ON THE

PRINCIPLES OF SOUND;

THEIR APPLICATION TO THE

NEW HOUSES OF PARLIAMENT,

AND

ASSIMILATION WITH THE MECHANISM OF THE EAR.

BY A. W. WEBSTER.

Price 5s.

To the Editor of the
Philosophical Magazine

ON THE

PRINCIPLES OF SOUND;

THEIR APPLICATION IN THE

CONSTRUCTION OF PUBLIC BUILDINGS;

PARTICULARLY TO THE

NEW HOUSES OF PARLIAMENT;

AND

ASSIMILATION WITH THE MECHANISM OF THE HUMAN EAR.

By A. W. WEBSTER,

AUTHOR OF A TREATISE ON THE STRUCTURE OF THE EAR, AND DEAFNESS.

" The mathematical theory of the propagation of Sound, and of vibratory and undulatory Motions in general, is one of the utmost intricacy; and, in spite of every exertion on the part of the most expert geometers, continues to this day to give continual occasion for fresh researches."—*Sir J. F. W. Herschel.*

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PREFACE.

The intention of the Author, in the original design of this Work, was to have confined his attention to a definition of the functions of the different parts of the Ear; but he found that, without an antecedent inquiry into the nature of Sound, his views would be liable to misapprehension, and he has therefore devoted Part I. to its detailed examination.

The preliminary investigation, thus rendered necessary, induced him to examine the evidence taken by a Committee of the House of Commons upon the Principles of Sound; but the information obtained being limited, and their application to Buildings erected for Oratorical Purposes involving an inquiry both interesting and useful, Part II. has been appropriated to this subject.

It is, however, in the structure of the Human Ear that these principles receive their most effective illustration. This organ, formed by Divine contrivance for one of the highest purposes of Creative Wisdom, not only exhibits a combination of every mechanical power conducive to the propagation of Sound, but embraces others of a neutralizing or opposing character, to counteract such of its properties as would be unfavourable to hearing. To render this portion of the Treatise of easy comprehension, Part III. has been divided into two chapters.

Chapter I. contains a description of the different parts of the Ear, rendered as brief as correctness will permit; with a diagram representing them of their natural size, and a plan in which their names are arranged in their relative positions; to which have been added short historical notices of any remarkable circumstances connected with their discovery.

Chapter II. contains, in many respects, a new view of the offices these different parts perform; and it will excite astonishment that so perfect a Sense can be produced from such complicated means.

In the exposition now offered of the principles of Sound and the organ of Hearing, the Author has submitted his conclusions, and the considerations upon which they are founded, to the judgment of the reader; being desirous that the opinions he has endeavoured to establish may, if correct, be rendered available to the relief of the deaf, and also supply that deficiency in physiological knowledge, which is admitted to exist in respect to the ear.

12, *Chapel Street, Bedford Row, London,*
31st October, 1840.

PART I.

ON SOUND.

ON SOUND.

CHAPTER I.

INTRODUCTION.

Few subjects of scientific pursuit are involved in greater uncertainty than the theory of Sound. Philosophers in every civilized country, from remote periods, have directed their attention to it, and numerous ingenious experiments have demonstrated some of its real or assumed phenomena; but the constant dependence of Sound upon Motion, and the existence of Motion unallied with Sound, have rendered many of these experiments unsatisfactory, from an inability to discriminate to which of these properties the results appertain.

It is, however, generally admitted, that for some of the most important purposes of life, our acquaintance with the nature of Sound is insufficient; and the following pages will be principally devoted to—

I. A popular definition of its principles.

II. Their application to the construction of public buildings for the facility of hearing, and

III. In determining the functions of the different parts of the ear..

In reference to the first of these practical objects, it may be merely necessary to state, that after the conflagration of the late Houses of Parliament, a Committee was appointed by the House of Commons to investigate the nature and properties of Sound, in conjunction with those of Warmth and Ventilation, with a view to their application in the erection of the new buildings; but though persons of the highest eminence in medical science, chemistry, and architecture were examined, one witness alone considered himself competent to afford information on the first of these subjects.

In respect to the other branch of inquiry, it may be remarked that the structure of the ear exhibits an anomaly in animal organization. It contains a secretion peculiar to itself, the principal purpose of which has not hitherto been explained; and within its central cavity, called the tympanum, are placed four small bones, which, at the period of birth, have acquired the largest proportions they ever attain. While all other parts of the body are subject to progressive increase for a shorter or longer period, those of the ear alone require fixation; and hence it becomes a matter of interesting as well as important inquiry, to discover what *are* those immutable principles of sound which require this departure from the general laws that regulate animal life.

Of the imperfection of our knowledge in this particular, it will be perhaps desirable to insert the opinions of some of the most accomplished modern authors.

The following remarks occur in his *Treatise upon Sound*, by Sir J. F. W. Herschel:—"Of all our organs perhaps the ear is one of the least understood. It is not with it as with the eye, where the known properties of light afford a complete elucidation of the whole mechanism of vision, and the use of every part of the visual apparatus. In the ear everything is, on the contrary, obscure; anatomists, it is true, have scrupulously examined its construction, and many theories have been advanced of the mode in which sounds are conveyed by it to the auditory nerve, where of course, as with the optic nerve in the eye, all inquiry terminates; * * * but nothing certain can be said to be known."

Dr. Arnott, in his *Elements of Physics,* in common with many others, admits the insufficiency of our acquirements upon this subject; upon which Sir Charles Bell has the following remark:—"As we find late physiological writers acknowledging their ignorance of the functions of the particular structures in this organ, we cannot therefore conceal that there is a difficulty in assigning the uses of the parts."

Another cause of regret has arisen from this defective knowledge; those physico-theologists who have endeavoured "to look through Nature up to Nature's God," having lamented that the occult formation of the ear has deprived them of that elucidation of Divine contrivance which is so conspicuous in the eye; and Dr. Paley, in his *Natural Theology,* after expatiating upon the wonderful adaptation of the latter organ to the principle of light, thus regrets our inability to associate the other with equal facility to the properties of sound. "It is probable the ear is no less artificially and mechanically adapted to its office than the eye, but we know less about it; we do not so well understand the action, the use, or the mutual dependency of its internal parts."

CHAPTER II.

On the Origin and First Principles of Sound.

"Nature, and Nature's laws, lay hid in night;
God said, Let NEWTON be, and all was light."
Epitaph by POPE.

THIS high eulogium upon our illustrious countryman was never more justly deserved than for his discovery of the principles of sound, which he attributed to the condensation and rarefaction of air. This subject being only incidental to the primitive object of these pages, the author had attempted a definition before that of Sir Isaac Newton had attracted his notice; and the work having been written with reference to that description, it has been retained, as it in no way deviates from the principle antecedently laid down, and is as follows:—

Sound is a property inherent in the atmosphere, and is elicited by the constriction and subsequent expansion of its particles.

The word *constriction* was adopted as expressive of the mode by which the condensation conducive to sound is effected, and *expansion* was preferred to rarefaction from the latter term being generally employed to denote the extension of the parts of a body by heat; and it was deemed desirable, as far as language would permit, to keep the verbal definition of those two great elementary properties, Sound and Heat, distinct.

Notwithstanding the admitted correctness of the principles above stated, many of the phenomena of Sound have been attributed to other causes, while several remain altogether without explanation; we have, therefore, selected some of the most diversified modes of its diffusion in order to associate them with this common origin; and shall proceed to consider of its cause in thunder, the ringing of a bell, the report of a cannon, in water, in the construction of musical instruments, in the human voice, and in echo.

I. *Of the Cause of Sound in Thunder.*

Thunder is one of the consequences resulting from lightning, and lightning appears to be occasioned by the combustion of some of the inflammable particles of the air; or, according to more recent opinions, of a condensation of aerial matter conducing to electricity, by which, in either case, a vacuum is created. The surrounding atoms which remain uninfluenced by this change, being forced together by the whole weight of the atmosphere, greatly constrict each other; but their elastic nature causes them immediately to expand, and by this enlargement their sonorous property is acquired. A centrifugal force being thus established, it acts in all directions alike; but as the circle extends, its propulsive power becomes gradually diminished, till at last its pressure is no longer felt, nor sound created.

