mandibular arches. In the mammals this tube never quite reaches the surface of the head, but is cut off by an epithelial membrane composed merely of a layer of ectoderm and a layer of entoderm without any intervening mesoderm (*EB*, Fig. 418). This membrane becomes the tympanic membrane, the portion of the tube within it the Eustachian tube, and the pit leading from it to the surface the external auditory meatus (Fig. 419).

EMBRYOLOGY.—That the ear is related to the lateral-line organs of the fishes is shown by its embryology, as well as by comparative anatomy. In all fishes there appears behind the eyes a thickened patch of ectoderm from which both the ear and the lateral-line canals of the head and trunk arise. The rudiment of the ear appears first, and then the two lateral-line rudiments on either side of it.

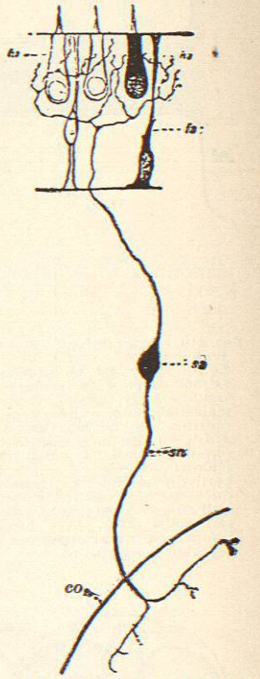


FIG. 426.—Scheme of the Peripheral Termination of the Nervus Vestibuli. (After Retzius, from Barker's text-book.) *co*, Central nervous system; *fz*, supporting cell; *hz*, hair cells; *sn*, neurite of N. vestibuli; *sz*, cell body of vestibular neurone.

In cases in which the ectodermal epithelium at this stage is simple, the whole epithelium in the auditory portion of this patch invaginates to form the "auditory saucer," and later a vesicular sac which sinks down below the surface. But in other cases, in which the ectoderm becomes earlier two-layered, it is only the inner, or nervous layer, which participates in this invagination, and the auditory vesicle never communicates with the surface of the body. Three successive stages in the differentiation of the auditory sac and lateral-line rudiments of the sea bass are shown in the accompanying figures (Figs. 420–422). A section through the auditory sac at about this period (Fig. 423) shows the auditory saucer in process of formation from the nervous layer of the ectoderm, the outer layer not participating. Sections taken cephalad and caudad of this point show that the lateral-line rudiments of the sea bass resemble this very closely. Though there is considerable variation in the mode of origin of the lateral lines in different fishes, they all have this in common: that they arise from the same ectodermal thickening as the ear. In the figure last cited it will be noticed that the invaginating ecto-

derm is directly continuous dorsally with that of the central nervous system, and that the auditory nerve is growing out from the same region, viz., the neural crest (*cf. Cranial Nerves*).

The auditory saucer, whether formed from the whole of the ectoderm or only from its inner layer, soon closes up and withdraws from the skin to form a vesicular sac, the auditory vesicle. In the elasmobranchs the vesicle retains its connection with the outer surface to adult life by means of a slender tube, the ductus endolymphaticus, in this point resembling the lateral-line canals, which open freely to the surface by means of a series of pores. But in all of the higher animals this connection is lost, though the tube persists as a blind pouch, the recessus vestibuli (*ER*, of Fig. 418), which later in man becomes the path of communication between the sacculus and the utriculus. These latter chambers are formed by the folding of the walls of the vesicle, and contemporaneously with this process the semicircular canals are pinched off from the dorsal or utricular portion, while the cochlea grows down from the saccular portion. The form of the membranous labyrinth of the human embryo of the eighth week is shown by the accompanying figure (Fig. 424).

