yond the analysis made many years ago by Frerichs. According to this observer the following is the composition of the lachrymal secretion:

COMPOSITION OF THE TEARS.

Water	990·60	to	987·00
Epithelium	1·40	"	3·20
Albumin	0·80	"	1·00
Sodium chloride, Alkaline phosphates, Earthy phosphates, Mucus, Fat	7·20	"	8·80
	1,000·00		1,000·00

The specific gravity of the tears has never been ascertained. The liquid is perfectly clear, colorless, of a saltish taste and a feebly alkaline reaction. The albumin given in the table is called by some authors, lachrymine, thrænine or dacryoline. This substance, whatever it may be called, resembles mucus in many regards and probably is secreted by the conjunctiva and not by the lachrymal glands. Unlike ordinary mucus, it is coagulated by water.

The secretion of tears is readily influenced through the nervous system. Aside from the increased flow of this secretion from emotional causes, which probably operate through the sympathetic, a hypersecretion almost immediately follows irritation of the mucous membrane of the conjunctiva or of the nose. The same result follows violent muscular effort, laughing, coughing, sneezing etc. The secretion of tears following stimulation of the mucous membrane is reflex.

CHAPTER XXIII.

AUDITION.

Auditory (eighth nerve)—General properties of the auditory nerves—Topographical anatomy of the parts essential to the appreciation of sound—The external ear—General arrangement of the parts composing the middle ear—Anatomy of the tympanum—Arrangement of the ossicles of the ear—Muscles of the middle ear—Mastoid cells—Eustachian tube—Muscles of the Eustachian tube—General arrangement of the bony labyrinth—Physics of sound—Noise and musical sounds—Pitch of musical sounds—Musical scale—Quality of musical sounds—Harmonics, or overtones—Resultant tones—Summation tones—Harmony—Discords—Tones by influence—Uses of different parts of the auditory apparatus—Structure of the membrana tympani—Uses of the membrana tympani—Mechanism of the ossicles of the ear—Physiological anatomy of the internal ear—General arrangement of the membranous labyrinth—Liquids of the labyrinth—Distribution of nerves in the labyrinth—Organ of Corti—Uses of different parts of the internal ear—Centres for audition.

IMPRESSIONS of sound are conveyed to the brain by special nerves; but in order that these impressions shall reach these nerves so as to be properly appreciated, a complex accessory apparatus is required, the integrity of which is essential to perfect audition. The study of the arrangement and action of these accessory parts is even more important and is far more intricate than

the physiology of the auditory nerves. The auditory nerves conduct impressions of sound, as the optic nerves conduct impressions of light; but there is an elaborate arrangement of parts by which the waves are collected, conveyed to a membrane capable of vibration, and finally carried to the nerves, by which the intensity and the varied qualities of sound are appreciated.

AUDITORY (EIGHTH NERVE).

The origin of the auditory nerve can easily be traced to the floor of the fourth ventricle, where it presents two roots. The external, or superficial root, sometimes called the posterior root, can be seen usually without preparation. It consists of five to seven grayish filaments, which decussate in the median line, and pass outward, winding from the fourth ventricle around the restiform body. The deep root consists of a number of distinct filaments arising from the gray matter of the fourth ventricle, two or three of which pass to the median line, to decussate with corresponding filaments from the opposite side. Filaments from this root have been traced to a gray nucleus in the inferior peduncle of the cerebellum and thence to the white substance of the cerebellum itself. The deep root passes around the restiform body inward, so that this portion of the medulla is encircled by the two roots. Passing from the superior and lateral portion of the medulla oblongata, the trunk of the nerve is applied to the superior and anterior surface of the facial. It then passes around the middle peduncle of the cerebellum, and receives a process from the arachnoid membrane, which envelops it in a common sheath with the facial. It finally penetrates the internal auditory meatus. In its course it receives filaments from the restiform body and possibly from the pons Varolii. Within the meatus the nerve divides into an anterior and a posterior branch, the anterior being distributed to the cochlea, and the posterior, to the vestibule and semicircular canals. The distribution of these branches will be fully described in connection with the anatomy of the internal ear.