The rumbling noise of thunder is produced by that portion of the sonorous circle which strikes upon the earth, whence it becomes condensed; and, being intercepted in its upward course by dense masses of vapour, it is again reflected, and this alternate motion and reverberation continue, until the interruption ceases, or the original force is exhausted. Echo is occasioned also by reverberation from one cloud to another.

II. *Of Sound in the ringing of a Bell.*

In whatever way the adhesion of metals is effected, whether by gravitation, mutual attraction, or partial cohesion, if their ultimate molecules are indestructible and of a definite shape, as is generally admitted, no specific form can be imagined by which, when indiscriminately mixed, their diversified surfaces can all be placed in contact; and consequently chasms for air must exist. The striking of a bell throws its metallic parts into motion, constricting the aerial particles interspersed throughout it, and causing their subsequent expansion; and, by the communication of these with the outer air, sound is produced, and diffused in the same manner as in thunder.

As this explanation is totally different from the generally received notion of the method by which sound from a bell is elicited, it may be necessary to refer to the experiment made at the *Academia del Cimento* at Florence, where water enclosed in a ball of gold was forced by pressure through its pores.

III. *Of Sound occasioned by the report of a Cannon.*

The sound produced by the discharge of a cannon is occasioned by a combination, though in a very different degree, of the two causes before described. The solid materials composing the gunpowder being changed, by the application of heat, into a gaseous or aeriform state, are prevented from immediate expansion by the constrictile power of the gun; and, being thus greatly compressed, they rush forward to its mouth, where, expanding upon the open air, they communicate their percussive and sonorous property to the surrounding medium, on the same principle as in thunder. The metallic influence, by which the report is associated with the sound of a bell, is but slightly perceptible; although a practised ear is capable of distinguishing at a distance whether a cannonade proceeds from brass or iron ordnance.

The distance to which sound can thus be conveyed is very great. The artillery at the siege of Genoa by the French was heard at Leghorn, a distance of 90 miles. The firing at the battle of Waterloo was heard at Dover, a distance in a direct line of 140 miles, of which 110 were over land, and the remainder over water. The sound in proving cannon at a foundry on the shores of the Baltic was conveyed 300 miles upon the sea; while the eruption of a volcano, which may be assimilated to the discharge of a piece of ordnance of enormous proportions, has been heard at a distance of 900 miles.

Gunpowder, on the other hand, when uncompressed, is heard at a comparatively short distance. The explosion of the powder mills near Kirby Lonsdale, containing five tons, or 11,200 lbs., was not heard beyond a distance of 12 miles; and, from this want of compression, thunder, which is the loudest sound of which we are sensible, seldom extends above 10 miles from its source, and in no recorded instance has exceeded 15 miles.

IV. *Of Sound in Water.*

Sound is distinguished under water at a distance of about four times greater than upon the land. The quantity of atmospheric air combined with the water will account for this mode of conduction; but the medium, though dense, being fluid, it does not afford the same degree of compression as solid substances, and is therefore greatly inferior, in the rapidity of its transmission, to wood and metals.

As this subject is very extensive and diversified, its consideration will form a part of nearly every succeeding chapter.

V. *Of Sounds produced by Musical Instruments.*

Musical instruments may be divided into three distinct classes, viz., first, stringed, or membranous instruments, as the harp, drum, &c.; secondly, wind instruments, as the flute, French-horn, organ, &c.; thirdly, metallic instruments, as bells, musical boxes, the jew's-harp, &c.

I. The action of the hand upon the harp, the bow upon the violin, the fingers upon the tambourine, or the sticks upon a drum, all cause vibration. The sound produced does not in the first instance arise from these vibrations acting upon the external air, as is usually considered, but in the constriction of the atmospheric particles interspersed within the elastic animal fibre; and these particles, thence expanding into the surrounding air, originate the production and diffusion of sound. Where the elasticity is destroyed by damp, motion is produced without occasioning sound, as in a wet drumhead.

II. Wind instruments, which may be said to consist of three kinds, as

1. The clarionet, flute, &c. into which air is propelled in a nearly equable manner, and their harmony is occasioned by opening and closing certain apertures in their sides, which may be considered as alterations of their structure.

2. By instruments admitting of no alteration of structure, as the trumpet, French-horn, &c., into which the harmony is propelled by the mouth and lips, the metallic surfaces merely deepening its intonation; or, as

3. In organs, where each tube is constructed to utter a separate note, and the harmony is produced by shutting or opening the tubes at pleasure.

III. Metallic instruments, as bells, which are dependent upon their composition and relative size for their diversity of tone; or the notes of musical boxes, which are regulated by the length and thickness of their springs, which, being elevated by points fixed on a movable barrel, produce, on their rebound, the degree of harmony required.

In all these instances it will be observed the same principle prevails, of a constrictile power being first produced, which afterwards leads to that modified expansion which creates sound, tone, and harmony.

VI. *Of Sound produced by the Human Voice.*

The first act in the production of sound by the organs of the human voice is a voluntary contraction of the cavity of the chest, which contains the lungs. These consist of two divisions, each provided with a tube, which uniting, forms the lower part of the *trachea* or windpipe. The trachea has been compared to a Corinthian column, from its gently tapering upwards, and having at the top an expansion called the *larynx,* which, in continuation of the simile, has been considered as its capital. The larynx is formed of five cartilaginous rings, extending outwards, and forming that prominence in the upper part of the throat known by the name of Adam's apple. The larynx also contains two strong ligaments, one on each side, which have been called *chordæ vocales,* from some influence they are supposed to possess upon the voice; but it is more probable that their purpose is to prevent the extension of the larynx upwards, and favour its expansion in a horizontal direction. The upper ring of the larynx is called the *glottis,* which is perforated by a very small hole, and this is surmounted by a cartilaginous flap called the *epiglottis,* which prevents the ingress of food, and becomes elevated for the purpose of respiration. Breath, thus influenced by compression and expansion alternately, at this aperture becomes sound, and is influenced in its character by the direction it takes towards the throat or nose, by which it is distinguished as guttural or nasal.

For the formation of language, sound undergoes the operation of the organs of voice, passing first through the soft or palatine arch at the back of the mouth, from the centre of which depends the *uvula*, a fleshy projection so named from its resemblance in form to a grape. Having passed this fleshy portal, the sound becomes compressed by the soft and flexible tongue against the bony palate or concave roof of the mouth, by which the greater proportion of articulate sounds is produced; but some require the compression of the cheeks, others the approximation of the teeth, or the direction of the tongue towards them; while many depend on the compression of the lips; and it is perhaps remarkable that the word *lips* cannot be pronounced if these organs are held apart. The vowels require the most simple action of these different organs, while the consonants depend upon a considerable modification of them. By these further means of constriction and expansion, sound becomes modulated into language; and, by its expansion upon the air, man acquires his distinctive attribute, viz., the expression of his thoughts through the medium of speech.

VII. *On the Reproduction of Sound by Echo.*

Echos may be considered of two kinds; first, the ordinary expansion of sound upon the air, which, being interrupted in its onward progress by opposing surfaces, is thus diverted from its natural direction, and, bounding from one obstruction to another, continues its successive reverberations until its original force is exhausted. But the species of echo which more immediately enters into our present illustration, is that in which the sound is re-collected, and returned to the spot whence it proceeded. This phenomenon is generally occasioned by circular or angular surfaces, which, receiving the radiations of sound in equal proportions, condense them into a focus, and, from the constriction they thus undergo, expansion again takes place, and the sound or language is almost instantaneously reproduced at the place of its utterance, with very little diminution of its primitive intonation.

In all these diversified instances one principle prevails, viz., the constriction and subsequent expansion of the particles of air; which, proceeding the one from the other, can alone create sound. The rarefaction of air by heat will not produce this effect: thus, a large fire will not occasion sound, while a small quantity of air, enclosed within a heated coal, will explode with a considerable noise, from the constriction the air undergoes previously to bursting.

