into the open end of a tube, it is conducted for extraordinary distances. This is the principle on which the effectiveness of the stethoscope depends. The relations of the parts of the human external ear, the *tragus* and *antitragus*, the oblique direction of the meatus and the bend in its course, are admirably adapted for the protection of the tympanic membrane from external violence.

The external auditory meatus acts as a resonator for tones in unison with its own fundamental, whose pitch corresponds to a vibration rate of about three thousand per second. The shrill intensity possessed by certain tones near the upper limit of the musical scale, as the chirp of a cricket, is due to the sympathetic resonance of the auditory canal (Helmholtz).

The *middle ear or tympanum* (Figs. 393, 401) is an air-holding cavity of irregular shape in the petrous bone, and it is broader behind and above than it is below and in front. Posteriorly it is in open communication with the complex system of air cavities in the mastoid bone known as the *mastoid antrum* and the *mastoid cells*. A considerable portion of the cavity lies above the level of the tympanic membrane and is known as the *attic*. It is separated from the brain cavity by a thin plate of bone (*tegmentum tympani*, Fig. 393). It is easy to see how

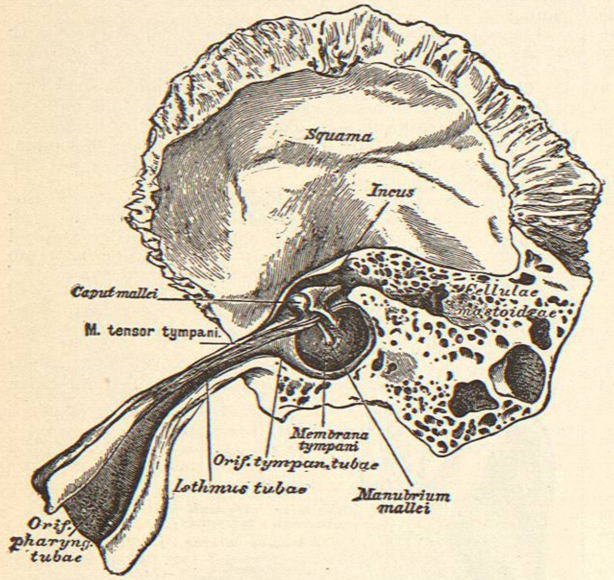

FIG. 394.—The Membrana Tympani and the Eustachian Tube, as Seen from Within. (After Heitzmann.)

suppurative inflammation of the middle ear not only may invade the mastoid cells but, by absorption of the thin roof of the cavity, and in other ways, may make *otitis media* the commonest source of pyogenic affections of the brain.* Anteriorly the tympanum is continuous with the pharynx through the Eustachian tube (Fig. 394). The inner wall of the cavity is formed chiefly by part of the bony envelope of the internal ear. The surface of the inner wall is pierced by two apertures, the *fenestra ovalis*, or oval window, and the *fenestra rotunda*, or round window, leading into separate divisions of the cavity of the bony labyrinth.

In life each fenestra is covered by a thin sheet of membrane, and the foot of the *stapes* (see below) is fastened by a ligamentous fringe in the oval window. The cavity of the tympanum is lined by mucous membrane continuous with that of the Eustachian tube and the pharynx, and the membrane, like that of the Eustachian

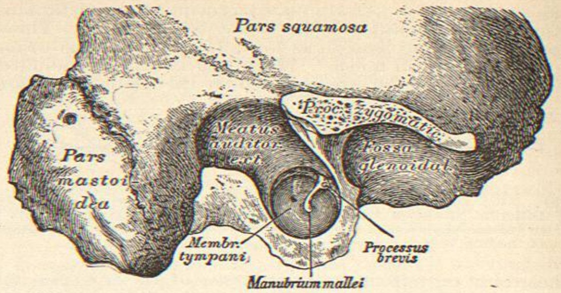

FIG. 395.—The Right Membrana Tympani as Seen from Without, After the Removal of a Part of the Osseous External Auditory Canal. (After Heitzmann.)

tube, is ciliated except over the surfaces of the ossicles and the tympanic membrane.

The *tympanic membrane or drum skin* (Figs. 393–397), separates the tympanic cavity from the auditory canal. It is a somewhat oval disc whose longer axis is directed from behind and above downward and forward, and whose length is about 9 mm. The membrane is inserted obliquely to the axis of the meatus, so that the floor of the latter is longer than its roof. The membrane varies considerably in its physical characters in disease, but normally it is semitransparent and of a pearly lustre to otoscopic vision (Figs. 396, 397). It is composed of an outer layer of thin skin, an inner layer of mucous membrane, with a coat of chiefly fibrous tissue between. The greater number of the fibres of this middle layer (*membrana propria*) radiate from near the centre to the periphery of the membrane; but there are also circular fibres of elastic tissue which are most numerous in a ring near the attached margin of the membrane. The surface of the drumskin is not flat, but is funnel-shaped with the apex of the funnel pointing inward, a position determined by the attachment of the handle of the malleus. Moreover, the radial lines of the membrane are not straight, but are slightly curved with the convexity outward, this shape being partly due to the tension of the circular elastic fibres. A small segment in the upper part of the membrane, *membrana flaccida*, or *Shrapnell's membrane*, lacks the tenseness of the rest of the structure. When light is thrown upon the normal tympanic membrane, a bright reflection (known as the pyramid of light) is seen in its lower anterior quadrant. The apex of the bright triangle is at the tip of the manubrium, and its base is on or near the periphery of the membrane.