The auditory nerves are grayish in color, and their consistence is soft, thus differing from the ordinary cerebro-spinal nerves, and resembling to a certain extent the other nerves of special sense. On the external, or superficial root, is a small, ganglioform enlargement, containing fusiform nerve-cells. The filaments of the trunk of the nerve consist of very large axis-cylinders, surrounded by a medullary sheath, but having no tubular membrane. In the course of these fibres, are found small, nucleated, ganglionic enlargements.

General Properties of the Auditory Nerves.—There can be no doubt, as regards the eighth, that it is the only nerve capable of receiving and conveying to the brain the special impressions produced by waves of sound; but it is an important question to determine whether this nerve be endowed also with general sensibility. Analogy with most of the other nerves of special sense would indicate that the auditory nerves are insensible to ordinary impressions; and this view has been sustained by direct experiments. In experiments made by passing electric currents through the ears, some physi-

ologists have thought that auditory sensations were produced; but it is probable that the sensations observed were due to clonic spasm of the stapedius muscle and not to impressions of sound produced by the action of the stimulus upon the auditory nerves. In cases of complete facial paralysis from otitis, in which paralysis of the auditory nerve could be positively excluded, it has not been possible to produce subjective auditory sensations, even by powerful Faradization by means of a catheter passed through the Eustachian tube into the tympanic cavity or by the external meatus (Wreden). In addition there are well established clinical observations which sustain the theory of muscular contraction and are opposed to the idea of impressions of sound produced by direct stimulation of the auditory nerves. The results, then, as regards stimulation of the auditory nerves, have been simply negative. Were it practicable to subject the nerves to mechanical or electric stimulation, in the human subject, without involving other parts, it might be possible to arrive at a definite conclusion; but the difficulties in the way of such an experiment have thus far proved insurmountable.

Topographical Anatomy of the Parts essential to the Appreciation of Sound.

Perfect audition involves the anatomical integrity of a complex apparatus, which, for convenience of anatomical description, may be divided into the external, middle and internal ear.

1. The external ear includes the pinna and the external auditory meatus, and is bounded internally by the membrana tympani.

2. The middle ear includes the cavity of the tympanum, or drum, with its boundaries. The parts here to be described are the membrana tympani, the form of the tympanic cavity, its openings, its lining membrane, and the small bones of the ear, or ossicles, with their ligaments, muscles and nerves. The cavity of the tympanum communicates by the Eustachian tube with the pharynx, and it also presents openings into the mastoid cells.

3. The internal ear contains the terminal filaments of the auditory nerve. It includes the vestibule, the three semicircular canals and the cochlea, which together form the labyrinth.

The pinna and the external meatus simply conduct the waves of sound to the tympanum. The parts entering into the structure of the middle ear are accessory, and are analogous in their uses to the refracting media of the eye. Structures contained in the labyrinth constitute the true sensory organ.

The External Ear.—The pinna, or auricle, is that portion projecting from the head, which first receives the waves of sound. The outer ridge of the pinna is called the helix. Just within this, is a groove called the fossa of the helix. This fossa is bounded anteriorly by a prominent but shorter ridge, called the antihelix; and above the concha, between the superior portion of the antihelix and the anterior portion of the helix, is a shallow fossa, called the fossa of the antihelix. The deep fossa, immediately surrounding the opening of the meatus, is called the concha. A small lobe projects posteriorly, covering the anterior portion of the concha, which is called the tragus; and the projection at the lower extremity of the antihelix is called the antitragus. The fleshy, dependent portion of the pinna is called the lobule of the ear.

The form of the pinna and its consistence depend upon the presence of fibro-cartilage, which occupies the whole of the external ear except the lobule. The structure of this kind of cartilage has already been described.

The integument covering the ear does not vary much from the integument of the general surface. It is thin, closely attached to the subjacent parts, and possesses small, rudimentary hairs, with sudoriparous and sebaceous glands.