This difference in effect may be instanced by another example. On lighting a fire in an iron grate, no sound will be created from the rarefaction which both the air and the metal undergo; but, on taking off the fire at night, particularly in winter, the cold which causes the metal to contract, occasions also a constriction of the air within it, and a crackling noise is produced, which continues until the iron cools.

CHAPTER III.

On Motion in relation to Sound.

THE origin or cause of sound, as we have already endeavoured to show, arises from the constriction and expansion of air; but, as it is a property *sui generis*, it can only be produced by methods peculiarly its own, and we therefore experience a difficulty in the definition of the degree of motion with which it is combined; that which is most common, as the locomotive exhibited in the flight of a bird, having the least relation to it.

The motion which is first associated with the propagation of sound is the tremulous, resulting from the contraction and expansion of the aerial molecule, in which either its centre or some part of its circumference undergoes no change of position; a degree of motion, exemplified in the gradual inflation of a balloon as it becomes enlarged by the accession of gas or collapsed by the action of the wind; or it may be illustrated by a deer feeding at the foot of a tree, his feet being fixed, but every portion of his frame trembling from the mere rustling of the leaves, or by the fall of the very fruit he desires.

The second degree of motion accessory to sound is the vibratory, which partakes slightly of the locomotive in the altered position which each particle of air undergoes in relation to bodies at rest, from the enlargement of adjoining ones, by which it becomes momentarily displaced; but as soon as the sonorous enlargement is over it regains its original position, without having caused or suffered any alteration in respect to its proximity with adjoining atoms. This degree of motion has been termed *vibration*, illustrated by Dr. Johnson, on the authority of Sir Isaac Newton, as "a state of being moved with quick reciprocations or returns."

To form an idea of the conveyance of language from one person to another across a field, without an alteration of the relative position of the particles of air by which it is conveyed, let us imagine a number of persons joined hand in hand, or foot to foot, receiving the shock of an electric battery: the sensation is felt throughout, but the bodies receiving and transmitting it continue in their original places. But, as this simile conveys no idea of the expansion of the particles by which sound is diffused, let us again imagine a bell, around which, to a certain extent, the atmospheric atoms are of a particular colour; then a second band, of the same width, of a different colour, and so on. The effect of sound, on striking the bell, would be to enlarge the particles contained within the first circle, so as to cause them to encroach upon the second; the second, in like manner, would press upon the third, but not in an equal degree, for, as every succeeding circle would contain a larger quantity of molecules, the primitive force would be more divided and become less perceptible; and thus it would go on diminishing, till the last circle would receive the impression on its inner surface without reaching its circumference, and in the intermediate space sound would necessarily terminate.

In addition to these degrees of motion consequent upon sound, another seems required, by which the sonorous impression is propelled outwards, while the air is prepared by some counteracting movement for subsequent intonations. Great diversity of motion exists in the collision of spherical bodies; and those who are accustomed to the game of billiards, will at once perceive a very great variety thus produced.

1st. If two balls are placed in a straight line with an object, and the nearest is struck a little above its equatorial line, it will communicate sufficient force to the further one to impel it onwards, and retain sufficient for itself to follow in the same direction, till both arrive at the goal.

2nd. If it is required that the further ball alone should be propelled, this can be effected by striking the nearer exactly on its centre, by which nearly its whole force is communicated to the other, and any slight momentum remaining will be expended by the first in rotary motion, upon the spot where the collision took place.

3rd. A different motion is obtained by striking a ball below its equator, by which it will drive another one forward, but recoil itself several inches. These differences of motion are all rectilinear; and there is a

4th, or lateral, far more common, when the stricken ball is urged in an angular direction against one at rest, and the divergence produced is dependent on the particular portions brought in contact, and on the velocity of the impelling force.

It is probable that all these degrees of motion are combined in the propagation of sound. The two first and the last will be more particularly alluded to in Chapter VI., which treats of its linear and superficial diffusion; but it is probably owing to the third that the sonorous particle, after communicating its intonation, is caused rapidly to collapse, and become suitable for another impression. As we find that the particular portion of the sphere on which the collision takes place determines the different degree of motion, may not the onward progress of sound be communicated by a blow below the equatorial line of the atmospheric molecule, by which its lower parts are turned upward, while the superior parts, being reversed, are turned backward, and the atom reacts upon the one by which it was impelled, and thus the diffusion of sound is promoted in one direction and neutralised in the other? This degree of rotary motion has some analogy in that of other bodies. A bullet projected from a gun is said to pass in a state of rapid rotation, and its whizzing sound is occasioned by inequalities of its surface, which cause additional friction on the air.—*Herschel on Sound*, Art. 145. The diurnal and other motions of the earth may be not only necessary for the alternation of night and day, the succession of the seasons, and the healthful action they produce on the fluids which support life, but may be equally requisite to control its annual revolution; and, as all the heavenly bodies are supposed to partake of rotary motion, it may not only be the means by which the solar system is regulated, but may also enter into that motion on which depends the rotation of the universe. Were it not for some force acting on this principle, no new sound could be created till the former one was exhausted; whereas, we find that concentric circles of sound may be passing through the air without the slightest interruption of each other. The clock at St. Paul's occupies about 30 seconds in striking the hour of six, and this sound is frequently heard at Beckenham, a distance of 10 miles, which it requires 47 seconds to traverse. It is therefore evident that the last intonation must have left St. Paul's before the first arrives at Beckenham; and thus these circles of sound are producing successive effects on all the sentient bodies over which they pass, without occasioning the slightest interference with each other.

This phenomenon, which is clearly demonstrable in the extensive illustration here selected, is equally perceptible in the rapid delivery of speech while each syllable is kept distinct.

The extent of this sonorous expansion it is impossible to determine; it may consist of a single line of atoms, or of several lines: the minuteness of the required pause in the utterance of language proves that it cannot be considerable. At the same time, this reflex action, though immediate, is not instantaneous; as a person may speak with such rapidity as to destroy all distinct articulation; and a child beating a drum, without regard to time, or the necessity of a pause, will occasion one unvarying sound.

It is doubtful whether undulatory motion appertains to sound. A wave is created by pressure upon a fluid; and if a drop of water fall perpendicularly on the even surface of a lake, it causes a depression, around which the water will become elevated; and, falling principally outwards, will occasion a succession of waves, till the equality of surface, which the first impression deranged, is restored. In this progressive motion, the particles of the water become displaced; which may be proved by the light substances floating upon it being removed to the periphery of the circle.

One impression will create many waves; and as the medium on which they act is incompressible, or nearly so, their motion is impeded by the friction of the particles of the water, by means of which, and the gravitation of the earth, the equilibrium of the fluid is regained.

In neither of these particulars does there exist any analogy to the diffusion of sound. Sound is created on a medium highly elastic, and is diffused by one general spherical expansion, without the alternation of waves.

One impression creates but a single sound, and successive impulses can arise only from renewed percussions.

No displacement of the particles of air, in relation to each other, takes place, but sound is transmitted by their juxtaposition and successive enlargement.

This comparison, however, has existed in our own language from the time of Chaucer, by whom it was employed, and has been adopted by every succeeding writer; yet the principles of the two motions are as dissimilar as the elements upon which they act; and their constant assimilation has been the cause of much misapprehension of the nature of sound.

CHAPTER IV.

Of sonorous Pressure.

