in the size of the individual liver nuclei, many of which show a compensatory hypertrophy. The central veins and capillaries are congested, and the liver cells of the central zone of the lobule contain much hæmatoidin, while those of the peripheral zone show an increased amount of fat.

In the atrophic kidney there is a decrease in the size of the tubules due to a decrease in size and to a diminution in number of the epithelial cells. Many tubules may be found containing few cells or completely collapsed. As a result of the loss of intervening tissue the glomeruli are brought closer together, so that from twenty to forty may be found in one low-power field. The epithelium and capillaries of the glomeruli also disappear, and as a result numerous obliterated glomeruli are found. In atrophy of the central nervous system the ganglion cells disappear or become smaller, while the neuroglia remains in normal amount or becomes increased. Atrophy of the lymph glands and spleen is shown by a disappearance of the follicles and a diminution in the number of the lymphadenoid cells. The trabeculæ are brought more closely together, and the finer stroma is increased in amount. In atrophy of bone the bone substance is decreased in amount and the marrow spaces are increased. With this there is usually an increase in the fatty marrow, but it occasionally disappears, leaving cystic spaces filled with fluid.

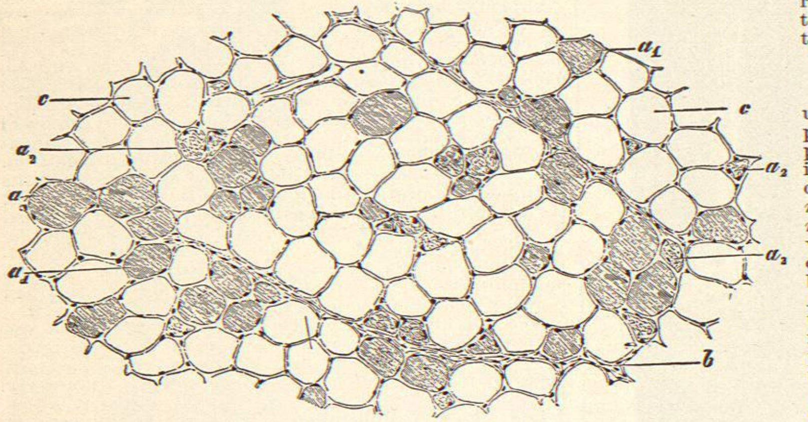

Fig. 383.—Lipomatosis of the Muscles of the Calf of the Leg, Together with Atrophy. (Müller's fluid, carmine.) Transverse sections of a normal (a) and an atrophied (a_1) muscular fibre; a_2, transverse section of a tubular sarcolemma containing contractile substance in a condition of disintegration; b, bands of connective tissue; c, fat tissue. Magnified 60 diameters. (After Ziegler.)

Course.—The course of the various forms of atrophy depends wholly upon their nature. Total atrophy occurs as the result of the exhaustion of the inherent histogenetic energy, as in the case of many of the fetal structures, the thymus, etc. In partial atrophies due to other causes, such as disturbances of nutrition, pressure, etc., a greater or less degree of restoration is possible in all structures in which the histogenetic limit has not been reached. If the causes leading to atrophy operate in the early periods of development, agenesia or aplasia may result. Certain organs, as the thyroid or sexual glands, may be thus affected and their lack of development may lead to retarded growth of other tissues. As stated above, these processes are not of the nature of true atrophies, but it is difficult in all cases to make sharp distinction. The atrophy of certain fully developed organs likewise may affect the growth of other organs or even of the whole body, as in progressive muscular atrophy where atrophic changes in the bones follow those in the muscles.

In so far as the function of the organ is concerned, the atrophy of its elements is of the greatest importance. Atrophic muscles lose their contractile power, atrophic glands their secretory function, osteoporotic bones are easily broken, and atrophic skin is easily injured by a very slight trauma. Further, the atrophy of one organ or set of tissues disturbs the function of other organs and leads to a general diseased condition of the organism.

The prognosis in atrophy is favorable only in those pathological conditions in which the cause of the atrophy may be removed, and in tissues in which the physiological limit of growth has not been reached. Atrophy of the vital organs, heart, medulla oblongata, kidneys, respiratory muscles, etc., not infrequently leads to death. There may also result a complete disappearance of certain structures caused by the atrophy of the matrices which form them. In atrophy of the periosteum the bone disappears, in atrophy of the skin there is a loss of the hair and nails, and in atrophy of the lymph glands there is a decrease in the formation of leucocytes.

It is evident that only the purely passive forms of atrophy admit of treatment. The removal of the cause and the restoration of the normal nutrition are the chief indications.

Aldred Scott Warthin.