FIG. 396.—Normal Membrana Tympani (right side). After Jacobson.)

FIG. 397.—Normal Membrana Tympani (left side). (After Jacobson.)

Auditory Ossicles.—The vibrations of the tympanic membrane are transferred to the *fenestra ovalis* of the labyrinth by a chain of three little bones: the *malleus* (hammer), *incus* (anvil), and *stapes* (stirrup), the so-called *auditory ossicles* (Figs. 398, 399). The *malleus* has a rounded head grooved on one side for articulation with the incus, a short neck and a long

* Macewen, "Pyogenic Diseases of the Brain and Spinal Cord," 1893.

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Audition.
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handle or *manubrium*, which is inserted in the tissue of the tympanic membrane from a point on its upper periphery to a little below its centre. The *processus brevis* of the malleus is a low conical projection which rises from the top of the manubrium and presses directly against that segment of the tympanic membrane which lies immediately below the *membrana flaccida*. These parts can usually be seen on inspection with the ear speculum (Figs. 393, 396, 397). The *processus gracilis* or *processus Folianus*, long and slender, arises from an eminence just below the neck of the malleus, and, passing forward and outward, is inserted in the Glaserian fissure in the wall of the tympanum. The malleus is held in position partly by ligaments. The *superior* or *suspensory ligament* passes downward and outward from the roof of the tympanum to be inserted into the head of the malleus. The main portion of the *anterior ligament* (Fig. 400) is attached to the neck of the malleus just above the *processus gracilis*; it embraces the latter, and, passing forward, finds its origin in the anterior wall of the tympanum and in the Glaserian fissure. Another division of this ligament, the *external ligament*, arises and is attached more externally than that just described. The ligaments of the malleus serve to keep its head in position (Figs. 400, 401). The external ligament being attached above the axis of rotation of the hammer, prevents the head of this bone from moving too far inward, and the manubrium from being pushed too far outward. The superior ligament, owing to its oblique course, restrains the head of the hammer from moving too far outward.

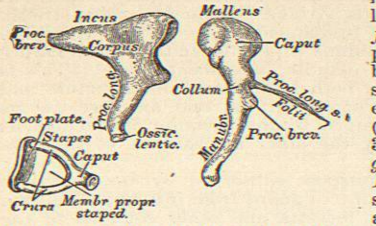

FIG. 398.—The Three Ossicles. (After Heitzmann).

The *incus*, *ambos*, or anvil bone, is shaped somewhat like a bicuspid tooth. Its body is hollowed on the surface and covered with cartilage for articulation with the head of the malleus. It has two processes, a *long* and a *short*, which project at right angles to each other. Their respective lengths are about 4 and 3 mm. When in natural position, the long process descends nearly parallel with the manubrium, but it has less than three-fourths the length of the latter. The free end of the long process is turned sharply inward at right angles, and terminates in a rounded projection, the *os orbiculare* or *lenticulare*, which is provided with cartilage for articulation with the head of the *stapes*.—The short process is conical in shape and is thicker than the long process. It has a horizontal position, and is attached by a thick ligament to the posterior wall of the tympanum.

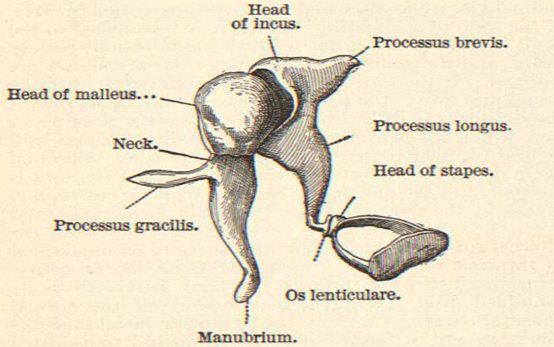

FIG. 399.—The Ossicles in Their Normal Relations. (After Henle.)

The *stapes* articulates with the end of the long process of the incus; its plane is horizontal and about at right angles to that process. It measures about 3 to 4 mm. in length by about 2.5 in breadth. The base of the stirrup bone is set in the *fenestra ovalis*, an aperture measuring about 3 by 1.5 mm., and is held in position by a narrow membrane made up of radial fibres of connective tissue (Fig. 402). When in position, the innerface of the base of the stapes is covered with lymphatic endothelium and is washed by the perilymph of the internal ear; the outer face, like the other ossicles and the wall of the tympanum, is covered by thin mucous membrane.