THE expansion of the particles of air, by which sound is diffused, has given rise to many phenomena, some of which naturalists have hitherto been unable to explain. One of these is the perception of sound by animals having no aural apparatus; a deficiency common to the whole class of insects, as well as to individual species in other classes. As it has been calculated that the animal kingdom consists of 100,000 varieties, 80,000 of which are insects, it follows that, unless some method of distinguishing sound, other than by the ear, existed, four-fifths of the animal creation would be deprived of a sensation necessary to their enjoyment and security. The faculty, therefore, of appreciating sound has been assimilated with the sense of touch; and hence various methods have been provided, by which it is rendered cognizable to the inferior creation, to such degrees as their necessities may require. This has been effected in different ways: in worms, slugs, and many species of caterpillars, by the delicate texture of their unprotected skin; in other animals by a sensitive covering of hairs with which they are provided; while this sense is attained in winged insects by the light feathery down with which their bodies are invested. But the principal organs for this perception are the antennæ or feelers, which project from the head, and, having generally the facility of movement in all directions, intimate with unerring certainty the progression of sound, from whatever quarter it may proceed. Doubtless other methods exist beside those which are here enumerated; and the spider appears to possess one peculiarly his own. Having none of the accessories before described, not even antennæ, he nevertheless enjoys great quickness of hearing; a sense which seems to arise from the structure of his web, a filament of which is always attached to his body, and may be considered as an extension of his nervous system, in respect to sound. When crawling on the earth, a thread is always elongating behind him; and when quitting a projecting eminence, or the branch of a tree, he first attaches it to his starting place, to facilitate his descent, or aid him like a rope on his return: in every instance the pressure of sound by this delicate attachment is conveyed to his sensorium. In this arrangement we perceive the rigid economy of nature, in not providing separate organs, where one can answer a double purpose; and as the web of the spider both affords him sustenance, and the indication of coming danger, the antennæ, which would otherwise have been required for the latter purpose, being no longer necessary, are withheld.

The effect, however, of the pressure of sound upon the human frame is scarcely perceptible, unless the sense of hearing by the ordinary organ is lost. I have observed, in several instances, that persons whose hearing was so feeble as to be unable to detect the ticking of a watch, except by absolute contact with the ear, have been nevertheless insensible to the sonorous pressure; but in cases where the acoustic nerve has been destroyed, and thus all hearing rendered impossible, its beating has been sensibly felt at a distance of from four to fourteen inches. It would, therefore, appear that when a sensation, however small, through the natural channel remains, it exceeds and even prevents the inferior one of touch; but when the first is totally destroyed, the second in a feeble degree supplies its place.

These observations induce me to endeavour to account for that augmented perception of sound which is experienced under water. Dr. Monro, who made many experiments upon this subject, describes the sensation of sound by the striking of two stones, held in the hands when under water, as painfully acute, and it was not only felt in the ear, but over the entire surface of the body.

With a view to increase our information upon this difficult subject of investigation, I have inquired of Colonel Pasley, of the Royal Engineers, who has recently been employed by Government in the destruction of sunken wrecks, whether, in any recent explosion under water, any person were submerged at the time; to which he replied that "no such occurrence had taken place, and very prudently, because the shock kills fish and sends them floating up to the surface. In one instance, the great pressure of water burst a wrought-iron vessel containing about 260 pounds of gunpowder, when the diver was near it at the bottom, and caused a report, which he took for an explosion of gunpowder, and immediately came up in great agitation, as he thought we had fired a charge while he was down, contrary to custom." It will be thus observed that the mere compression of the small quantity of air contained in a cylinder full of dry materials, under water, caused a noise or report equal to an explosion in the air, and that it would be highly dangerous to be immersed on such an occasion, except at a considerable distance. As some time must elapse before such experiments can be made, we will endeavour to explain what appears to be the cause of this extraordinary perception.

The ears of fishes consist generally of a small bag filled with an aqueous fluid, at the bottom of which is a slightly gelatinous matter, into which the acoustic nerve is distributed. This bag or ear has no external opening, being covered by the ordinary skin of the fish. The human ear, being destined for another element, is divided into two parts; viz., the pneumatic apparatus for the collection, constriction, and transmission of air impressed with sound; and an aquatic or hydrostatic apparatus, in which, as in the case of fishes, the acoustic nerve is distributed. While under water, the first or pneumatic machinery may be considered as rendered nugatory, water occupying the outer or auditory channel, while the inner one, at the back of the nose, is kept closed from the same necessity which closes the mouth against the admission of water into the stomach. Hearing, therefore, by the ordinary apparatus, is destroyed; and hence the sense of feeling arising from the general distribution of the nerves, which pervade man in a greater degree than any other animal, becomes perceptible.

The effect of pressure from sound is by no means confined to the animal kingdom, having had the effect, in several well-authenticated instances, of quelling the turbulence of the ocean. Several records exist of naval engagements, which, having commenced in a storm, terminated in a tranquil state of the sea; an effect by no means surprising, if we consider the principle which governs the waves. Though a stormy sea may extend to several degrees of longitude and latitude, it must still be considered local, being created by the violence of the wind, which, causing inequalities in the surface of the water, gives to that fluid an alternation of action, which the gravitation of the earth is calculated to suppress. The agitation, therefore, which pressure from a considerable altitude has created, is counteracted by the pressure of sound, which, acting horizontally, tends to diminish those inequalities which the more elevated pressure had occasioned. This effect has been very correctly delineated in a representation of a naval engagement that took place in the Adriatic Sea, with the squadron commanded by Captain Hoste. The battle is represented at three different periods,—its commencement, middle, and close; in the first of which the sea is very high, in the second less so, and in the third perfectly calm. The drawings from which these plates were published were taken by an officer on board the commodore's ship.

This effect is more strikingly exhibited in the water-spout, which, by a particular confluence of the air, is supported to a considerable height, and in such quantity as to overwhelm the largest ship that may come in contact with it; but a single discharge of a gun destroys the aerial current, and at once dissipates the watery mass.

It has been remarked that a very loud report accompanies its dispersion, which may be thus accounted for:—Previously to its descent, the water-spout assumes a funnel-shaped appearance, the top greatly overhanging the base, thus presenting an aqueous cavern in all directions; and in its fall, the air thus enclosed becomes compressed, and produces sound by its subsequent expansion on the surrounding atmosphere.

CHAPTER V.

Of the Transmission of Sound through Air and Liquids, and the sonorous Properties of different Substances.

Considerable doubt has been excited, whether the property of sound is wholly confined to our atmosphere, from the circumstance that meteors, which have passed at an altitude greater than its supposed elevation, have been distinctly heard; but of the state of that expanse, called ether, which separates this globe from the celestial bodies, nothing is positively known respecting either its density or temperature. It has been satisfactorily proved, that sound is but feebly perceived in a rarefied or attenuated atmosphere. and in a perfect vacuum is not distinguishable. In hydrogen gas it is but faintly heard; and even by the admixture of atmospheric air, in even proportions with hydrogen, its intensity is not greatly increased; the want of affinity in the two rendering the introduction of the denser medium of little avail. Dr. Priestley discovered that, in carbonic acid and oxygen, it was louder than in common air. The late Professor Leslie instituted some interesting experiments upon this subject, which were terminated by his premature death; and no others have been subsequently attempted (of which the results have been published), conducted on a scale sufficiently extensive to form accurate data.

Of the transmission of sound through air, numerous experiments have been made at various periods, in different countries; but differences of temperature, as well as the insufficiency of the instruments employed, have rendered the results by no means uniform, as the following estimates, principally collected by Sir J. F. W. Herschel, evince:—

	Feet per Second.
Mersennes, Balistica	1474
Walker, Philos. Trans.	1305
Roberts, do. do.	1300
Boyle, on Motion	1200
Cassini and others, Duhamel	1172
Florentine Academicians (1660)	1148
Flamsteed, Halley, Derham	1142
(*Which, at 77½° Fahrenheit, is correct.*)	
G. E. Müller	1109
Parry, Philos. Trans., 1828	1038
Arago, Matthieu, Humboldt and others, 1822.	1086
Moll, Vanbeek, and Kytenbrouwer, in Holland	1089
Gregory, Dr. Olinthus, at Woolwich (1823)	1088

The three latter experiments appear to be nearly coincident, and were made in dry air, at the temperature of 32 degrees; those by the French philosophers, by the aid of a watch which made one revolution in a second, and was provided with an apparatus supplied with printers' ink, which, by means of a lever, dotted the dial at the precise portion of a second when the flash was observed. The experiments by the Dutch were regulated by a clock of such extreme delicacy of construction as to register the hundredth part of a second. The velocity of sound may therefore be determinately fixed at the average these experiments produce, of 1,090 feet in a second, at the temperature of 32 degrees of Fahrenheit; and every additional degree of temperature adds 1·14 foot to the velocity. At 62 degrees, it passes at the rate of 1,125 in a second; and these being determinate points, it will be perceived that, in 30 degrees increase of temperature, the velocity of sound is extended 35 feet, or $1\frac{1}{7}$ of a foot for each degree, which, though not mathematically correct, is sufficiently near, and more convenient for common calculations, a like allowance being made for the retardation of sound at every degree below the freezing point. Sound thus passes, at the temperature of 62 degrees, 9,000 feet in eight seconds, equal to 12¾ British standard miles in a minute, or 765 miles in an hour, which is about three-fourths of the diurnal velocity of the earth's equator. These calculations, however, represent the velocity of sound in open air; its rapidity, superficially, is considerably greater, but has not yet been subjected to accurate investigation.