The muscles of the external ear are not important in the human subject; and excluding a few exceptional cases, they are not under the control of the will. The extrinsic muscles are the superior, or attollens, the anterior, or attrahens, and the posterior, or retrahens aurem. In addition there are the six small intrinsic muscles, situated between the ridges upon the cartilaginous surface. The pinna is attached to the sides of the head, by two distinct ligaments and a few delicate, ligamentous fibres.

The external auditory meatus is about an inch and a quarter (31·8 mm.) in length and extends from the concha to the membrana tympani. Its course is somewhat tortuous. Passing from without inward, its direction is at first somewhat upward, turning abruptly over a bony prominence near the middle, from which it has a slightly downward direction, to the membrana tympani. Its general course is from without inward and slightly forward. The inner termination of the canal is the membrana tympani, which is quite oblique, the upper portion being inclined outward, so that the inferior wall of the meatus is considerably longer than the superior.

The walls of the external meatus are partly cartilaginous and fibrous, and partly bony. The cartilaginous and fibrous portion occupies a little less than one-half of the entire length and consists of a continuation of the cartilage of the pinna, with fibrous tissue. The lower two-thirds of this portion of the canal is cartilaginous, the upper third being fibrous. The rest of the tube is osseous and is a little longer and narrower than the cartilaginous portion. Around the inner extremity of the canal, except at its superior portion, is a narrow groove, which receives the greater portion of the margin of the membrana tympani.

The skin of the external meatus is continuous with the integument covering the pinna. It is very delicate, becoming thinner from without inward. In the osseous portion it adheres very closely to the periosteum, and at the bottom of the canal it is reflected over the membrana tympani, forming its outer layer. In the cartilaginous and fibrous portion, are short, stiff hairs, with sebaceous glands attached to their follicles, and the coiled tubes known as the ceruminous glands. The structure of these glands and the properties and composition of the cerumen have already been described in connection with the physiology of the glands of the skin.

General Arrangement of the Parts composing the Middle Ear.—Without a very elaborate description, fully illustrated by plates, it is difficult to give a

clear idea of the structure and relations of the complex anatomical parts in the middle and the internal ear. Such a minute and purely anatomical description would be out of place in this work, where it is desired only to give such an account of the anatomy as will enable the student to comprehend the physiology of the ear, reserving for special description certain of the most important structures. It will be useful, however, to give a general outline of the different parts, with their names.

The arrangement of the parts constituting the external ear is sufficiently simple. The middle ear presents a narrow cavity (Fig. 263, 11), of irregular shape, situated between the external ear and the labyrinth, in the petrous portion of the temporal bone. The general arrangement of its parts is shown in Fig. 263. The outer wall of the tympanic cavity is formed by the membrana tympani (Fig. 263, 6). This membrane is concave, its concavity looking outward, and oblique, inclining usually at an angle of forty-five degrees with the perpendicular. This angle, however, varies considerably in different individuals. The roof is formed by a thin plate of bone. The floor is bony and is much narrower than the roof. The inner wall, separating the tympanic cavity from the labyrinth, is irregular, presenting several small elevations and foramina. The fenestra ovalis, an ovoid opening near its upper portion, leads to the cavity of the vestibule. This is closed in the natural state by the base of the stapes and its annular ligament. Below is a smaller opening, the fenestra rotunda, which leads to the cochlea. This is closed in the natural state by a membrane called the secondary membrana tympani. In addition the posterior wall presents several small foramina leading to the mastoid cells, which cells are lined by a continuation of the mucous membrane of the tympanic

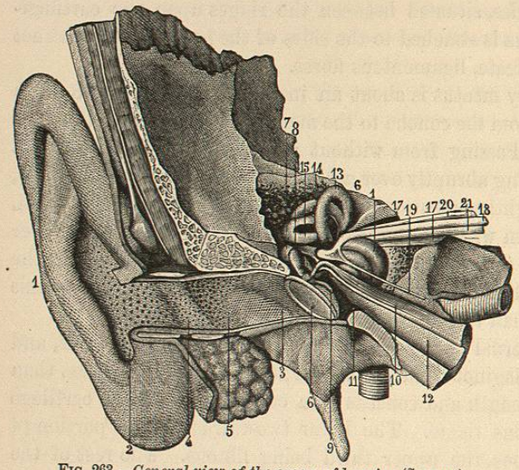

FIG. 263.—*General view of the organ of hearing* (Sappey).