Movements of the Ossicles.—The *malleus-incus* articulation is so arranged that with outward movements of the manubrium the head of the malleus glides freely in the joint; but the lower margins of the articulating surfaces project in such a way that the prominences catch upon each other and interlock when the manubrium is moved inward. Thus, in inward movements of the tympanic membrane and its attached manubrium, the malleus and incus move together like one rigid piece of bone, the motions of the manubrium and of the long process of the incus being parallel. In the outward movements the locking teeth or projections are probably, under ordinary conditions, still kept in apposition through the elastic

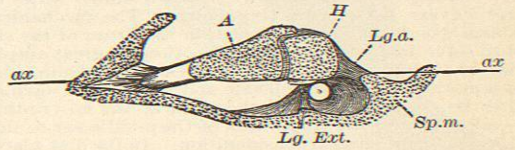

FIG. 400.—A Nearly Horizontal Section through the Tympanum, Including the Malleus-Incus Articulation. *H*, Head of hammer, inner surface; *A*, anvil or incus, whose short process is held by ligaments in a bony niche: *Sp.m.*, spina major of tympanic wall; *Lg.a.*, anterior ligament; *Lg. Ext.*, external ligament. The line *ax–ax* represents the axis of rotation of the two ossicles. (After Hensen.)

reaction of the ligament and the stapedial attachment of the incus. Should, however, the tympanic membrane be forced unduly outward, as by increase of pressure within the tympanum or rarefaction of the air in the auditory meatus, the incus only follows the malleus for a certain distance, the latter completing its motion by gliding in the joint. There is thus no danger of the stapes being torn out of the oval window. Of the malleus-incus articulation Helmholtz says: "In its action it may be compared with the joints of the well-known Bréguet watch keys, which have rows of interlocking teeth, offering scarcely any resistance to revolution in one direction, but allowing no revolution whatever in the other." The hammer and the anvil, suspended by their ligaments, move freely about an axis one end of which is found at the origin of the anterior part of the anterior ligament of the malleus, and the other end in the origin of the ligament which is continuous with the short process of the incus (Fig. 400).

In inward motions of the tympanic membrane (and probably under ordinary conditions in outward motions as well), the ossicles move like a single bone about the axis of suspension. The three bones may be likened, then, to a single rigid lever of peculiar form. The power is applied to this lever at the tip of the manubrium, the effect is produced at the footplate of the stapes. Observation shows that the fulcrum is found at the end of the short process of the incus. From the latter point the distance measured to the *umbo* or tip of the manubrium is about one and one-half times the distance from the fulcrum to the end of the long process of the incus. Therefore, motions imparted to the stapes can have but two-thirds the amplitude of those arising at the umbo; but, according to the principles of the lever, the former movements have one and one-half times the force of the latter. It will be noticed that a large proportion of the mass of both anvil and hammer is found above their axis of rotation; this upper portion acts as a counterpoise to the parts below which are directly concerned in the lever action. The bony lever being thus balanced, it is less difficult to understand its known sensitiveness to impulses that are inconceivably weak. The tense tympanic membrane, by reason of its funnel shape, resists strong inward compression; hence the stapes is prevented from being pressed too far inward. The maximum amplitude of motion of the end of the long process of the incus is very small, being only about $\frac{1}{18}$ to $\frac{1}{14}$ mm., while that of the centre of the tympanic membrane is about $\frac{1}{12}$ to $\frac{1}{9}$ mm.

The great rapidity of aërial vibrations to which the chain of ossicles can respond suggests that it conducts the sound pulses as molecular or longitudinal vibrations, as a rigid rod of wood transmits the tick of a watch. But Helmholtz has shown reasons for believing that the functional movements of the ear bones is molar, that they oscillate as a whole, the chain moving in a body with each impulse. It is open to suspicion that the upper limit of the scale of pitch may be determined by the superior rate of vibration to which the chain of bones is capable of responding. The sole purpose of this apparatus of the middle ear is to transmit exactly the variations of pressure in the air of the external auditory meatus to the perilymph which bathes the foot of the stapes; in other words, to convert air waves into a similar series of water waves. As put by Helmholtz: "The mechanical problem which the apparatus within the drum of the ear had to solve was to transform a motion of great amplitude and little force, such as impinges on the drum skin, into a motion of small amplitude and great force, such as had to be communicated to the fluid in the labyrinth." The adaptation of the apparatus of the middle ear to this end is worthy of careful consideration. In the first place, it will be noticed that the area of the fenestra ovalis which receives the impulses of the stapes is but a small fraction of the surface of the tympanic membrane on which the air waves impinge, the latter area being some fifteen to twenty times greater than the former, so that the energy of air motion is, in a fashion, concentrated. In the second place, as previously observed, the lever mechanism of the auditory ossicles is such that the movements of the end of the long process of the incus have two-thirds the amplitude of those of the tip of the manubrium, but about one and one-half times their force. It should also be noticed that the membrane fastening the foot of the stapes in the fenestra is somewhat less tense on the upper side, so that the top of the oval footpiece has a freer motion than the bottom, and, as the end of the incus process moves somewhat upward and inward, the head of the stirrup rises slightly with inward motions. In other words, the stapes itself forms an independent lever, of which the long arm is the height of the stirrup and the short arm less than the breadth of its footpiece, by which the motion imparted by the incus is further reduced in amplitude but increased in power. In the third place, it has been demonstrated by Helmholtz that the shape of the tympanic membrane peculiarly adapts it for transforming weak movements of wide amplitude into strong ones of small compass. For this membrane is not a simple funnel depressed inwardly, but the radii are slightly curved with the convexity outward, a shape chiefly due, it is said, to the tension of the elastic circular fibres of the membrane on its inner face, these being most numerous toward the circumference. Air waves beating upon this convexity flatten the curve somewhat, and their whole energy must be concentrated, with increased intensity, but loss of motion, near the central point of the membrane. The same effect is illustrated by the fact that when a string or rope is stretched horizontally between two points, no matter how tightly, it always sags in the middle; the weight of the cord, however slight, drags it down in a curve, and produces a corresponding traction on the points of support.