While the auditory vesicle is still in a quite undifferentiated condition, its lining epithelium develops a patch of sensory cells which enlarges very irregularly in such a way that during the subsequent plications of the walls of the vesicle each of the chambers thus evaginated (except the recessus vestibuli) receives a portion of this modified epithelium. These patches now become separated by non-sensory pavement epithelium and constitute the three cristæ in the ampullæ of the semicircular canals, the maculæ of the utriculus and sacculus and the organ of Corti of the cochlea.

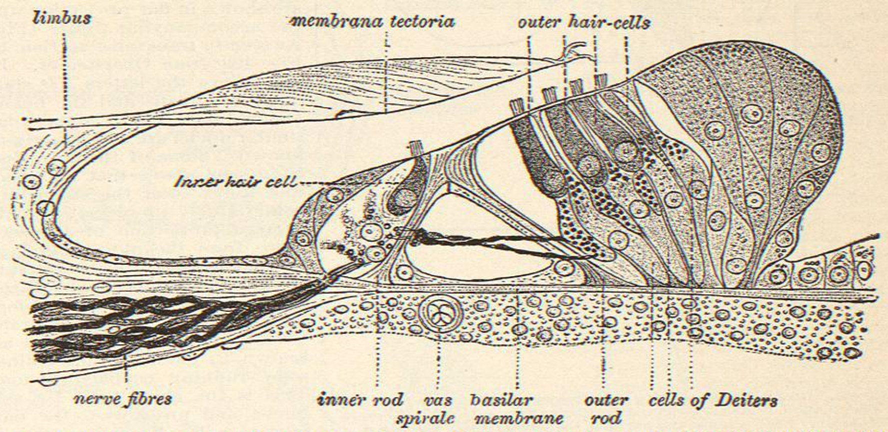


FIG. 427.—Section through the Organ of Corti of the Middle Turn of the Human Cochlea. (After Retzius, from Quain's "Anatomy.")

The auditory vesicle, which is primarily ectodermal, at first lies simply embedded in the surrounding mesoderm (Fig. 418). A portion of this mesoderm is added to the vesicle, and thus the definitive membranous labyrinth is formed from both of these germ layers. The enveloping cartilages—which become, when ossified, the bony labyrinth—develop a short distance removed from the membranous labyrinth, and the intervening mesoderm is dissolved, leaving the perilymphatic spaces between the membranous and the bony labyrinth. The scala tympani and the scala vestibuli are the continuations of these spaces into the cochlea, while the scala media is the only part of the cochlea which is lined by a derivative from the original ectodermal auditory vesicle. Accordingly, the organ of Corti is developed in the floor (membrana basilaris) of the scala media.

THE AUDITORY NERVE OF MAN.—The accompanying figure from Retzius (Fig. 425), together with Fig. 419, above, and the preceding accounts of development, will render a detailed description of the accessory auditory apparatus unnecessary. It must be remembered that there are two distinct sensory mechanisms in the eighth nerve and internal ear, mechanisms which have had a common origin and which possibly even in man are only incompletely differentiated from each other. These are the labyrinth, serving the static sense, and the cochlea, the organ of hearing. The maculæ and cristæ of the membranous labyrinth are very simple sensory epithelia, in structure almost identical with the organs of the lateral line figured above. The supporting cells constitute a simple columnar epithelium. Among these cells are the shorter hair cells, or specific sensory cells, extending only about half-way through the thickness of the epithelium. Their relations to the termini of the nerve are shown in the accompanying diagram (Fig. 426).

The organ of Corti of the cochlea, on the other hand, is so complicated that the details of its minute structure are still in large measure obscure. The general relations of the parts of the organ of Corti are expressed by the accompanying diagram (Fig. 427). Neglecting the accessory structures in the organ of Corti, concerning whose structure and functions there is considerable difference of opinion, the sensory epithelium here, as in the organs of the vestibule, consists essentially of a simple columnar non-sensory epithelium (curiously modified), and among its cells shorter specific sensory cells, the hair cells. The latter are related to the terminal ramifications of the nerve very much as are the hair cells of the vestibular organs. That is, according to the majority of authorities, the cochlear nerve ends free among the hair cells, without effecting protoplasmic continuity with their substance.