Of the transmission of sound through liquids, the experiments of M. Perrole appear to be the most correct; I have therefore copied from his own statement the mode by which they were effected:—

"I closed all the joints of my watch with soft wax, and then suspended it by a silk thread. In this state I hung it by an iron branch fixed in the wall, so that the watch remained suspended in the middle of a glass vessel, five inches in diameter, and seven inches high, taking care that neither the watch nor the thread touched the vessel in any part. I remarked the kind of sound afforded by the watch, and the distance at which I ceased to hear it. After having marked this point, I then filled the vessel with water, into which I again suffered the watch to descend, with the same precaution of not letting it or the thread touch the vessel.

"The tone (*timbre*) was changed in the water in a striking manner. The sound was propagated in so lively a manner, that the glass and a small table of wood, on which it stood at a distance from the wall, seemed to undergo direct percussion as from a solid body. But what appeared still more astonishing was, that in the midst of all these agitations the fluid in which the watch was plunged was perfectly tranquil, and its surface not in the slightest degree agitated.

"By substituting different liquids in the place of the water, I had results in general analogous to those I had obtained with that fluid; but each medium gave a different modification to the sound, of which the intensity was noted as follows :—

Intensity of Sound observed in different Fluids.

	Feet.
1. In the air, serving as the term of comparison, it ceases to be heard at the distance of	8
2. In the water at that of	20
3. Oil-olive	16
4. Oil of turpentine	14
5. Spirit of wine	21

"It is proper to observe, that on repeating these trials I observed some variations in the intensity, which appeared to depend on the organ of sense or accidental noises.

" From the experiments made upon liquids it follows :—

" 1. That these, as well as solids, do transmit sounds much better than air, and that even the fat oils are not to be excepted.

" 2. That each fluid upon trial is found to modify the sound in a peculiar manner.

" 3. Philosophers maintain the opinion that sound is propagated in the air by means of certain motions or undulations, which the transparency of that fluid prevents our seeing. My experiments with fluids which do not elude the sight, and in which no motion was perceived, notwithstanding the very effectual transmission of sound, may render this in some respect doubtful."

As glass is the most sonorous of substances, these experiments would have been better conducted by means of a membranous bag; but the remark I have previously made in the chapter on Motion appears to be confirmed by this ingenious philosopher, that undulatory motion is not connected with sound.

These experiments, it will be observed, exhibit the intensity of sound after passing through liquids, and subsequently distinguished in the air; but the transmission of sound through water, and heard in the water itself, is more rapid, and may be heard at a greater distance than any calculations have hitherto ascertained. Dr. Franklin, having plunged his head under water, heard distinctly the striking of two stones at the distance of half a mile; and Dr. Monro ascertained that its velocity below the surface was about four times greater than in the open air. The experiments made by Calladon in the lake of Geneva, in the year 1826, though they merely confirmed the calculations of Monro, were so ingenious and complete, as to set the matter at rest, and render any future experiments unnecessary. Having discovered that a bell was the most effective mode of propagating sound under water, he contrived that the same lever which struck the bell should also ignite gunpowder, so that the precise moment might be denoted. Having marked out a distance of nine miles upon the lake, he caused a thin cylinder of tin, about nine feet long and eight inches in diameter, closed at the downward end, to be inserted in the water, leaving but a small portion above the surface. From the result of 44 experiments made on three different days, he ascertained that the velocity of sound was 4,708 feet in a second, the water being of the temperature of 46 degrees. As sound, at the same temperature, would pass at the rate of 1,106 feet in the air, its velocity in water is four times greater, with a surplus of 284 feet. Some interesting experiments may still be made upon this principle, and it is highly probable that if the tube were increased in length, and made in the shape of an ear-trumpet, some of the enormous charges of gunpowder, exceeding 2,000 lbs. weight, which have been employed for the demolition of vessels under water, might be heard across the British channel.

Sound created in the open air is heard, though but faintly, under water, and sound made in water is as feebly distinguished in the air; that of the bell used by M. Calladon not having been heard at the distance of 300 feet by persons upon the surface. Colonel Pasley has informed me, as the result of some of his experiments, "that a ton of gunpowder fired at Spithead, at the depth of about 14 or 15 fathoms, makes a report not exceeding that of a 24-pounder at a moderate distance."

To account for this difference in the intensity of sound by these diverse modes of propagation, it is submitted whether the particles of water may not assume a flattened shape, and be distributed in a laminated form, and thus transmit sound in a horizontal direction with more force than vertically or upward. This hypothesis, which is only suggested, has some analogy in the transmissible qualities of wood, which conveys sound longitudinally, or in the direction of its growth, with great rapidity, while it is not transmitted so sensibly by the continuity of transverse planks or sections.

The different degrees in which substances derived from the mineral, vegetable, and animal kingdoms are favourable to the transmission of sound, appear to be regulated by laws not easily demonstrable.

In the mineral kingdom those which are most loosely combined appear to possess this quality in the smallest degree, which increases with their augmented hardness; thus, vegetable earth, sand, pumice-stone, marble, limestone, and flint are graduated in this scale. Clay is insonorous from the quantity of water it contains, but when formed into tiles, bricks, and pottery, and baked, the water becomes evaporated, and air chambers are formed, and it is then highly sonorous.

In metals, which in this inquiry we must separate from minerals, their efficacy in producing sound appears to depend upon their lightness and brittleness. Glass, which from its artificial composition may for the purpose of this inquiry be considered as a metal, exhibits the greatest susceptibility, as it does not require the contact of other tangible bodies to elicit sound from it, but becomes sonorous from sound already existing. A person sneezing loudly in a room in which a tumbler is placed on a table will cause it to ring; a violoncello played near a table containing wine glasses will cause them to fall off (Arnott); and a violin played in proximity to a piece of glass covered evenly with sand, will cause such changes of its surface, by the expansion of the aerial particles within it, as, on the subsidence of sound, to leave geometrical figures indicative of the valleys and elevations into which it had been thrown.

Bell-metal is a composition of zinc and tin, two of the lightest and least ductile metals, rendered by their amalgamation still more brittle, and containing a larger proportion of internal cavities; thus affording the best medium for sound. Brass, which is a combination of zinc and copper, possesses the sonorous property in the next greatest degree; while in the unalloyed metals it declines from iron, silver, copper, gold, and tin, to lead; its declination appearing to be produced by their increased softness.