Special Properties of the Tympanic Membrane.—It is evident that any marked tendency of the transmitting apparatus of the middle ear to vibrate at a particular rate—that is, possession by it of a strong fundamental tone—would render impossible the conduction of aërial pulses in their actual proportion of intensity. Membranes have fundamental tones (see p. 613) whose pitch is determined by their area, thickness, and tension, but they differ from rods, strings, etc., in being less strictly confined to a single fundamental tone in their vibration. The tympanic membrane is peculiar in that it can hardly be said to have a definite fundamental tone. This is prevented probably both by reason of its structure and the peculiar form of its surface, and also because its oscillations are damped by the pressure of the malleus held in position by the other mechanisms of the tympanum.

One important purpose subserved by the tympanic membrane is no doubt to guard from injury the delicate membranes of the fenestræ and other contents of the middle ear. The astonishing freedom of the normal membrane from foreign particles is probably due to a radial movement of its surface epithelium in the course of cellular renewal.

When the tympanic membrane is perforated or is even wholly removed, without destructive inflammatory changes in the middle ear, sounds are still heard, though usually with diminished loudness. An artificial drum inserted in the meatus occasionally improves hearing in the absence of the normal membrane, or when the transmitting mechanism is abnormally relaxed. It is said that it should be placed in contact with the malleus, and its mode of action seems to be to bring aërial vibrations to bear effectively upon the ossicles. A small wad of cotton has been employed with the same result.

When the tympanic membrane is absent, air waves beat directly upon the membranes of the fenestræ, and certain sounds may then be heard with increased loudness. But in the absence of the elaborate arrangement described above for abolishing sympathetic vibration of the sound-conducting mechanism, it is probable that the fenestral coverings are crude and inaccurate interpreters of the sounds beating upon them. Thus, a musician who had suffered loss of his tympanic membranes was no longer able to play his violin, probably because sounds of different pitch ceased to be perceived in their true relations of loudness (Dr. E. C. Rivers).

Hearing by Bone Conduction.—Just as the sound of a watch or tuning fork may be conducted through a wooden rod, so molecular vibrations may pass to the auditory apparatus through the bones of the skull. Such movements probably have the nature of the longitudinal vibrations discussed in a previous section (p. 611). If the stem of a sounding tuning fork be touched to the skull or held between the teeth the tone will be plainly heard, and the sound becomes louder when the ears are stopped. If the fork be held between the teeth until the sound dies away, the tone reappears upon closing one of the auditory canals and on the same side as the closure. A fork which has become silent to air conduction may still be heard if held between the teeth; and when the sound again dies away, it returns when the stem of the fork is inserted into the meatus.* Hearing by bone conduction occurs in the absence of the tympanic membranes, and even when the membranes covering the fenestræ of the internal ear are so altered by disease as to be ill adapted to transmit vibrations. Such vibrations are, probably, transmitted directly through the bony labyrinth to its contained fluid, though in the presence of the normal fenestral coverings and of the tympanic membrane the vibrations are, without doubt, taken up and transmitted by these structures. Closing the ears would then reflect and intensify the sound.

In deafness due to middle-ear trouble sound can still be plainly heard by bone conduction. The *audiphone* is essentially a sheet of some elastic material, as hard rubber, easily set into sympathetic vibration, which is held

* Hensen: Hermann's Hdb. d. Physiologie, Bd. iii., Th. 2.

against the teeth to which it transmits vibrations that it has taken up like a sounding board.

In deafness due to disease of the internal ear vibrations conducted through the bones of the skull make no auditory impression. According to Egger,* even when there is deafness to skull vibrations, a tuning fork may still be heard and pitch recognized when it is applied to the bones of the extremities (olecranon, tibia). As this power fails when the part is made anæmic by Esmarch's bandage, the author ascribes the sensation not to bone conduction, but to irritation of the auditory centres by way of the nerves of common sensation.