ATROPIC POISONS.—The natural order *Solanaceæ* comprises many plants possessing actively poisonous properties. Among these the more important are: *Atropa belladonna*, deadly nightshade; *Hyoscyamus niger*, henbane; *Datura stramonium*, thornapple or Jamestown weed; *Mandragora officinale*, mandrake; *Scopolia Japonica*, Japanese belladonna; and several species of *Duboisia*. It is worthy of note that several of the most widely used foods—*e.g.*, potato, tomato, and egg plant—are derived from plants of this order.

The poisonous qualities of the *Solanaceæ* depend on well-marked alkaloids, analogous in composition and properties, notably as regards the power to produce dilatation of the pupil, for which reason the term *mydriatic alkaloids* has been applied to them collectively. Since the toxicology will include the effects of both the plants and the active principles, it will be more satisfactory to consider them under the title of the "Atropic Poisons." The deadly nightshade, *Atropa belladonna*, is the most important of the group, and its alkaloid, atropin (atropina, U. S. P.), has been extensively used by ophthalmologists, but of late years it has been often replaced by a derivative, homatropin, and by another natural alkaloid of the class, scopolamin; the effects of these being more transient than those of atropin. According to recent investigations, the so-called daturin—derived from *Datura stramonium*—is identical with atropin, but commercial daturin often contains some hyoscyamin. Statistics collected by Witthaus show that of the reported cases of poisoning by the plants of this class or their alkaloids, over sixty per cent. are by belladonna or atropin, and next in order by *Datura stramonium*. The majority of cases were accidental.

The *symptoms* produced by toxic doses of the preparations of belladonna usually manifest themselves within an hour, and are marked and characteristic. They are heat and dryness of the mouth and throat, increasing to a feeling of burning or constriction, difficulty of swallowing, giddiness, nausea and vomiting frequently, but not invariably; great mental excitement, delirium, and hallucination, often decidedly maniacal or hysterical. The circulation is decidedly affected, the pulse being quickened, the face becoming red and turgid, and in some instances a scarlet eruption has appeared over the body.

Dilatation of the pupil with insensibility to light and impairment of vision is a usual and important symptom. The mental symptoms often take the form of wild and uncontrollable laughter. The following case, detailed by Taylor ("Treatise on Poisons"), illustrates the clinical history of belladonna poisoning. A boy, aged fourteen, ate about thirty belladonna berries. In about three hours it appeared to him as if his face was swollen, his throat became hot and dry, vision impaired, objects appeared double, and seemed to revolve and run backward. His hands and face were flushed and his eyelids swollen, and occasional flashes of light were experienced. He tried to eat, but could not swallow on account of the state of his throat. In endeavoring to walk home he staggered, and felt giddy whenever he attempted to raise his head. He was incoherent, frequently counted his money, and did not know the silver from the copper coin. His eyes had a fixed and brilliant look, he could neither hear nor speak plainly, and was very thirsty; he caught at imaginary objects in the air. There was headache, but no vomiting nor purging. These symptoms were much the same nine hours after the taking of the poison. The pupils were so strongly dilated that there was merely a narrow ring of iris; the eyes were quite insensible to light, the eyelids did not close when the hand was passed suddenly over them, but the nerves of common sensation were unaffected. The pulse was 90, feeble, and compressible. He continued in this state for two days, but gradually recovered.

Fatal cases usually terminate in coma, less frequently in convulsions.

The *treatment* of belladonna (or atropin) poisoning is both direct and physiological. Free evacuation of the stomach by means of emetics or the stomach pump should be resorted to; as antidotes, animal charcoal or tannic acid may be given. The former has been found efficacious by actual experiment on the human subject; it acts by absorbing the alkaloid; tannic acid renders it insoluble. Both these agents are, however, only temporary; they do not set aside the necessity for evacuating the stomach or using other remedies. Since physostigmin—the active principle of the Calabar bean—and also morphin cause contraction of the pupil, they have been naturally suggested as physiological antidotes to atropin, and clinical experience has borne out this view. The hypodermic use of these agents should therefore be cautiously employed, the condition of the pupil and the general nervous symptoms being used as guides to the medication.

Many of the recorded cases of belladonna poisoning have recovered under treatment. When a fatal result takes place, no special or characteristic post-mortem appearances are discoverable.

There are no striking or easily applied chemical tests for atropin. It may be identified by its physiological action, dilatation of the pupil. *Henry Leffmann.*

ATROPINE. See *Belladonna.*

AUDITION.—Audition or hearing is the result of processes by which certain vibrations of physical media are taken up by a peripheral sense organ, the ear, and transformed into nerve stimuli which excite in consciousness sensations of a peculiar kind. These sensations we know as *sound.* They are a function of a certain part of the cerebral cortex. Unfortunately, it is also the rule to designate by the name of "sound" those physical vibrations which are the objective cause of sound sensation but which have nothing in common with it.

This article will be chiefly limited to the treatment of objective or physical sound and the manner in which it affects the mechanism of the ear in giving rise to impulses in the auditory nerves.