In the vegetable kingdom, the degree appears to be regulated by lightness and dryness. A succulent vegetable possesses little of this quality, fir the greatest; and, according to experiments made by M. Perrole, other woods in the following proportions—mahogany, box, oak, cherry-tree, and chesnut. Fir has preserved its reputation in this particular for above 3,000 years, it being mentioned in the second book of Samuel, chapter the sixth, that "David and all the house of Israel played before the Lord, on all manner of instruments made of fir-wood," &c. A peculiar pine grown in Norfolk Island has been deemed the most sonorous hitherto discovered; but the late Rev. John Williams, who has been styled "The Apostle of the South Sea Islands" (an appropriate title, whether we contemplate his active life or melancholy end), in his *Missionary Enterprises*, in enumerating the different woods in the Navigators' Islands, states that "the tou (*cordia*) would be exceedingly valuable for musical instruments, as the wooden drums made from it by the natives produce a far more sonorous and mellow sound than those constructed from any other tree." But long exposure to the air obtains this quality for sorts otherwise less sonorous; as by time the aqueous and resinous particles become evaporated, and the wood approaches nearer to the friability of metals. Violins, from this cause, are esteemed more valuable from their age, and when properly taken care of are guarded against damp. The proportion, however, of water in wood is always great, and would have been deemed incredible had it not been made the subject of frequent experiments. Dr. Prout states the proportion of carbon and water in willow as follows:—

Carbon, 49·8; water, 50·2

In box:—

Carbon, 50·0; water, 50·0

Of the two principal animal substances, flesh and bone, experiments have been so few as to afford no satisfactory data. From the facts that will be hereafter stated of the transmission of sound through the bones, they will appear to possess this property in a considerable degree; and a very easy experiment will show the extent of the reverberating power possessed by the flesh. If a watch be suspended in the open air, and a person remove to the distance at which its sound is very feeble, or imperceptible, and the same watch be afterwards held in the palm of the hand, the sound will become greatly strengthened, and heard at an increased distance. Though this effect is produced partly on the principle of echo, yet it shows that flesh is a good reverberating substance.

The dried fibres and skins of animals, from which violin strings and drum-heads are constructed, possess this quality in a still greater degree; and the sound which they produce arises entirely from the constrictile power of their filaments upon the air interspersed within them, as in the case of metals, and in no degree from their vibration, if by that term is meant their action upon the external air; as, after wetting them, nearly the same degree of motion may be produced, but, the constrictile power being destroyed, they no longer generate sound.

There is a tendency in the arrangement of the molecular aggregations of both animal and vegetable matter, which renders them more favourable for the propulsion of sound in particular directions. The suitableness of wood for masts is ascertained in the dock-yards by placing a watch at one end of the spar and the ear at the other: if the sound be heard in a harmonious manner, well known to experimenters, the timber is deemed sound; but if any horizontal crack exist, its unfitness is detected. The cause of this effect in all substances, whether stone, wood, or metal, may be easily understood. In their perfect state all possess a homogeneity or graduated admixture of their solid, aqueous, and aerial particles; and if these are dissevered by a crack, continuity of the internal vibrations is interrupted, the chasm admitting an expansion of the air, and losing a degree of compressibility which cannot afterwards be regained.

The following calculations are the result of experiments, made by different persons, of the velocity of sound, through various substances; but, not having been effected with the same accuracy as those through air and water, they are not equally to be depended upon:—

	Feet per Second.
In Tin	7,800
Silver	9,300
Brass	11,800
Copper	12,500
Iron	17,500
Tobacco pipes	10 to 12,000
Wood (various)	11 to 18,000
Fir-wood	17,300
Glass	17,500
Crown glass	17,700

CHAPTER VI.

On the Attraction of Sonorous Atoms to Solid Bodies, and the Superficial Diffusion of Sound.

The expansion resulting from previous constriction, by which the sonorous property is produced, causes corresponding lightness in the bulk of the particle so enlarged, in comparison with others not similarly influenced. In consequence, we find that the law of gravitation, by which lighter bodies are attracted to ponderous ones, operates on the sonorous particles of air, and gives rise to many of its most curious phenomena. The diffusion of sound from this cause not having been hitherto promulgated, we shall endeavour to illustrate it by reference to a mode of comparison often adopted to elucidate other properties of sound to which it is inapplicable. The method to which I allude is the effect produced in water when a stone is thrown into it. A succession of undulations is thus produced by which the particles of the water become displaced and are distributed principally outward, but those which do not reach the summit of the wave flow inward; and thus, when all motion has subsided, light substances, which overspread the surface before this interruption, and obscured the transparency of the water, will be found at its termination to have been driven to the sides of the pool or basin, and to be held there by gravitation, while a few of those substances will be collected in the centre, leaving every other part of the surface free.

The sonorous particles of air become diffused and separated in a manner apparently similar, though on a different principle, but which will tend to explain the causes of the *foci* of sound, which have been frequently observed to exist in circular and oval apartments; there being generally one sonorous centre in the first and two in the latter. The rotary action of the air, as described in Chapter III., on Motion, diffuses the sonorous expansion outwards; but the reflex action, by which the air is rendered suitable for a second impression, directs the intonation inwards, and thus arises the increased perception of sound in the centre of circular rooms. An oval room has generally a door opening into it in its shortest diameter, with probably a fire-place, or some projection opposite, and thus the circles of sound which become attracted to the wall, being interrupted at these places, cross over, and two sonorous *foci* are produced.

Another principle also conduces to the rapidity by which the transmission of sound along walls, on the earth, and still more upon water, is effected.

If we imagine a sonorous atom in the open air, we must consider that it will give off its propulsive power equally to every atom surrounding it; but if we imagine such an atom placed against a building or wall, it will be seen that it can affect particles only on one of its sides, and thus radiate sound into one hemisphere only. Those particles, therefore, that are placed in a direct line with the wall, receive its pressure with accumulated force; and as their number must diminish in proportion to their enlargement, sound will hence be conveyed to a greater distance through a smaller quantity of atoms, and therefore in quicker time, than by those other particles which receive their percussion laterally: an effect previously pointed out, as resulting from the first, second, and fourth degrees of motion produced in billiard balls, described in page 16, on Motion.

In corroboration of this theory, I will select two instances taken from Dr. Arnott's *Elements of Physics*, being anxious rather to establish my views from examples recorded by others, than by experiments of my own.

"The blow of a hammer given to a wall by a person at one end may be heard twice by a person at the other, namely, almost immediately, if an ear be applied to the wall, and after, through the air," page 491. "The report of a cannon placed on ice is carried much farther by the ice than by the air around," page 486; and Mr. Inman relates that, in the aqueducts of Paris, sound is first heard along their sides, and afterwards in the open space.

D'Aubigné relates that Henry IV. of France had not only a piercing and strong sight, but a very quick sense of hearing, of which he gives the following example:— "The king was once in bed at La Garnache, in a large state chamber, and his bed surrounded with curtains and a thick frieze. Frontenac and I lay in an opposite corner of the same room, in a bed enclosed in the same manner, and speaking jocularly of the king in as low a voice as possible, with my mouth close to his ear; Frontenac repeatedly told me he could not hear, and asked what I said. The king heard, and reproached him for his deafness, saying, 'D'Aubigné tells you I want to make two friends by doing one good office.' We bade his majesty fall asleep, for we had a great deal more to say of him."

This perception of sound, which the woollen curtains of the two beds would have prevented, may probably be attributed to its superficial distribution, to which the oak panelling, both then and even at present employed for the covering of internal walls in France, affords the best medium of transmission.

In the whispering gallery of St. Paul's cathedral, during the middle of the day, when from the external noises it becomes a Babel of sound, speech uttered in a whisper can be perfectly distinguished on the opposite side, being a distance, in the circuitous mode by which it travels, of about 210 feet; and at the same period of time, a watch, whose ticking at three feet in the open space was undistinguishable, was perfectly heard at thirty feet along the wall: on removing the watch three inches from the wall, it was not better heard than in the first instance. Thus proving that, by positive contact alone, the perception of sound is greatly extended.

The diffusion of sound is greatly promoted by three concomitant circumstances, viz.,—

The density of the air; the smoothness of the surface over which it is impelled; and stillness, or freedom from disturbing causes of the region in which it is expanded; to each of which we will endeavour to give a separate consideration.

I. *Of Density.*

The rapid declension of the atmospheric pressure, as we ascend, has been calculated by Dr. Prout in the following manner. "At three miles in height the density of the atmosphere is one-half of what it is at the surface of the earth, or equal to a column of mercury 15 inches in height; at six miles the barometer would stand at one-fourth of its usual height, or seven inches and a half; at nine miles, at three inches and three quarters; and at fifteen miles, at about one inch."