Eustachian Tube.—Any steady inequality of air pressure on the two sides of the tympanic membrane would evidently more or less interfere with its functional movements. As air is probably continuously absorbed from the tympanum and as external barometric pressure is ever varying, the drum of the ear needs some arrangement for the maintenance of an equilibrium of air pressure on the two sides of the tympanic membrane. Such a mechanism is found in the *Eustachian Tube*, a somewhat trumpet-shaped canal which, beginning in the lower, anterior wall of the tympanum, runs downward, forward, and inward, and terminates in a slit in the side of the upper part of the pharynx (Fig. 394). The Eustachian tube is lined, like the walls of the tympanum, with ciliated epithelium, the cilia working in such a way as to convey into the pharnyx such secretions as may be poured into the middle ear, as well as the foreign matter that may enter the canal from the pharynx. A consideration of the ordinary mode of infection of the middle ear from the pharnyx suggests how important a rôle must be borne by the ciliated epithelium in the preservation of health.

The pharyngeal opening of the Eustachian tube is probably usually closed, but may be made to open by considerable increase of air pressure within the pharynx, as may be produced by closing the nose and mouth and either forcing air into the pharynx by strong expiratory movement or rarefying it by suction. In the former case air pressure within the middle ear is increased, in the latter it is diminished. When air is thus made to enter or leave the tympanum a sensation of a sudden snap and a dull crackling noise in the ear are experienced. The lower end of the tube is normally opened during the act of swallowing, and it is at this moment that the intra- and extra-tympanic pressures are equalized. The well-known method of Politzer for inflation of the middle ear consists in forcing air into one nostril during the act of swallowing, while the other nostril and the mouth are closed.

Muscles of the Middle Ear.—There are two intrinsic muscles of the middle ear which serve to adjust the tension of its transmitting mechanism. Roughly speaking, they are antagonistic in action. The *tensor tympani* muscle is lodged within a groove which is just above and about parallel with the Eustachian tube (Fig. 394). It terminates externally in a long tendon which bends nearly at right angles round the outer edge of the groove and is inserted into the handle of the malleus near the neck. Contraction of the tensor tympani thus pulls the tympanic membrane inward, renders it more tense, and somewhat dampens its vibrations (Fig. 401). At the same time the toothed processes of the incus and malleus are brought closely together so that there can be no loss of motion in vibration of the ossicles, and the stapes is driven further into the oval window, increasing tension within the labyrinth. Opinion is somewhat divided as to the conditions of functional activity of the tensor tympani. The normal tone of the muscle probably gives it some constant tensor effect. It is said that the relaxed tympanic membrane, particularly after section of the tensor tympani muscle in lower animals, is thrown into sympathetic vibration with comparative ease, and is in this condition best adapted to respond to weak aërial impulses and to the periodic waves of musical notes. When the membrane is tense its vibrations are more or less damped and it is then best fitted to transmit with distinctness the irregular vibrations of noises and consonantal sounds. It would follow that the action of the muscle facilitates distinct appreciation of speech while it diminishes acuteness of hearing. According to Hensen* the tensor tympani muscle is reflexly excited to contract by the initial waves of a sound, resulting in a closer interlocking of malleus and incus, thereby preventing loss of motion in subsequent vibrations. But Osterman† has given reason for believing that the muscle is chiefly a protective mechanism called into play only or mainly by

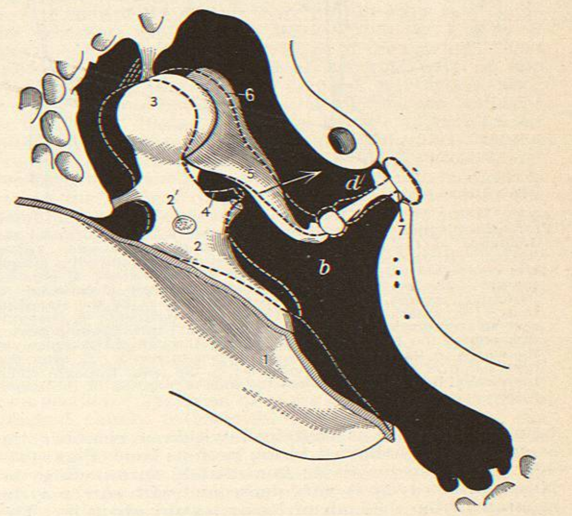

FIG. 401.—Diagram Representing the Mode of Displacement of the Ossicles under the Influence of the Contraction of the Tensor Tympani Muscles. (After Testut.) *a*, External auditory canal; *b*, tympanic cavity; *c*, vestibule of the inner ear; *d*, fenestra ovalis; 1, membrana tympani; 2, manubrium mallei; 2′, section of the long process of the malleus; 3, head of the malleus; 4, insertion of the tendon of the tensor tympani muscle; 5, vertical or long process of the incus; 6, head of this ossicle; 7, the stapes. The dotted lines indicate the positions which the ossicles and tympanic membrane will assume when the tensor tympani muscle contracts; the arrow shows the direction of this movement.

very loud and painful noises. Its action prevents oscillations of the tympanic membrane which would otherwise be of so great amplitude as to damage the ear.

The *stapedius* is a small muscle embedded in the inner wall of the tympanum near the fenestra ovalis. Its tendon, passing forward, is inserted into the neck of the stapes. Contraction of the muscle would have the effect of pressing the hinder part of the foot of the stapes either against the edge of the oval window or farther into the opening, and of withdrawing the forward part from it (Fig. 402). The muscle may therefore be considered to diminish pressure within the labyrinth, causing the membrane of the round window to be drawn inward. Its action in these respects is the opposite of that of the tensor tympani. It is said that the stapedius is controlled by the facial and the tensor tympani by the fifth nerve.