Physical sound, as contrasted with sound sensation, is due to vibrations of particles of solid, liquid, or gaseous media. In its vibration a particle may move back and forth in a straight line, as in the transmission of an air wave or in the propagation of a tremor longitudinally along a rod of metal; or it may describe a more or less elliptical or circular path as in a wave of water, and tranverse to the direction of wave movement. When a particle is forced from its position of equilibrium, the force with which it tends to resume that position is a measure of the elasticity of the substance of which it forms a part. Elasticity is the property by virtue of which vibrations are propagated.

Transverse and Longitudinal Vibrations. Waves of Sound.—The vibration of particles gives rise to waves having definite form, length, and rate of progress. The waves most familiar to us are those seen on the surface of water formed by an up-and-down motion of the particles in an elliptical curve. The vibration is *transverse* to the direction and length of the wave, and the amplitude or depth of the wave and that of the vibration correspond. The wave length is the distance measured from crest to crest or hollow to hollow; it has no necessary relation to the amplitude of vibration. A stretched string or a tuning fork also executes transverse vibrations, when plucked or rubbed in the usual way. But if a stretched string or a rigid rod be scratched at one end the particles there will be set in oscillation back and forth (longitudinal vibration), and this vibration will be transmitted as a wave along the string or rod and may be heard as sound at the further end, but will make no visible movement. It is important to consider how these longitudinal waves are formed. The particles which are struck or scratched at the end of the string or rod are forced against those immediately adjoining, these in turn crowd upon the particles in front; the energy of the first displacement measures the degree of crowding or condensation thus produced. The particles unnaturally strained together spring away from one another by virtue of their elasticity, and their energy of movement carries them beyond their position of rest, making the number of particles at the previous point of condensation less numerous than normal, thus producing a condition of *rarefaction* as a result of the oscillation. The forward vibration of the particles is thus transmitted as a phase of *condensation* to successive layers of the substance traversed, each condensation being succeeded by a complementary *rarefaction.* The two phases of condensation and rarefaction make up the wave of sound. The length of the wave is the distance measured between two points of extreme condensation or rarefaction. This wave length has no necessary connection with the length of the path described by the individual particles whose motion gives rise to the sound wave.

Aërial vibrations resemble the longitudinal vibrations of solids and liquids in that the sound waves move in the same direction as the particles whose movement produces the waves. The amplitude of movement of the individual particles is very much less than the wave length produced by that movement. In the mobile air the path described by the particle is relatively great, but in a rod of wood or metal or under water, the excursion of each particle in its vibration is infinitesimal in its relation to the wave length or distance between successive condensations or rarefactions. The amplitude of movement of the vibrating particle is a measure of the energy which has been imparted to it, and it has extraordinary physiological significance, for upon it depends the *loudness* of sound. In exact language, the intensity of sound sensation is proportional to the square of the amplitude of the vibrations which cause it. Tyndall in his work on sound illustrates by a diagram the method by which a "sound pulse" is transmitted (see Fig. 384). The apparatus consists of a series of wooden balls separated from one another by spiral springs (the balls represent

Fig. 384.—Illustrating Passage of an Air Wave. The balls, E, C, B, etc., represent air particles and the springs the elastic force restoring them to position. (After Tyndall on "Sound.")

air particles and the springs the elastic force restraining their displacement). On striking the knob A, a rod attached to it impinges upon the first ball B, which transmits its motion to C, thence it passes to E, and so on throughout the entire series. The arrival at D is announced by the shock of the terminal ball against the wood, or, if we wish, by the ringing of a bell. Here the elasticity of the air is represented by that of the springs. The "pulse" may be reduced to such a degree of slowness that it can be followed by the eye.

Vibrations occurring in any medium may be transmitted by direct contact to another medium. Thus, when the bell of a stethoscope is applied to the chest, the vibrations of the chest wall are transmitted to the ear either by the air columns of the instrument or by its solid structure or by both. Vibrations of the bones of the skull are transmitted directly to the tympanic membrane and probably also to the lymph of the labyrinth.

The Production of Tones.—When the pendulum of a clock swings to and fro it might be supposed that a sound would be produced by each excursion of the rod, and this would be the case were not the air so mobile that its particles instantly retreat from the front to the back of the slowly moving pendulum, so that no sensible condensation, which is necessary to the production of a sonorous wave, occurs. That is to say, a certain suddenness of impulse is necessary to start an air wave. Such an impulse is developed when a mixture of oxygen and hydrogen are ignited by an electric spark. The heat generated by their union causes a sudden expansion which starts a sonorous wave which comes to the ear as a sharp report.

Simple Pendular Vibrations.—Suppose our pendulum to gradually increase its rate of movement; when it swings so fast as to accomplish one complete to-and-fro movement in about the one-sixteenth of a second a continuous sound of very low pitch should be expected.