From this attenuation of the atmosphere, hearing would be very imperfect, were not this tendency counteracted by the increasing coldness we experience after passing that altitude, which varies in different latitudes, but has been denominated the line of perpetual congelation. The only method by which correct deductions on this subject can be obtained, must arise from the observation of aëronauts, whose attention however has not been particularly directed to it. Mr. Green, who has exceeded all others in the frequency of his ascents, states that the facility of hearing rapidly lessens as we ascend, but, on attaining the altitude of 27,146 feet, equal to 5 miles, 1 furlong, and 86 feet, he was still enabled to distinguish the ticking of his watch, and the voice of his companion; the temperature having undergone a very considerable change, being 61 degrees when he quitted the earth, and 5 degrees at the highest altitude; and he felt assured that, had he been able to continue there long enough to allow the mercury to adjust itself to the atmosphere, it would have fallen below zero; the barometer having fallen from 30 inches to 11.

It will thus be seen, that while the barometrical pressure had lessened, the coldness which tends to the condensation of air had greatly increased, and the 61 degrees of temperature would produce, at the rate of $1\frac{1}{7}$ of a foot per degree, a reduction in the rapidity of sound of not less than 70 feet in a second, or 1-16th of its whole velocity; and as its intensity is increased in an indeterminate but probably greater proportion, the facility of hearing at this great altitude is accounted for. The following instance by Mr. Bakewell exhibits the effect produced in the condensation of air by cold:—"In the road between Savoy and France, cut by Napoleon, there is, about two miles from Les Echelles, a gallery 27 feet high and broad, and 960 feet in length, cut through the solid rock. Mr. Bakewell states, that when this road was nearly complete, and the excavations commenced at each end almost met, the partition was broken through by a pickaxe, and a loud and deep sound was heard. Mr. Bakewell accounts for this in the following manner: 'The mountain,' he says, 'rises full 1,000 feet above the passage, and 1,500 feet above the valley. The air on the eastern side of the mountain is sheltered both on the south and west from the sun's rays, and consequently must be much colder than on the western side. The mountain, therefore, formed a partition between the hot air of the valley and the cold air on the eastern side. When the opening was made, the cold, and therefore denser air, rushed into that rarefied by heat, and a loud report was produced.'"—*Higgins on Sound*, p. 146.

Sir John Ross experienced no difficulty in conversing at the distance of a mile, in the still and silent atmosphere which occurs in the polar regions. Lieutenant Foster conversed at the distance of a mile and a quarter across a frozen lake at Fort Bowen; and in both these instances the distance of the perception was attributed to stillness, which doubtless contributed to it, but which was equally owing to the density of the atmosphere, and the smoothness of the surface over which the sound passed.

II. *On Smoothness.*

The facility which has always been observed in the conveyance of sound over water was exemplified in some experiments made upon the Thames at Chelsea, by Dr. Hutton, who found that he was enabled to hear the reading of a book at the distance of 140 feet upon the river, although the sound was interrupted by the splashing of the water against the boat, while, on land, he was only enabled to hear the reading of the same person at 76 feet. There is a ferry across the Wye, at a place where the river is too wide for the voice to be heard on the opposite side through the open air, but, by placing the lips on the surface of the stream, the boatman is enabled to convey information across, and receive replies, with greatest facility.

III. *On Quietude.*

Stillness of air can scarcely be called a property of sound; but its interruption by noises, or variableness of temperature, disturbing its homogeneity, is prejudicial to its diffusion. Perfect silence probably never exists, but it increases as we proceed from the equator to the poles. The greater rapidity of the earth's motion within the tropics, though it may carry the atmosphere along with it, must tend to create a greater attrition of the atmospheric particles, increased by the constant dashing of the waves on every shore which they approach, with the action of the wind upon each wood and forest; to which must be added, the perpetual sound resulting from animal life, so thickly distributed along these regions, and which, in many parts, is increased by the hum of cities and the mechanic arts of life: all these causes diminish in the frozen regions, where the water is rendered immovable by the ice, lofty vegetation scarcely exists, and the human race no longer congregates in sufficient numbers to disturb the tranquillity of the air. A degree of sound, however, is always distinguishable, and will exist in every region suitable to the support of life; which may be demonstrated by applying a shell to the ear, either by day or night, in the most tranquil spot that can be selected. Sound, from such cause, will always be distinguished, and this sound must be produced by the motion of atoms, to which the internal configuration of the shell gives an audible perception.

A degree of tranquillity, however, is to be obtained in the more noisy latitudes, by an elevation of about a mile in the air, above the places where this confluence and intermingling of sound exist; and Mr. Green remarks, that " the agreeable stillness in the atmosphere causes delight and astonishment in all who ascend; in fact, it far exceeds the silence of night, though enjoyed with the sunshine of day."

I shall conclude these remarks with a selection from the works of approved authors, of a few instances in which the perception of sound has appeared most remarkable; and it will be observed in every instance, that two, and sometimes the whole, of the concomitant circumstances here detailed, have united in producing them.

"At a particular place near the top of the hill at Cawsand Bay, the laugh and conversation of the sailors on board the frigates, and other vessels there, is frequently heard; the distance being two miles."—*Dr. Reid's Evidence.*

"Sounds seem more intense, and are heard to a greater distance by night than by day. In a still night, the voices of the workmen at the distillery at Battersea may be heard at Westminster Bridge, over an interval of about three miles."—*Notes to Perrole.*

"The watchword at Portsmouth may be heard at Ryde, in the Isle of Wight, the distance of which is between four and five miles."—*Ibid.*

"The clear voice of a street-crier, in a town situated on the borders of a lake, may be heard across the water, in a calm evening, at a distance of more than five miles." —*Arnott.*

"In the stillness of night, a steam-boat, by the splashing of its wheels, will announce its approach to persons waiting at a distance of fifteen miles."—*Ibid.*

Two of these causes, viz., density and stillness, likewise combine to account for the phenomena produced by echos, which repeat oftener by night than by day.

In these instances the sound is not reverberated differently at one time than at another; but the density of the air, and the absence of disturbing noises, cause it to be extended further, and thus add to the number of previous reverberations.

Dr. Plot, in his *History of Oxfordshire*, states that in his time there existed an echo in Woodstock Park, which repeated seventeen times by day and twenty by night; and the report of a small cannon fired from a particular spot on the shore of the lake of Killarney is reverberated oftener by night than by day.

Two different properties connected with sound are frequently assimilated, or taken for each other, viz., its Intensity and its Velocity. The former can generally be appreciated by the ear, and may not only be distinguished by its loudness, but by the extent of its diffusion. The late Mr. Saunders made some interesting experiments on this subject, and found that the extreme distance, every way, on a plane at which the voice could be heard with distinctness, was 92 feet in front, 75 feet on each side, and only 31 feet behind the speaker. The general position of pulpits, which has been regulated rather by experience than calculation, has placed them at a distance of about one-quarter, or at most one-third, of the extent of the church from the wall at the back of the preacher; an arrangement by which he has two thirds or three-quarters of its length in front: its diffusion, therefore, in the direction of its propulsion, will be greater than in any other.

It is generally asserted that the velocity of sound in all directions is the same, which however can scarcely be the case, if the instances previously recorded be correct. If the blow of a hammer, which creates only a single sound, be heard twice, it is clear that it must travel with different degrees of rapidity; and the cause I have assumed for this effect appears to arise not only from the equable and rectilinear manner in which sound, unless interrupted, is admitted to take, but also from the supposition that the attraction of solid bodies gives to the sonorous particles a degree of fixation which facilitates this rapidity of transmission. It is difficult, perhaps, in a mass of atoms, to determine which receives direct or only lateral pressure; but where the former is obtained, we have observed, as in the case of billiard balls, that the whole force is communicated to another while the motion of the propelling one is instantly arrested. The voice in the gallery of St. Paul's is generally heard on the same level with the lips of the speaker, while it is far less easily perceived if the ear be raised above or placed below it. It is, therefore, extremely probable that the report of a cannon might be heard not only twice, but thrice, by different persons, if the experiment were made where a rock rises perpendicularly from the ocean;—in which case it would probably be heard, first, at the base of the rock, proceeding along the water; secondly, at its summit, conveyed by superficial attraction; and, thirdly, at the same place, proceeding from its lateral diffusion and want of superficial assistance.