A bundle of fibres passing backward from the anterior part of the tympanum to be inserted into the malleus just above the root of the processus gracilis has been described as the *laxator tympani muscle*. It will receive no further notice since Helmholtz and others consider it to be merely a ligamentous support for the malleus.

The Internal Ear or Labyrinth.—This is the seat of

* Egger, M.: Compt. rend. de la soc. d. biol., 1898, 815; Jahresbericht d. Physiologie, 1899, S. 98.

* Hensen: Hermann's Hdb. d. Physiologie, Bd. iii., 1880.
† Osterman: Arch. f. Anat. u. Physiologie, 1898, s. 75.

the sensory organ of hearing. It is composed of a complicated system of membranous tubes and sacs, the *membranous labyrinth*, in which terminate at particular points bundles of filaments of the auditory nerve. The mem-

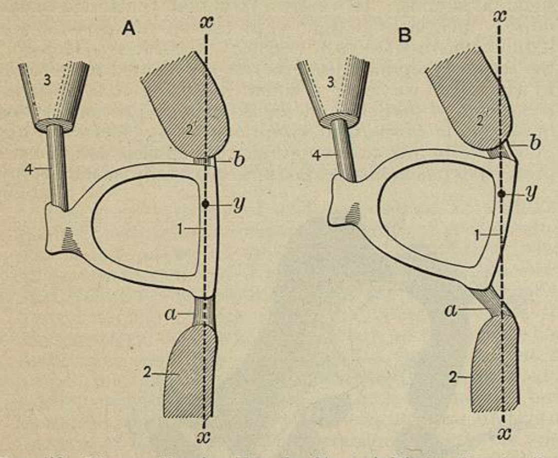

FIG. 402.—Diagram Showing How the Stapes is Displaced under the Influence of the Contraction of the Stapedius Muscle. (After Testut.) *A*, Stapes in repose; *B*, stapes after the stapedius muscle has contracted. 1, Base or footplate of the stapes; 2, anterior margin of the fenestra ovalis; 2′, posterior margin of the same; 3, pyramidal process, giving exit to the tendon (4) of the stapedius muscle; *a*, anterior portion of the annular ligament; *b*, posterior and shorter portion of the same ligament; *xx*, antero-posterior diameter of the fenestra ovalis, passing through the footplate of the stapes in its two positions—*A*, when in repose, *B*, after the contraction of the stapedius muscle; *y*, the point through which the vertical line that represents the axis of rotation of the stapes passes.

branous labyrinth is contained within a chamber, the *bony labyrinth*, hollowed in the petrous bone (Figs. 403–406). The osseous tissue immediately surrounding the labyrinthine cavity is very dense and with care may be separated from the bone of looser texture about it. The cavity of the bony labyrinth (Figs. 403, 404) consists of

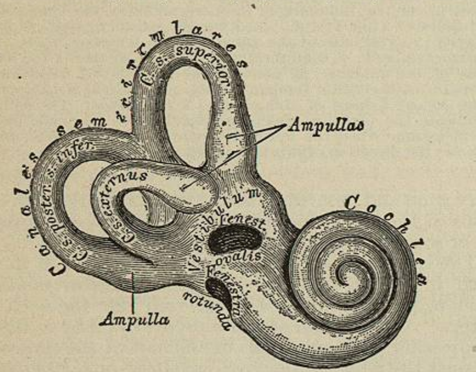

FIG. 403.—The Bony Shell of the Labyrinth. (After Heitzmann.) $\frac{3}{1}$.

a median part, the *vestibule*, which is prolonged posteriorly in the system of *semicircular canals* and anteriorly in the *cochlea*. The vestibule is a space which measures in man about one-fifth of an inch in diameter, and it is perforated on its outer wall by the oval opening known as the *fenestra ovalis*. The semicircular canals are three tubes of circular section, known respectively as the anterior or superior, the posterior, and the external or horizontal semicircular canal. Their planes are about at right angles to one another, so that they occupy the three possible dimensions of space. Each canal is dilated at one extremity into a globular cavity which is known as the *ampulla*. The anterior and posterior canals unite near the ends not provided with ampullæ, and they enter the vestibule as a common tube. Anteriorly the vestibule is continued as a tube which is coiled upon itself two and one-half times, and which, from its resemblance to the shell of a snail, is known as the *cochlea*. The osseous cochlea (Fig. 405) may be conceived as formed by a bony tube coiled about a bony central pillar, the *modiolus*, which is of spongy texture and diminishes in diameter from the base to the apex of the cochlea. From the modiolus a bony shelf, the *lamina spiralis*, stretches into the cavity of the tube, incompletely dividing it into two tubular chambers, and winds round the central pillar like a spiral staircase. The separation of the spaces on either side of the *lamina spiralis* is rendered complete by membranous structures to be considered later. The tubular area on that side of the lamina spiralis which faces the apex of the cochlea is in free communication with the vestibule and is known as the *scala vestibuli*. The part of the canal which is on the opposite side of the lamina spiralis, facing the base of the cochlea, is known as the *scala tympani*, because it comes into relation with the tympanum at the fenestra rotunda (Figs.