In practice it is customary experimentally to produce sounds by the transverse vibrations of tuning forks set upon resonance boxes (see below). The effect of such vibration upon the air is illustrated in Fig. 385, in which the dark spaces, a, b, c, d, represent the phases of condensation, and the light spaces, b', c', d', the phases of rarefaction of the air waves. The wave length is the distance measured from a to b or from b' to c'.

Such to-and-fro oscillations are known as *simple pendular vibrations.* They make no audible sound until they attain the rate of sixteen to twenty-four per second, according to the perceptive power of the hearer.

The Pitch and Loudness of Tone.—Instead of using the tuning fork as a source of sound the following familiar device would serve: Take a circular disc, A–B in Fig. 386, of cardboard or metal about twelve inches in diameter, and let it be perforated at equal intervals along a circle near its circumference. The disc is fastened at its centre to the axis of a wheel capable of rapid rotation. A bent tube, m, communicating with a bellows giving a continuous blast of air, is brought with its orifice over the circle of holes. When the disc is rotated and air is forced through the tube m, a puff of air passes through the disc when one of the holes coincides with the open end of the tube, but the air stream is cut off by the solid plate between the holes. As the rate of rotation of the disc is gradually increased a low-pitched sound is heard when the puffs of air succeed one another at the rate of about sixteen per second, and as the rate of succession increases the sound becomes a well-marked *musical tone*, and the *pitch* of the tone is found to rise and fall with the number of puffs in a second which have caused it. If, instead of the single tube m, two tubes were used to convey the blast of air simultaneously through two different holes, the pitch of the sound would not be altered but its loudness would be increased, because the two forces leading to condensation of the air would be added together. The demonstration of the laws of sound production in air owes much to an instrument called the *siren*, which is essentially elaborated from the perforated rotating disc.

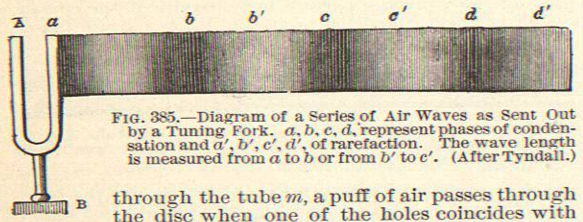

FIG. 385.—Diagram of a Series of Air Waves as Sent Out by a Tuning Fork. a, b, c, d, represent phases of condensation and a', b', c', d', of rarefaction. The wave length is measured from a to b or from b' to c'. (After Tyndall.)

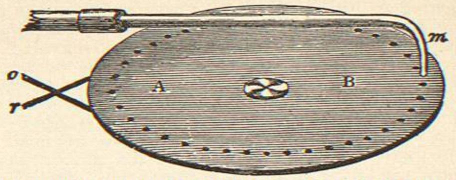

FIG. 386.—Illustrating the Production of a Musical Tone by Puffs of Air through a Perforated, Rotating disc. (After Tyndall.)

The Range of Pitch of Audible Sounds.—As already mentioned, physical vibrations do not so affect the ear as to give rise to a *sensation of sound* until they succeed one another at the rate of sixteen to twenty-four per second. As the rate of vibration is progressively increased the pitch of the tone is raised until it becomes a painful squeak, and it is said that for most persons vibrations become inaudible when they reach a frequency of 16,000 per second, though some ears are still impressed with sounds caused by 38,000 to 40,000 vibrations in a second. Some of the lower animals can probably hear tones produced by still more rapid oscillations. It is a familiar experience that when a sounding bell or whistle, as of a locomotive, rapidly approaches, its pitch seems to rise, and then to fall as it recedes. The reason for this variation is that the motion of the locomotive adds to or subtracts from the number of sound waves reaching the ear in a given time. In the rendition of music a much narrower compass is employed, beyond which tones cease to have a pleasing character. The droning note of the sixteen-foot organ pipe and the lowest bass of the piano (C_1) represent a vibration rate of thirty-three per second. The highest treble of the piano has a vibration rate of 4,224 per second. Finely trained ears can distinguish differences of pitch represented by only half a vibration per second. As to the number of vibrations necessary to produce the sensation of sound, it has been found that two or three vibrations excite the sensation of a mere stroke; four or five vibrations are necessary to give a tone; and some twenty to forty are required to develop the full musical qualities of a tone. Thus from a physical scale representing aërial vibrations of indefinitely various rapidity the mind selects and appreciates as *sound* a small fraction, about a range of eleven octaves, and receives æsthetic pleasure from a still narrower range of about seven octaves.