1, pinna; 2, cavity of the concha, on the walls of which are seen the orifices of a great number of sebaceous glands; 3, external auditory meatus; 4, angular projection formed by the union of the anterior portion of the concha with the posterior wall of the auditory canal; 5, openings of the ceruminous glands, the most internal of which form a curved line which corresponds with the beginning of the osseous portion of the external meatus; 6, membrana tympani and the elastic fibrous membrane which forms its border; 7, anterior portion of the incus; 8, malleus; 9, handle of the malleus, applied to the internal surface of the membrana tympani, which it draws inward toward the projection of the promontory; 10, tensor tympani muscle, the tendon of which is reflected at a right angle, to become attached to the superior portion of the handle of the malleus; 11, tympanic cavity; 12, Eustachian tube, the internal, or pharyngeal extremity of which has been removed by a section perpendicular to its curve; 13, superior semicircular canal; 14, posterior semicircular canal; 15, external semicircular canal; 16, cochlea; 17, internal auditory canal; 18, facial nerve; 19, large petrosal branch, given off from the ganglioform enlargement of the facial and passing below the cochlea, to go to its distribution; 20, vestibular branch of the auditory nerve; 21, cochlear branch of the auditory nerve.

cavity. The tympanic cavity also presents an opening leading to the Eustachian tube, and a small foramen which gives passage to the tendon of the stapedius muscle. The Eustachian tube extends from the upper part of the pharynx to the tympanum.

The small bones of the ear are three in number; the malleus, the incus, and the stapes, forming a chain and connected together by ligaments (D, Fig. 264). These bones are situated in the upper part of the tympanic cavity. The handle of the malleus (A, 2, Fig. 264) is closely attached to the membrana tympani, and the long process (A, 3, Fig. 264) is attached to the Glasserian fissure of the temporal bone. The malleus is articulated with the incus. The incus (B, Fig. 264) is connected with the posterior wall of the tympanic cavity, near the openings of the mastoid cells. It is articulated with the malleus, and by the extremity of its long process (B, 2, Fig. 264), with the stapes. The stapes (C, Fig. 264) is the most internal bone of the middle ear. It is articulated by its smaller extremity with the long process of the incus. Its base is oval (C′, Fig. 264) and with its annular ligament, is applied to the fenestra ovalis. The direction of the stapes is nearly at a right angle with the long process of the incus, in the natural state (8, Fig. 265). Some anatomists describe a fourth bone as existing between the long process of the incus and the stapes, but this is seldom distinct, usually being united either with the incus or with the stapes.

There are two well defined muscles connected with the ossicles of the middle ear. One of these is attached to the malleus, and the other, to the stapes. The so-called laxator tympani probably is not composed of muscular fibres and should not be enumerated with the muscles of the tympanum.

The larger of the two muscles is the tensor tympani. Its fibres arise from the cartilaginous portion of the Eustachian tube, the spinous process of the sphenoid bone and the adjacent portion of the temporal. From this origin it passes backward, almost horizontally, to the tympanic cavity. In front of the fenestra ovalis it turns nearly at a right angle over a bony process, and its tendon is inserted into the handle of the malleus, at its inner surface near the root. The tendon is very delicate, and the muscular portion is about half an inch (12·7 mm.) in length (10, Fig. 263). The muscle and its tendon are enclosed in a distinct, fibrous sheath. The action of this muscle is to draw the handle of the malleus inward, pressing the base of the stapes against the membrane of the fenestra ovalis and producing tension of the membrana

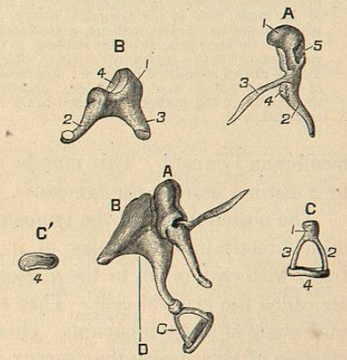

FIG. 264.—*Ossicles of the tympanum of the right side; magnified 2 diameters* (Arnold).