The division of the auditory nerve into vestibular and cochlear rami, while convenient descriptively, is not of special morphological significance, for, while the vestibular ramus is distributed wholly to sensory organs of the labyrinth proper (superior and external ampullæ and macula utriculi), the so-called cochlear ramus supplies, in addition to the cochlea, the posterior ampulla and the macula sacculi. The two branches of the cochlear ramus last named are termed by Schwalbe the ramus medius, a natural division, as they belong more properly with the vestibular ramus than with the cochlear. The vestibular and cochlear divisions can best be described separately.

Vestibular Ramus—The fibres of this nerve arise from ganglion cells lying in the internal auditory meatus, the vestibular ganglion, or ganglion of Scarpa. These cells, like all of the others connected with the nerves of the internal ear (and the lateral-line nerves of fishes as well), remain bipolar throughout life in all animals. The method of the termination of the peripheral processes about the specific cells of the sensory spots has already been illustrated. The central processes form the vestibular (mesial or anterior) root of the eighth nerve. It enters the brain ventrally and cephalad of the cochlear root, and passes dorsad between the fibres of the restiform body

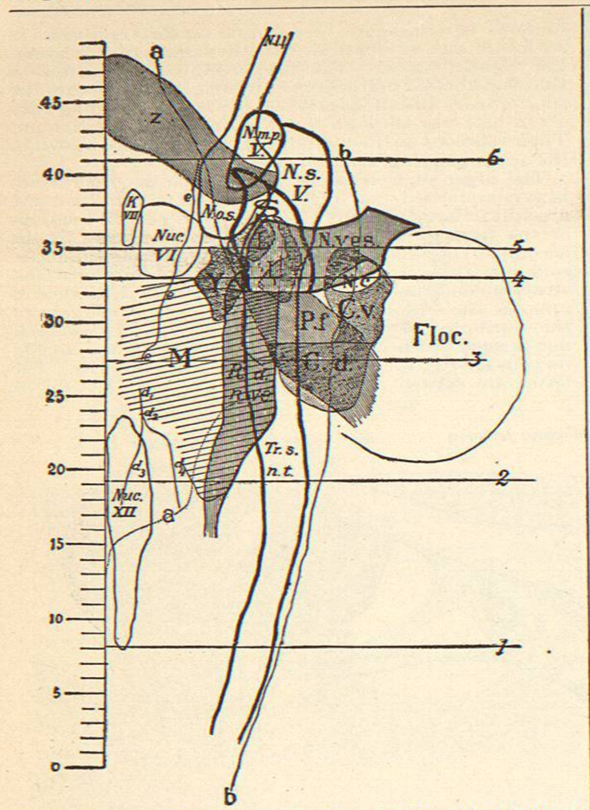


FIG. 428.—Diagram Representing Flat Reconstruction of the Nuclei of Termination of the Cochlear and Vestibular Nerves. (After Florence R. Sabin.) The scale at the left is in the median line; the line *a*, *a* represents the lateral wall of the ventricle; the line *b*, *b* corresponds to the lateral outline of the corpus restiforme; the lines d_1 to d_4 and the line *e*, *e*, *e* correspond to the sulci in the floor of the fourth ventricle; *C.d.*, nucleus nervi cochleæ dorsalis; *C.v.*, nucleus nervi cochleæ ventralis; *Floc.*, flocculus; *K VII*, knee of the nervus facialis; *L.*, medial portion of nucleus nervi vestibuli lateralis (Deiters); *L*, lateral portion of nucleus nervi vestibuli lateralis (Deiters); *M*, together with *Y*, nucleus nervi vestibuli medialis (Schwalbe); *Nuc. XII*, nucleus nervi hypoglossi; *Nuc. VI*, nucleus nervi abducentis; *P.f.*, pedunculus flocculi; *N. m.p. V.*, nucleus motorius princeps nervi trigemini; *N.o.s.*, nucleus olivaris superior; *N.s. V.*, nucleus nervi trigemini (sensory); *N.c.*, root bundle of nervus cochleæ; *N. vest.*, root bundle of nervus vestibuli; *R.d.n.ve.*, radix descendens nervi vestibuli; *S.*, nucleus nervi vestibuli superior (Bechterew) (area enclosed in the broad black line); *Tr.s.n.t.*, tractus spinalis nervi trigemini; *Y*, nucleus; *y* = antero-lateral portion of nucleus nervi vestibuli medialis: *z*, decussatio nervi trigemini.