Summary.—The foregoing discussion may be summarized in the statement that *simple tones are due to waves which are produced by the pendular vibration of the particles of elastic bodies. The intensity of the sound sensation increases as the square of the amplitude of vibration, and the pitch of the sound rises in proportion to the rate of vibration.*

The Origin of Sound Quality. Overtones.—It is but seldom that sonorous bodies are confined to the simple pendular vibration of their particles; but the sound wave is the resultant of several vibrations of different rates simultaneously imparted to the moving particles. When a stretched string is plucked or bowed at its middle it vibrates throughout its whole length, the greatest amplitude of movement being at the middle point, which moves to and fro like a pendulum. The musical note so produced is the lowest in pitch which the string is capable of giving. If the cord is held at its middle, or simply touched there with a feather, and a bow is drawn across one of the segments, vibration is renewed; but now the string divides, as it were, into two halves with a point of rest, or a "node," between. Each inter-node or "ventral segment" is half the length of the whole string, but its vibration is twice as rapid. The note given out is therefore the octave of that produced in the first instance. If the feather be applied at a point one-third the distance from one end, bowing the smaller segment will cause the string to break up into three equal vibrating parts, separated by two nodes or points of rest. In a similar way the string may be caused to vibrate in four, five, etc., segments. In each case the rate of vibration is as many times that of the whole string as there are segments of vibration. It is not necessary to keep the feather applied after the node is once formed.

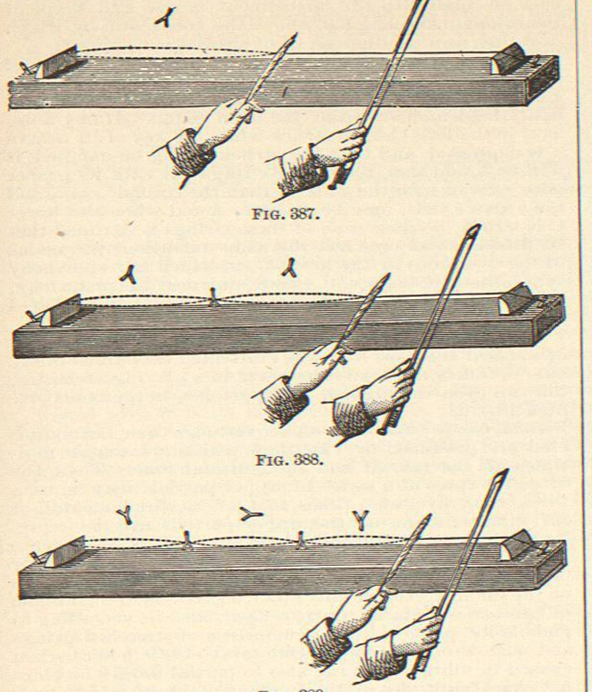

FIG. 387.

FIG. 388.

FIG. 389.

FIGS. 387–389.—Illustrating the Segmental, Transverse Vibration of a String. (Tyndall.)

The relative immobility of the nodes is illustrated by placing over the string a series of paper riders; when the string is thrown into vibration the strips of paper are violently displaced along the ventral segments but retain their position at the nodes (see Figs. 387, 388, 389). It is not possible to make a string vibrate as a whole without at the same time its breaking up, to a greater or less degree, into its vibrating segments. The result is that the oscillation of any particle is not a simple pendular movement, but is the algebraic sum of an indefinite number of such movements. The sound which is heard is a note in which are contained as many simple tones as there are separate rates of vibration. The tone produced by the movement of the string as a whole, which is the slowest rate of vibration, is known as the *fundamental tone.* The various tones produced by the segmental vibrations are known as *overtones, upper partials,* or *harmonic sounds.* The *pitch* of the compound note is identical with that of its fundamental tone. But the blending of the various segmental vibrations with the primary results in an extraordinary æsthetic modification of the sound, for thereby its *quality, timbre,* or *clang tint* is determined. Different sound-producing bodies may give out notes in which the number of upper partial tones is different. Again, certain partial tones occurring in the note of one musical instrument may be wanting in that of another, or a given harmonic may be different in intensity in two notes. As an outcome of these facts it has been demonstrated that *the quality of a compound tone depends upon the number, order, and relative intensities of its constituent partials.* Thus, a violin, a cornet, and a piano, though sounding a note of the same pitch, would never be mistaken for one another. But were all their overtones obliterated the three instruments would be indistinguishable to the ear.