A, malleus; 1, its head; 2, the handle; 3, long, or slender process; 4, short process; B, incus; 1, its body; 2, the long process, with the orbicular process; 3, short, or posterior process; 4, articular surface, receiving the head of the malleus; C, stapes; 1, head; 2, posterior crus; 3, anterior crus; 4, base; C′, base of the stapes; D, the three bones in their natural connection, as seen from the outside; A, malleus; B, incus; C, stapes.

tympani. The fibres of this, and of all the muscles of the middle ear, are of the striated variety. The tensor tympani is supplied with motor filaments from the otic ganglion, which are probably derived from the facial nerve.

FIG. 265.—*The right temporal bone, the petrosal portion removed, showing the ossicles seen from within.* From a photograph (Rüdinger).

4, the incus, the short process of which is directed nearly in a horizontal direction backward; 5, the long process of the incus, free in the tympanic cavity, articulated with the stapes; 6, the malleus, articulated with the incus; 7, the long process of the malleus, in the Glasserian fissure; 8, the stapes, articulated with the incus. This is drawn somewhat outward; otherwise the base of the stapes alone would be visible. This figure shows the handle of the malleus, attached to the membrana tympani.

The stapedius muscle is situated in the descending portion of the acquæductus Fallopii and in the cavity of the pyramid on the posterior wall of the tympanic cavity. Its tendon emerges from a foramen at the summit of the pyramid. In the canal in which this muscle is lodged, its direction is vertical. At the summit of the pyramid, it turns at nearly a right angle, its tendon passing horizontally forward, to be attached to the head of the stapes. Like the other muscles of the ear, this is enveloped in a fibrous sheath. Its action is to draw the head of the stapes backward, relaxing the membrana tympani. This muscle receives filaments from the facial nerve, by a distinct branch, the tympanic.

The posterior wall of the tympanic cavity presents several foramina, which open directly into a number of irregularly shaped cavities communicating freely with each other in the mastoid process of the temporal bone. These are called the mastoid cells. They are lined by a continuation of the mucous membrane of the tympanum. There is under certain conditions a free circulation of air between the pharynx and the cavity of the tympanum, through the Eustachian tube, and from the tympanum to the mastoid cells.

The Eustachian tube (12, Fig. 263) is partly bony and partly cartilaginous. Following its direction from the tympanic cavity, it passes forward, inward and slightly downward. Its entire length is about an inch and a half (38·1 mm.). Its caliber gradually contracts from the tympanum to the spine of the sphenoid, and from this constricted portion it gradually dilates to its opening into the pharynx, the entire canal presenting the appearance of two cones. The osseous portion extends from the tympanum to the spine of the sphenoid bone. The cartilaginous portion is an irregularly triangular cartilage, bent upon itself above, forming a furrow with its concavity presenting downward and outward. The fibrous portion occupies about half of the tube beyond the osseous portion, and completes the canal, forming its inferior and external portion. In its structure the cartilage

of the Eustachian tube is intermediate between the hyaline and the fibro-cartilage.

The circumflexus, or tensor palati muscle, which has already been described in connection with deglutition, is attached to the anterior margin, or the hook of the cartilage. The attachments of this muscle have been accurately described by Rüdinger, who called it the dilator of the tube.