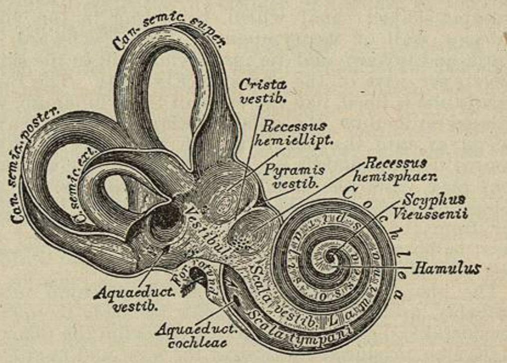

FIG. 404.—The Bony Labyrinth, Open toward the Front. (After Heitzmann.) $\frac{3}{1}$.

405–408). In the upright position of the head the axis of the modiolus is nearly horizontal, pointing from base to apex, outward and slightly downward and forward, the base of the cochlea being formed by the inner surface of the petrous bone. Contained within the cavity of the bony labyrinth, and on the whole parallel with its walls, is the *membranous labyrinth*, in which are found the

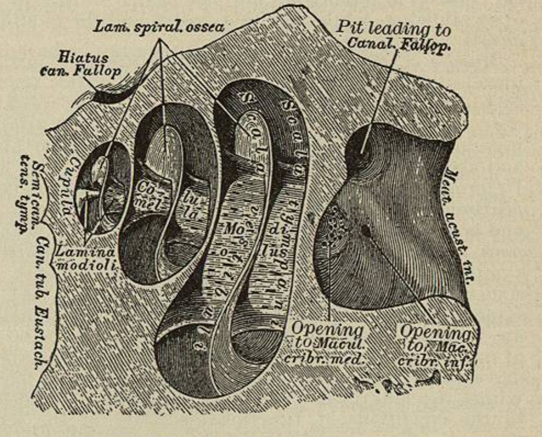

FIG. 405.—The Cochlea, Opened in a Direction at Right Angles to the Axis of the Pyramidal Portion of the Temporal Bone. (After Heitzmann.) $\frac{4}{1}$.

essential structures of the organ of hearing (Figs. 406–408). The membranous labyrinth is filled with a somewhat watery, mucin-holding fluid, the *endolymph*, while a similar fluid, the *perilymph*, fills the space between the membranous labyrinth and the bony walls outside it.

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The perilymphatic space is lined with lymphatic epithelium and is in communication, along the sheath of the auditory nerve, with the subdural and subarachnoid lymph areas of the brain. Numerous sheets and bars of connective tissue reach from the wall of the bony to that of the membranous labyrinth and help support the latter.

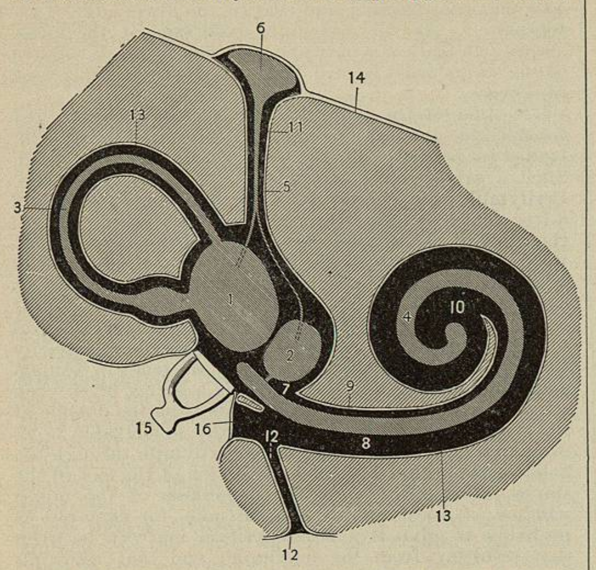

FIG. 406.—Diagram Indicating the Peri- and Endo-lymphatic Spaces of the Inner Ear. (After Testut.) The endolymphatic spaces are represented in gray, the perilymphatic in black. 1, Utriculus; 2, sacculus; 3, semicircular canals; 4, cochlear canal; 5, endolymphatic canal, with its two initial branches; 6, endolymphatic cul-de-sac; 7, canal of Hensen or canalis reuniens; 8, scala tympani; 9, scala vestibuli; 10, their point of union at the helicotrema; 11, aquæductus vestibuli; 12, aquæductus cochleæ; 13, periosteum; 14, dura mater; 15, stapes in the fenestra ovalis; 16, fenestra rotunda and secondary tympanic membrane.