and those of the spinal root of the fifth nerve. Mesially of the restiform body the fibres bifurcate, one limb of each fibre turning caudad to form the descending or spinal root of the vestibular nerve, finally to arborize about the cells of the spinal nucleus associated with this tract. The other limbs of these fibres effect various connections in the region dorsally and cephalad of this point. The primary connections of the vestibular root have been thus summarized by Dr. Lewellys F. Barker:

There are at least four well-defined primary nuclei of termination in connection with the vestibular nerve: (1) The nucleus medialis (Schwalbe); (2) the nucleus spinalis (radix descendens); (3) the nucleus lateralis (Deiters); and (4) the nucleus superior (Flechsig, von Bechterew). In addition, the nervus vestibuli comes into direct conduction-relation, (*a*) (probably chiefly by means of collaterals) with the nucleus nervi cochleæ ventralis; (*b*) (by means of ascending limbs of divided root fibres or collaterals from these) with the mass of nerve cells (Ramón y Cajal's nucleus cerebello-acusticus) in the lateral wall of the ventricle, dorsad to Bechterew's nucleus; and (*c*) with the nuclei of the roof of the fourth ventricle (nuclei fastigii) on both sides of the middle line, and (*d*) possibly, according to Cajal, by means of a few fibres with the nucleus dentatus cerebelli and the cerebellar cortex.

The topographical relations of these nuclei to one another and to the surrounding structures in the oblongata are shown in flat projection upon the horizontal plane in the accompanying figure (Fig. 428), after Miss Sabin. As seen in transverse section the relations are shown in Fig. 429, from Obersteiner. It should be noted that in this figure the letters *ND* stand in the position of the nucleus spinalis and the nucleus of Flechsig, as well as Deiters' nucleus. The secondary connections of the vestibular nuclei are exceedingly diverse and none too well known. Some of them are indicated in Fig. 429. We have seen above that a considerable number of direct root fibres enter the cerebellum, their connections there being largely problematical. It is, however, certain that a large proportion of the secondary fibres, especially those from the more lateral group of nuclei, pass into the cerebellum. Others reach a lateral vestibular bundle lying between the spinal fifth tract and the emerging fibres of the sixth nerve, some ascending and some descending in it. A considerable number of secondary fibres from both the medial and the lateral nuclei are known to enter the fasciculus longitudinalis medialis, some running cephalad, some caudad in this bundle. This is the chief path for reflexes to the oculomotor nuclei, and probably to the motor centres of the spinal cord as well. There are other descending and ascending paths less perfectly known, some of the latter undoubtedly entering the fillet.