The brilliancy and richness of musical notes is dependent on their wealth of upper partials. It is believed that a sound-producing body, like a stretched string, does not send to the ear a separate set of waves representing each of its segmental vibrations, but all the waves aroused by it fuse together into a single series of waves of peculiar form. Such a composite wave may be represented graphically by depicting under one another a series of waves having two, three, four, etc., times the rate of succession of the curve indicating the fundamental tone (Fig. 390). If a vertical line be drawn across the series representing the vibration rates of the various tones, and an algebraic addition be made of the distance of each point of intersection above or below the line of rest, the result will determine the position of the composite wave on the same vertical. It is evident that the *form* of the composite wave must change with every change in the number and relative prominence of the overtones; and the movement imparted by it to the tympanic membrane, and the wave generated in the labyrinthine fluids (see below) must have corresponding differences. Notes of different quality are

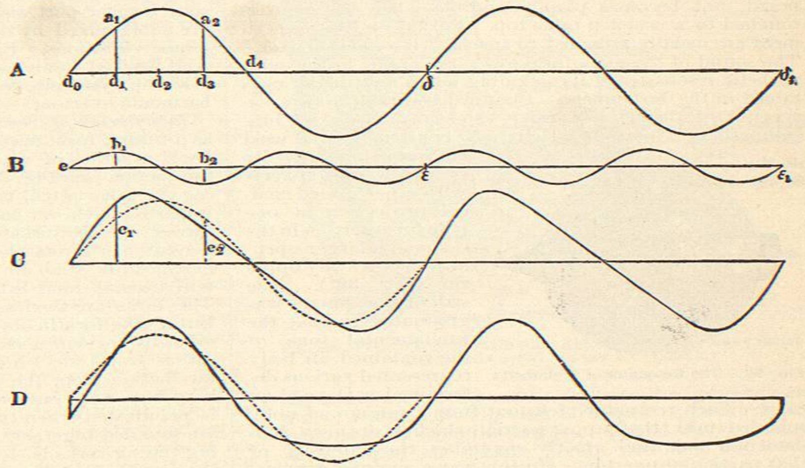

FIG. 390.—A Composite Wave (C, solid line), formed by the algebraic addition of two simple pendular vibrations, A and B. A and B are in the same phase; but if curve B is moved to the right until c of B coincides with d' of A, the phases of the curves will be different and their addition will give curve D (solid line). Such change of phase, however, does not change the musical quality of the composite note.

produced by composite air waves of different forms. But waves differing somewhat in form may still produce notes of the same quality; for if, in the graphical figure, one or more of the curves representing simple tones be slid to the right or left, the form of the composite wave will thereby be changed, but not the quality of the sound produced by it. In other words, change of "phase" of the partial tones does not alter the quality of the note.

Conditions Determining the Kind of Overtones.—The series of overtones accompanying the fundamental varies under definite conditions. Thus, in a metal rod fixed at both ends the longitudinal vibrations set up by rubbing the rod lengthwise produce tones whose vibration numbers are to each other as the odd numbers 1, 3, 5, 7, etc. The tones of a rod free at both ends have vibration rates proportionate to the even numbers 2, 4, 6, 8, etc. In a stretched string the order of the overtones depends upon the place at which the string is plucked or struck. In general, it may be said that no overtone is heard which requires for its production the existence of a node at the point plucked or struck.

Difference between Noise and Music.—Sound sensations may be divided into two groups, *musical tones* and *noises*. The requisite for the former is that the vibrations that produce them shall be *periodic*, that the motions shall repeat themselves at regular intervals. Irregularity of the vibration period or rapid breaks from one periodic motion to another produce the sensation of "noise." The singing voice restricts itself chiefly to the musical notes formed by periodic vibration of the vocal cords; but in articulate speech the distinguishing consonantal sounds are chiefly noises.

Sympathetic Vibration. Resonance.—Every elastic body is capable of *sympathetic vibration;* that is, air waves beating upon it at its own natural rate of vibration set it into corresponding motion. In the same manner a heavy pendulum may be forced into violent movement by exceedingly light taps with the finger, the only necessary condition being that the impulses imparted by the finger be exactly timed to the periodic motion of the pendulum or to some multiple of it. A body capable of sympathetic vibration with some particular tone is set into vibration by that tone, and reinforces or magnifies it whether the tone exists alone or as the fundamental of a complex note, or is contained in the latter simply as an upper partial. The property of increasing the intensity of sound by sympathetic vibration is known as *resonance*. The tone of a tuning fork held in the fingers is scarcely heard, but becomes plainly audible when the stem is touched to a wooden table top. Forks used for experiment are usually attached to special "resonance boxes." The sound of the pianoforte owes its volume to the sympathetic resonance of its sounding board and the air contained in the instrument. Confined bodies of air are, on account of their low density, especially easily set into sympathetic vibration. Helmholtz constructed and used as resonators a series of hollow brass spheres with a perforated conical projection at one pole for insertion in the ear, and a larger opening diametrically opposite (Fig. 391). The size of the spheres was graduated so that the fundamental tone of the contained air body represented various determined vibration rates. Each resonator picks out from a compound note, sounded near, that upper partial which is its own fundamental tone and greatly magnifies the intensity of that particular overtone. In this way a complex musical note may be analyzed into its constituent simple tones. Conversely, Helmholtz was able to reconstruct a complex note by simultaneously sounding a series of tuning forks, and appropriately regulating the intensity of the various simple pendular vibrations by means of resonators.