That part of the membranous labyrinth which is contained within the bony vestibule is composed of two separate sacs which only indirectly communicate with each other (Figs. 406, 407). The posterior sac is larger and is known as the *utriculus* or *utricle*. From it spring the membranous semicircular canals. The smaller anterior sac is called the *sacculus* or *saccule*. The cavities of the utricle and saccule are indirectly continuous through two small tubes which arise from either sac and, uniting, form a single tube, the *ductus endolymphaticus*, which runs inward through a canal in the petrosal bone and ends blindly in a dilated, flattened extremity, the *saccus endolymphaticus*, which is supported between the layers of the *dura mater* within the cranial cavity. The plane separating the two vestibular sacs is perpendicular to, and opposite the fenestra ovalis (Fig. 406). The sacculus communicates by a narrow tube, the *canalis reuniens*, with that division of the membranous labyrinth which is contained within the bony cochlea and known as the *canalis* or *ductus cochlearis* (Fig. 406).

The *auditory nerve* consists of at least two divisions having separate origins and different distributions. One of these branches passes finally to the cochlea, and the other to the vestibule and semicircular canals. The nerve approaches the labyrinth by way of a canal known as the *meatus auditorius internus*, and on reaching the angle between the base of the cochlea and the vestibule, the cochlear branch passes to its destination, while of the remainder of the nerve a superior division is distributed to the utricle and to the ampullæ of the anterior and horizontal semicircular canals, and the inferior division supplies the saccule and ampulla of the posterior canal.

The inner wall of both utricle and saccule is elevated at a particular spot into a low eminence, the *macula acustica*, formed by development of the connective tissue of the membranous wall. In a similar way, the inner wall of each ampulla of the semicircular canals is developed in a ridge projecting into the cavity across its long axis and known as the *crista acustica*. Both *maculæ* and *cristæ* are covered by peculiarly modified columnar epithelial cells, called *auditory epithelium* because they receive the terminal twigs of the auditory nerves. The auditory cells are said to be of two kinds. One variety is cylindrical in shape and reaches only part way to the basilar membrane, the *hair cells;* the other, narrow and elongated, the supporting or *sustentacular cells*. From the free ends of the former there project long, stiff, hair-like processes, the *auditory hairs*, which are longer on the cells of the cristæ than on those of the maculæ. The auditory nerve filaments supplying this part of the labyrinth pass through the maculæ and cristæ and, breaking up into nodulated fibrils, encircle the bodies of the hair cells. Seated on the free surface of the macular epithelium is a fibrous mass which is said to be a normal structure and not, like a somewhat similar mass found covering the cristæ in post-mortem sections, a coagulum due to the method of preparation. Embedded in the membrane over the maculæ of both sacs are small crystals, *otoliths* or *otoconia*, composed chiefly of carbonate of lime. Otoliths are found at times also in the ampullæ and even in the perilymph space of the cochlea. In some fishes there are large masses of calcareous matter, otoliths, attached to the walls of the vestibular sacs.

The Membranous Cochlea.—By far the most complex structure of the ear is found in the cochlea. The membranous cochlea (Figs. 408, 409), sometimes known as the *canalis* or *ductus cochlearius*, is a tube of nearly triangular cross section. The base or outer side of this triangle is attached closely to the wall of the bony cochlea; the upper side, supposing the modiolus to be vertical with its apex above, is made of a thin sheet of cells known as the *membrane of Reissner;* the lower side is made up partly of the bony margin of the *lamina spiralis* and partly of a membrane radially striated, stretched across from the edge of the spiral lamina to the side wall of the cochlea; this is called the *basilar membrane* or *membrana basilaris* (Fig. 409).

The coiled tube of the osseous cochlea is thus divided longitudinally into three parallel tubes: the *scala vestibuli* and the *scala tympani* on either side of the lamina spiralis,

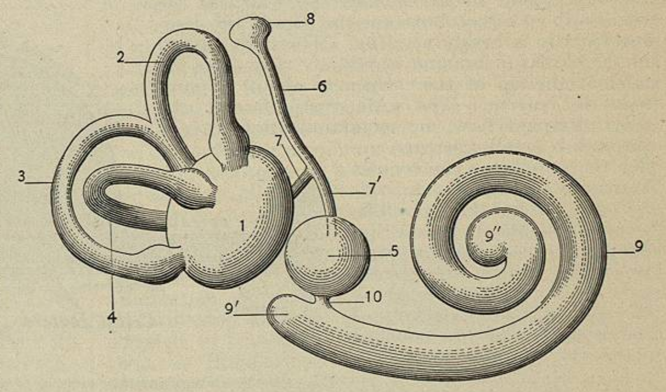

FIG. 407.—Membranous Labyrinth of the Right Side. (After Testut.) 1, Utriculus; 2, superior semicircular canal; 3, posterior semicircular canal; 4, external semicircular canal; 5, sacculus; 6, endolymphatic canal, *ductus endolymphaticus*, with (7 and 7′) its parent canals; 8, its terminal cul-de-sac, *saccus endolymphaticus*; 9, cochlear canal, with (9′) its vestibular cul-de-sac and (9″) its terminal cul-de-sac; 10, canalis reuniens of Hensen.

and the *canalis cochlearis* between them, where the spiral lamina is wanting.

The *canalis cochlearis* contains endolymph and is closed at each end, but its cavity communicates by way of the narrow *canalis reuniens* with that of the saccule. The