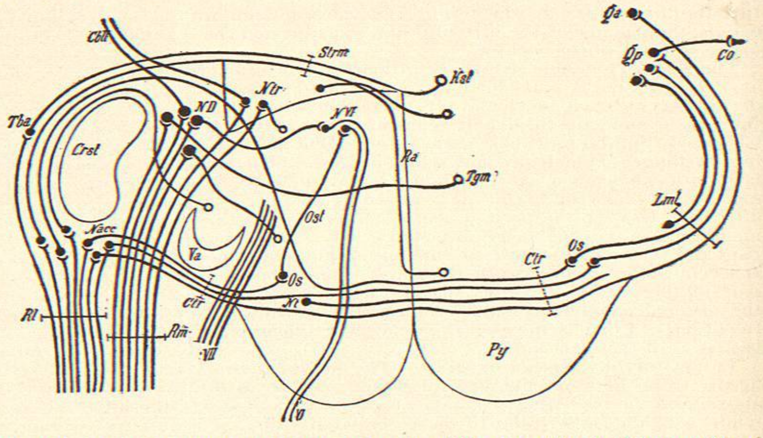


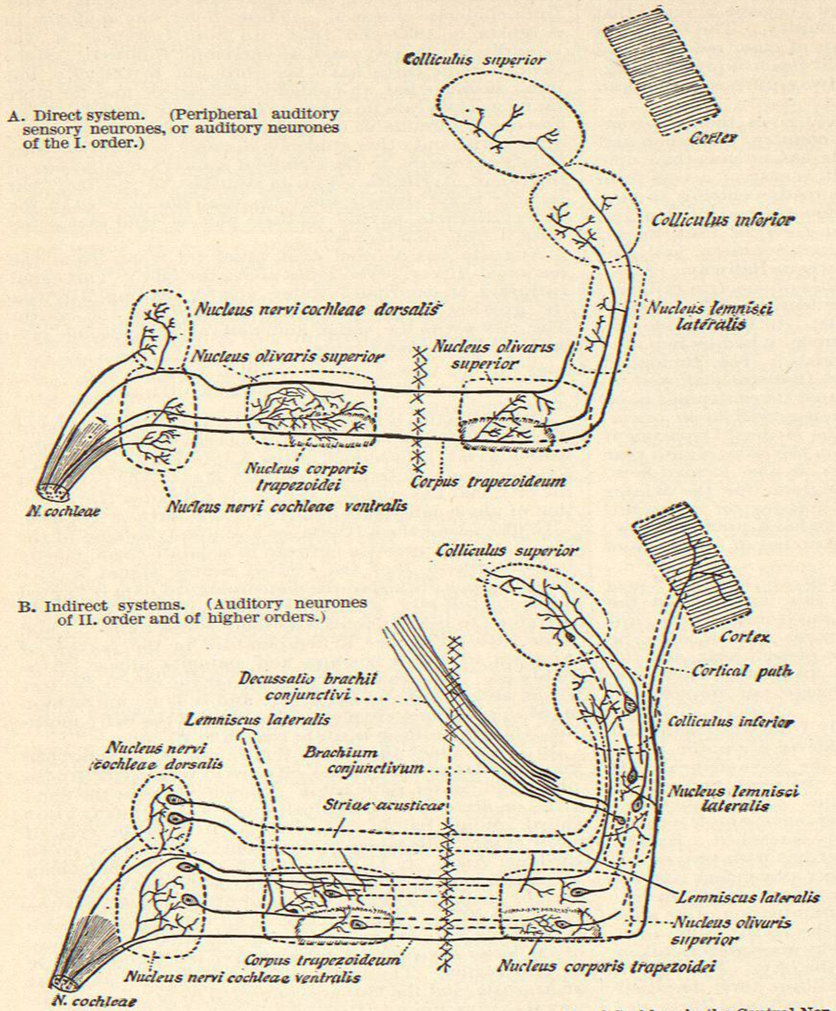
FIG. 429.—Schema of the Central Acoustic Apparatus. (After Obersteiner.) *Cbll*, Cerebellum; *Co*, cerebral cortex; *Crst*, corpus restiforme; *Ctr*, corpus trapezoides; *Kst*, conductor sonorus (*Klangstab*); *Lml*, lateral fillet; *Nacc*, nucleus accessorius (ventral cochlear nucleus); *ND*, Deiters' nucleus; *Nt*, trapezoid nucleus; *Ntr*, nucleus medialis (triangular nucleus); *N VI*, abducens nucleus; *Os*, superior olive; *Ost*, stalk of the superior olive; *Py*, pyramid; *Qa*, *Qp*, upper and lower corpora quadrigemina; *Ra*, raphe: *Rl*, lateral (cochlear) acusticus root; *Rm*, medial (vestibular) acusticus root; *Strm*, striæ medullares (striæ acusticæ); *Tba*, dorsal cochlear nucleus (tuberculum acusticum); *Tgm*, tegmentum; *Va*, spinal trigeminus root; *VI*, abducens root; *VII*, facialis root.