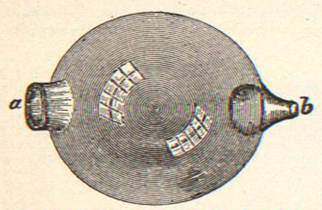

FIG. 391.—The Resonator of Helmholtz.

The vowel sounds of the human voice owe their difference of quality to the adjustment in size and shape of the resonant air chambers above the vocal cords by which now one, now another set of overtones is magnified.

That apparently simple tones are actually made up of a number of partials, having rates of vibration which form simple multiples of the fundamental tone, may easily be demonstrated at the open piano. If any note, as C in the bass clef, be struck while the key of its octave *c* is depressed, and then the struck string be damped, it will be found that the octave *c* rings out with its proper note. So in turn the *g* above that, the second octave and the *e* above that, may be made to sound when the lower C is struck, because each of these strings is so tuned that its fundamental note has the same vibration rate as one of the overtones of the lower C, to which it responds by sympathetic resonance. A note sung near the piano may, in the same way, be more or less completely analyzed into its component tones.

The organ of hearing certainly has some such power of musical analysis, for some cultivated ears are not only able to follow a special instrument in a playing orchestra, but can even distinguish the overtones in the notes produced by it.

Inharmonic Overtones.—All overtones thus far considered are produced by vibrations which are simple multiples of the rate of the fundamental tone. Thus, the vibration rates of a series of upper partials may be two, three, four, five, etc., times that of the fundamental, or the vibration rate of the upper partials may be represented by the series of odd or even numbers, as the case may be. Such vibrations do not interfere with one another or with the fundamental tone, and their union produces on the ear an agreeable effect which gives them their name of *harmonics*. Harmonic upper partials are, according to Helmholtz, particularly characteristic of stretched strings and narrow organ pipes. But most elastic bodies when caused to vibrate give rise also to partial tones which are not exact multiples of the fundamental, and which may be termed *inharmonic* upper partials. The high-pitched jingle heard when a tuning fork is first struck represents the inharmonic upper partials of the fork. Stretched membranes have a great number of such inharmonic overtones, a fact which is of great importance in the function of the tympanic membrane. Inharmonic upper partials, as might be expected, rapidly die out in a note of which they form a part, because the vibrations causing them are antagonized by one another and by the stronger harmonic vibrations. For this reason the development of a well-marked fundamental tone is repressed in structures (like the tympanic membrane) which easily produce inharmonic overtones.

Interference of Sound. Beats.—Any source of sound, as a tuning fork, may be imagined as sending out from itself a series of waves of alternate condensation and rarefaction (see Fig. 385). If a second tuning fork, having the same pitch, is brought near the first, the motion imparted to the air particles will be a resultant of the two forces. If the forks vibrate in such order that the condensation or rarefaction produced by each simultaneously engages the same air particles, each of these conditions will become more intense and the sound will be *louder*. The forks are then said to vibrate in the same phase. But if one fork in its movement precedes or follows the other by *one-half* a vibration, then the phases of condensation from one tuning-fork correspond with those of rarefaction from the other, and the result is *silence*. A very important outcome of this principle of interference is manifested when two tones slightly different in pitch are sounded together. Let a prong of one of two vibrating tuning forks be loaded with wax; its vibrations will thereby be made slower and its pitch lowered. Though the forks may start vibrating in the same phase, the vibrations of one fork will outpace those of the other until a phase of condensation of the first will correspond to a phase of rarefaction of the second, and the result will be perfect or comparative silence. The unequal rate of vibration continuing, like phases will again fall together and the sound will become louder than from either fork alone (Fig. 392). An alternate augmentation and diminution in the intensity of the sound is the result. These sound pulses are known as *beats*, and they are the cause of all discord in music. When two notes not included in a perfect chord are sounded on the piano, beats are heard not only from the interference of the fundamental tones, but of the upper partials as well. It is the absence of beats in tones that should be in harmony, as those of the major chord, that determines the instrument to be in tune. When two tones produce beats, the number of beats in a given time is equal to the difference between the number of vibrations involved in the two tones in the same time. For example, a tone produced by 256 vibrations in a second sounded with one of 228 vibrations would give 28 beats in a second. It is evident that the frequency of beats may be increased either by increasing the interval between the tones or by striking tones of the same interval in a higher part of the scale. Beats which are not too frequent—from four to six in a second—have important musical value; but when they number 30 or 40 in a second they become exceedingly disagreeable, irritating the ear in a manner analogous to the effect of a flickering light on the eye. When sufficiently near together the beats no longer produce an intermittent sensation.

FIG. 392.—The Two Broken Lines Represent Air Waves of Slightly Different Vibration Rates. The solid line represents the "beats" or variations in sound intensity produced by the algebraic addition of the first two.