The action of certain of the muscles of deglutition dilates the pharyngeal opening of the Eustachian tube. If the mouth and nostrils be closed and several repeated acts of deglutition be made, air is drawn from the tympanic cavity, and the atmospheric pressure renders the membrane of the tympanum tense, increasing its concavity. By one or two lateral movements of the jaws, the tube is opened, the pressure of air is equalized and the ear returns to its normal condition. The nerves animating the dilator tubæ come from the pneumogastric and are derived from the spinal accessory.

A smooth, mucous membrane forms a continuous lining for the Eustachian tube, the cavity of the tympanum and the mastoid cells. In all parts it is closely adherent to the subjacent tissues, and in the cavity of the tympanum it is very thin. In the cartilaginous portion of the Eustachian tube there are mucous glands, which are most abundant near the pharyngeal orifice and gradually diminish in number toward the osseous portion, in which there are no glands. Throughout the tube the surface of the mucous membrane is covered with conoidal cells of ciliated epithelium. The mucous membrane of the tympanic cavity is very thin, consisting of little more than epithelium and a layer of connective tissue. It lines the walls of the cavity and the inner surface of the membrana tympani, is prolonged into the mastoid cells and covers the ossicles and those portions of the muscles and tendons which pass through the tympanum. On the floor of the tympanic cavity and on its anterior, inner and posterior walls, the epithelium is of the conoidal, ciliated variety. On the promontory, roof, ossicles and muscles, the cells are of the pavement-variety and not ciliated, the transition from one form to the other being gradual. The entire mucous membrane contains lymphatics, a plexus of nerve-fibres and nerve-cells, with some peculiar cells, the physiology of which is not understood.

The above is merely a general sketch of the physiological anatomy of the middle ear, and it will not be necessary to treat more fully of the cavity of the tympanum, the mastoid cells or the Eustachian tube, except as regards certain points in their physiology. The minute anatomy of the membrana tympani and the articulations of the ossicles can be more conveniently considered in connection with the physiology of these parts.

General Arrangement of the Bony Labyrinth.—The internal portion of the auditory apparatus is contained in the petrous portion of the temporal bone. It consists of an irregular cavity, called the vestibule, the three semicircular canals (13, 14, 15, Fig. 263) and the cochlea (16, Fig. 263). The general arrangement of these parts *in situ* and their relations to the adjacent structures are shown in Fig. 263. Fig. 266, showing the bony labyrinth isolated, is from a photograph in Rüdinger's atlas.

The vestibule is the central chamber of the labyrinth, communicating with the tympanic cavity by the fenestra ovalis, which is closed in the natural state by the base of the stapes. This is the central, ovoid opening shown in Fig. 266. The inner wall of the vestibule presents a round depression, the fovea hemispherica, perforated by a number of small foramina, through which pass nervous filaments from the internal auditory meatus. Behind this depression is the opening of the aqueduct of the vestibule. In the posterior wall of the vestibule are five small, round openings leading to the semicircular canals, with a larger opening below, leading to the cochlea.

The general arrangement of the semicircular canals is shown in Fig. 266 (6, 7, 8, 9, 10, 11, 12).

The arrangement of the cochlea, the anterior division of the labyrinth, is shown in Fig. 266 (1, 3, 4). This is a spiral canal, about an inch and a half (38·1 mm.) long, and one-tenth of an inch (2·5 mm.) wide at its beginning, gradually tapering to the apex, and making in its course, two and a half turns. Its anterior presents a central pillar, around which winds a spiral lamina of bone. The fenestra rotunda (2, Fig. 266), closed in the natural state by a membrane (the secondary membrana tympani), lies between the lower portion of the cochlea and the cavity of the tympanum.