Cochlear Ramus.—The cell bodies from which the fibres of this nerve arise lie chiefly (if not wholly) in the spiral ganglion, or ganglion of Corti, in the axis of the bony cochlea. The peripheral processes of these ganglion cells (excluding the ramus medius of Schwalbe) terminate in the organ of Corti. The central processes constitute the cochlear (lateral or dorsal) auditory root. In the embryological development they become medullated somewhat later than those of the vestibular root, a feature to be correlated with the fact that this nerve appears in the phylogeny at a later period than the vestibular nerve.

All of the fibres of the cochlear nerve appear to enter the ventral or the dorsal cochlear nucleus either to terminate in them or to pass through them. The ventral nucleus is often spoken of as the accessory nucleus, and is thought by Sala and Onufrowics to contain some of the ganglion cells of the peripheral auditory neurones. The dorsal nucleus is the tuberculum acusticum of human anatomy. The fibres of the cochlear nerve bifurcate, upon entering the oblongata, into ascending and descending limbs. The ascending limbs generally enter the ventral cochlear nucleus, while the descending limbs may enter the dorsal cochlear nucleus.

The figures already given illustrate the relations of these terminal nuclei. The accompanying diagrams from Held (Figs. 430, 431) will serve in lieu of extended descriptions of their further connections. These are much too complicated to be given in detail here. The reader is referred to the extended review in Barker's recent text-book, "The Nervous System," chapter liv. In general terms, the central auditory path extends from the ventral nucleus, by way of the trapezoid body, and from the dorsal nucleus, by way of the striæ acusticæ (both root fibres and secondary fibres in each case), to the region of the superior olive, partly crossed and partly uncrossed. The path then goes by way of the lateral fillet to the inferior member of the corpora quadrigemina. This appears to be the general centre for the elaboration of the higher auditory reflexes, the reflex connections being very numerous, notably with lower centres and with the superior member of the corpora quadrigemina (optic reflex path). Cortical projection fibres also pass from this body viâ the brachium quadrigeminum inferius to the corpus geniculatum mediale. The path seems to be interrupted here and the fibres of the cortical acoustic path arise at this point, to terminate in the auditory sense area of the cortex; viz., according to Flechsig, "the two transverse gyri of the temporal lobe (particularly the anterior), and that portion of the gyrus temporalis superior immediately adjacent."

C. Judson Herrick.



FIGS. 430 AND 431.—Schemes Illustrating the Terminations of the Nervi Cochleæ in the Central Nervous System. (After Held, from Barker's text-book.)

AUGUSTA, Georgia (latitude, 32° 28′ N.; longitude, 81° 54′ W.), is located on the southwestern bank of the Savannah River, about 231 miles from its mouth. In an air line, or "as the crow flies," it is about 90 miles from the Atlantic coast. Its elevation above the sea level is 167 feet. Augusta proper is bounded on the north and northeast by the Savannah River, which separates the States of Georgia and South Carolina at this point; and on the west and southwest by a row of sand hills which rise to a height of from 298 feet to 350 feet above the level of the city. Toward the east and southeast there extends a level plateau of farming land, so that one gets here a variety of scenery of hill and vale and river.

According to the last census taken by the Maloney Directory Company, Augusta, with her immediate suburbs, has a population of about 63,000. The city proper is very level and has wide streets, the beauty of which have made her famed throughout the country. The main resident street—Greene Street—is 175 feet wide, and, for