The number of beats required to result in this fusion increases as we ascend the musical scale, varying from 16 beats at C of 64 vibrations a second to 136 beats at *c'''* of 1,024 vibrations.

Harmony and Discord.—Tones are *concordant* or *harmonic* when they produce no beats on being sounded together; they are *discordant* when beats are produced, and the painful sense of dissonance increases in intensity up to about 33 beats per second. Perfect concord is obtained by blending tones whose vibrations are to one another as small whole numbers.

Thus, in the major chord C E G C the vibration numbers are 132, 165, 198, 264, their ratios are 4, 5, 6, 8.

If tones the ratio of whose vibration rates can be represented only by large whole numbers are combined, a discord is formed, for the reason that their upper partials interfere with one another and cause beats; there is no especial virtue in the small integer.*

Thus in the discord C D E the vibration numbers are 132, 148.5, 165, which are not reducible to small whole numbers.†

Resultant Tones.—When two powerful tones of different pitch are sounded together there may be heard in addition a third tone of much lower pitch than either. This is a *resultant* of the two primary tones and has been called a *difference tone*, because its pitch corresponds to a vibration rate equal to the difference of rates of the two primary tones. "Difference tones," though having the same numerical relations as "beats," are not to be confused with the latter. As two tones may generate a third which represents the difference between their vibrations, so, it was predicted and demonstrated by Helmholtz, they may give rise to *summation tones* whose pitch is determined by the *sum* of the vibrations of the primary tones. The vast complexity of the system of aërial waves to whose impress and analysis the ear is sensitive and capable, is well expressed by Tyndall:‡ "In the music of an orchestra, not only have we the fundamental tones of every pipe and of every string, but we have the overtones of each, sometimes audible as far as the sixteenth in the series. We have also resultant tones; both difference tones and summation tones; all trembling through the same air, all knocking at the self-same tympanic membrane. We have fundamental tone interfering with fundamental tone, overtone with overtone, resultant tone with resultant tone. And, besides this, we have the members of each class interfering with the members of every other class. The imagination retires baffled from any attempt to realize the physical condition of the atmosphere through which these sounds are passing."

(Out of the wealth of literature upon the physics of sound, mention may be confined to the work of Helmholtz: "Die Tonempfundungen," translated by Ellis, "Sensations of Tone," etc., which covers the field of physiological acoustics. Also, the lectures of Tyndall on "Sound," Appleton, 1877, are full of clear beauty on the physical side.)

ANATOMY AND PHYSIOLOGY OF THE EAR.

(Detailed description of the structure of the various parts of the ear may be found under appropriate captions. In this section anatomy and histology will receive as little attention as is consistent with clear exposition of functions.)

The *organ of hearing* is usually described as consisting of the following divisions: 1. *The external ear*, composed of the *pinna* or *auricle* and the *external auditory meatus*. 2. The *middle ear*, including the tympanic cavity with its contents, the communicating Eustachian tube and the tympanic membrane. 3. The *internal ear* or *labyrinth*, including the vestibule, cochlea, and semicircular canals, with their corresponding membranous contents and the *ductus endolymphaticus*.

The *pinna or auricle* (Fig. 393) has less functional importance in man than in some of the lower mammals, as the deer, in which its trumpet shape is especially adapted for the collection of waves of sound. The extreme mobility of the auricle in such animals must make it of use in locating sounds, a function important to the preservation of its life from enemies. Even the human auricle, and especially the *concha*, must serve an important use in the collection of sound waves.

The *external aaditory meatus or canal* (Fig. 393) serves the purpose of conveying with undiminished intensity the sound collected by the auricle to the tympanic membrane, while allowing this structure to be buried at a safe distance from the surface. Sound waves produced in the open air radiate in all directions and rapidly diminish in intensity (the decline in intensity is proportional to the square of the distance traversed). When sound is prevented from radiating, as when one whispers

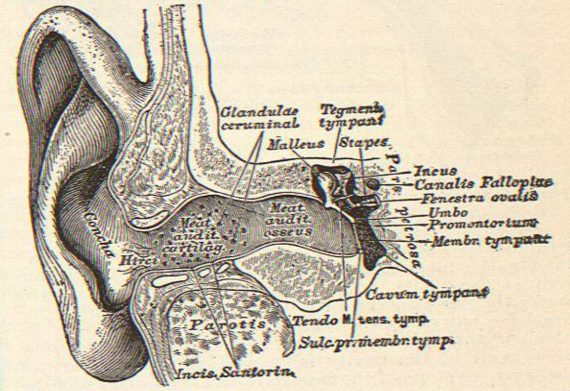

FIG. 393.—Vertical Section through Right External Auditory Canal and Tympanic Cavity. (After Heitzmann.)

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* Tyndall: "Sound."
† Waller: "Human Physiology," 1891.
‡ Tyndall: "Sound," 1872, p. 381.