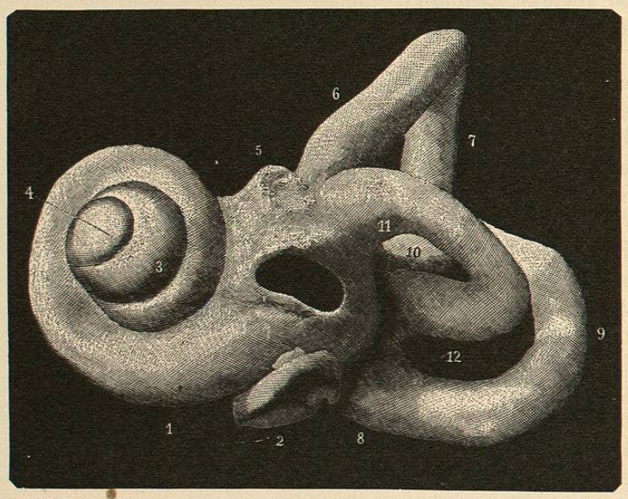

FIG. 266.—*The left bony labyrinth of a new-born child, forward and outward view.* From a photograph (Rüdinger).

1, the wide canal, the beginning of the spiral canal of the cochlea; 2, the fenestra rotunda; 3, the second turn of the cochlea; 4, the final half-turn of the cochlea: 5, the border of the bony wall of the vestibule, situated between the cochlea and the semicircular canals; 6, the superior, or sagittal semicircular canal; 7, the portion of the semicircular canal bent outward; 8, the posterior, or transverse semicircular canal; 9, the portion of the posterior connected with the superior semicircular canal; 10, point of junction of the superior and the posterior semicircular canals; 11, the ampulla ossea externa; 12, the horizontal, or external semicircular canal. The explanation of this figure has been modified and condensed from Rüdinger.

What is called the membranous labyrinth is contained within the bony parts just described. Some of the anatomical points connected with its structure and the distribution and connections of the auditory nerve have

direct and important relations to the physiology of hearing, while many are of purely anatomical interest. Such facts as bear directly upon physiology will be considered fully in connection with the uses of the internal ear.

PHYSICS OF SOUND.

The sketch just given of the general anatomical arrangement of the auditory apparatus conveys a general idea of the uses of the different parts of the ear. The waves of sound must be transmitted to the terminal extremities of the auditory nerve in the labyrinth. These waves are collected by the pinna, are conducted to the membrana tympani through the external auditory meatus, produce vibrations of the membrana tympani, are conducted by the chain of ossicles to the openings in the labyrinth and are communicated through the fluids of the labyrinth to the ultimate nervous filaments. The free passage of air through the external meatus and the communications of the cavity of the tympanum with the mastoid cells, and by the Eustachian tube, with the pharynx, are necessary to the proper vibration of the membrana tympani; the integrity of the ossicles and of their ligaments and muscles is essential to the proper conduction of sound to the labyrinth; the presence of liquid in the labyrinth is a condition essential to the conduction of the waves to the filaments of distribution of the auditory nerves; and finally, from the labyrinth, the nerves pass through the internal auditory meatus, to the auditory centre in the brain, where the auditory impressions are appreciated.

Most of the points in acoustics which are essential to the comprehension of the physiology of audition are definitely settled. The theories of the propagation of sound involve wave-action, concerning which there is no dispute among physicists. For the conduction of sound a ponderable medium is essential; and it is not necessary, as in the case of the undulatory theory of light, to assume the existence of an imponderable ether. The human ear, though perhaps not so acute as the auditory apparatus of some of the inferior animals, not only appreciates irregular waves, such as produce noise as distinguished from sounds called musical, but is capable of distinguishing regular waves, as in simple, musical sounds, and harmonious combinations.

In music certain successions of regular sounds are agreeable to the ear and constitute what is called melody. Again, there is appreciation, not only of the intensity of sounds, both noisy and musical, but of pitch and different qualities, particularly in music. Still farther, musical notes may be resolved into certain invariable component parts, such as the octave, the third, fifth etc. These components of what were formerly supposed to be simple sounds —which may be isolated by artificial means, to be described farther on—are called tones; while the sounds themselves, produced by the union of the different tones, are called notes, which may themselves be combined to form chords.

The quality of musical sounds may be modified by the simultaneous production of others which correspond to certain of the components of the predominating note. For example, if there be added to a single note, the third,