CHAPTER VII.

On the General Principles of Sound and Recapitulatory Remarks.

The principles we have endeavoured to establish respecting the origin and propagation of sound are few and simple, and may be briefly enumerated; viz.,

That every variety of sound is created by the constriction and expansion of the particles of air, and that this expansion conduces to two effects:

I. Pressure, by which sound is diffused and made sensible to the most numerous class of animals by the sense of touch; and

II. Lightness of the sonorous atoms, by which they become attracted to solid bodies, and thus propagate sound with greater rapidity superficially.

The intensity of Sound is increased by density of the air; its transmission is promoted by the quietude of the region in which it is expanded, and the equality of its temperature; and its velocity is augmented by the accession of heat and the smoothness of the surface over which it is propelled. There are different degrees of motion accessory to sound. First, the tremulous, arising from the contraction and expansion each atom undergoes without change of position. Secondly, the vibratory, produced by the action of adjoining sonorous particles, causing temporary displacement; and, thirdly, the rotary, an assumed degree of motion apparently rendered necessary for the propulsion of sound outwards, and the counteraction of the impulse by which it is produced. Undulatory motion does not appear to be associated with sound.

Before closing this division of the work, it will be requisite to consider what are the prevalent opinions of the most eminent modern authorities respecting the propagation of sound.

Dr. Prout, in that portion of his Bridgewater Treatise devoted to *Meteorology*, observes, "When a bell is struck, philosophers have satisfactorily demonstrated that a vibratory motion, excited in the bell, and depending upon its elasticity, is communicated to the air in contact with it, and through this medium is propagated to the ear, in which organ, we know not why, the sensation of sound is excited." These vibrations have been made the subject of calculation, Dr. Arnott having stated that "the lowest note which is perceptible to the human ear has about thirty *beats* in a second; and the highest, about thirty thousand; and there is included between these two, a range of nearly ten octaves." Dr. Thomas Young nearly coincides with this statement, by fixing the limits at from sixteen to thirty thousand. Professor Wheatstone has estimated that the vibrations produced from musical instruments extend from ten to fourteen thousand in a second. The Rev. S. Barrow, in his *Dictionary of Facts and Knowledge*, states, that "If a string perform one hundred vibrations in a second, the ear receives one hundred strokes, which we call sound; and if another make two hundred vibrations, the first is lower or flatter, and the latter higher and sharper. Every key of the pianoforte contains a determinate number of vibrations, which accord at regular intervals and are completed in a second. The note marked C makes one hundred vibrations in a second; but the note C, three octaves higher, makes one thousand six hundred vibrations in the same time. It appears by experiment, that we cannot determine the sound of a string which makes less than thirty vibrations in a second, because it is too low; nor of one which makes more than seven thousand five hundred and fifty-two vibrations in a second, because it is too high. These limits determine the power of the human ear." The Rev. W. Whewell, in his *Bridgewater Treatise*, observes, "Differences are produced by the different rapidity of vibrations of the particles of air. The gravest sound has about thirty vibrations in a second; the most acute, about one thousand." Whatever discrepancy may exist in these estimates, all are founded upon the same hypothesis, viz., that certain quick motions made upon the air are necessary to sound.

In the seven instances adduced, at the commencement of this work, as the most common modes for the propagation of sound, three depend entirely upon the action of the air upon itself; as in thunder, the report of a cannon, and in echo. The first is occasioned by the compression those portions of the air undergo which lightning has separated; the second, by the propulsion of rarefied and highly-condensed air upon the common atmosphere; and in echo, by the collection of the dispersed sonorous particles, which, being conducted towards each other from opposite directions with equal preponderance, constrict each other, and reproduce sound on the principle already described as occasioning thunder. In these examples no secondary cause is admitted; the sonorous body, the air, being the sole agent.

In the sound produced by a vibrating harp-string, a great degree of motion is observable. The string, being pressed upon one side, becomes elongated, and, by laws appertaining to motion alone, forms an arc of nearly equal extent in the opposite direction: the elastic nature of the string counteracts this tendency, and after successive vibrations it recovers its pristine tension and repose. In this example, motion is incidental to sound, but not its cause; which arises from the perpetual friction of the filaments of the string upon the minute portions of air interspersed throughout it, and which cease to be sonorous when this constriction terminates.

In the louder sound of a bell, this vibratory motion is less distinguishable; a slight tremour is perceived, and the air around its edge and sides presents that glazy appearance which is observable on the surface of a heated German stove, proving that, in both instances, rarefaction of the air is produced; in the one creating sound, in the other not. The vibratory motion, however, is so slight as to render its action on the external air quite insufficient for the production of sound, which being nevertheless elicited, the question necessarily occurs,—from what cause does it arise? To this no satisfactory answer can apparently be made but the following:—Not by the action of the bell upon the external air, but by the constriction of the particles of air within the metal.

It has been remarked by several writers, that the scratch of a pin upon a log of wood will be heard distinctly at the other end, though the same sound would not be conveyed half that distance through the open air; an effect produced on the same principle as in the preceding examples. The compression made by the pin affects the particles of air within the wood and creates alternate constriction and expansion; and by this process the sound becomes stronger at its termination than at its commencement. In this instance, however, it will not be contended that any vibration is created by the log of wood upon the outward air.

The celebrated experiments of Chladni present the same integral principles of sound, but exhibit a great difference with respect to motion. By strewing sand over a plate of glass, if perfectly homogeneous and of even thickness, on drawing the bow of a violin against its edge, the sand assumes definite, and, in some instances, corresponding shapes; and this may be produced, to a limited extent, by the proximity of a musical box, without absolute contact. The particles of air thus rendered sonorous by enlargement act upon those within the glass, and, from their equal diffusion, create those alternations in its surface which the position of the sand on the subsidence of the sound demonstrates. In this instance, therefore, motion is the result of sound, and not sound of motion; and the difference which we have endeavoured to distinguish appears to arise from a misapprehension of the nature of those two elementary properties.

Sound is always accompanied by motion, but Motion is independent of sound; and the difficulty therefore arises in determining what are those cases in which motion conduces to sound, and those in which it bears no relation to it. In all the instances adduced, sound appears to arise from one invariable cause, while motion, on the contrary, assumes a diversity of character, and is sometimes the effect, and at others the cause, of sound; on some occasions being actuated by quick returns, as in the vibration of a harp-string; feeble, or scarcely demonstrable, in the creation of sound by metal or timber, and variable in the greatest degree in the production of sound by glass, of which a strong instance is furnished by Sir J. F. W. Herschel, who relates, "It is a pretty well authenticated feat, performed by persons of clear and powerful voice, to break a drinking glass by singing its proper fundamental note close to it. Looking glasses are said to be occasionally broken by music, the excursions of their molecules, in the vibrations into which they are thrown, being so great as to strain them beyond the limits of their cohesion."

To render my own views still more explicit, I have selected the following description of the mode by which sound is created, from one of the most eminent of the authorities previously quoted, who states that "the slow waving of the hand through the air is noiseless, but the sudden displacement and collapse of a portion of that medium by the lash of a whip produces the effect of an explosion." From the method thus described I totally dissent, conceiving that the noise created by the smack of the whip arises from the compression of the particles of air intermixed within the thong and lash, which being suddenly elongated, create a crack or noise, but that, being attached at one end only, each smack creates only a single sound; whereas, in vibrating strings, each end being fixed, the elongation is continued, and sound is produced till the motion ceases. It may also be remarked (what every boy's experience will confirm) that a whip, after being frequently smacked, produces a fainter sound; and if long continued, the noise will become dull, which arises from the stretching of its fibres destroying their contractile property; whereas, if the sound depended upon the displacement of the air, it would, with the same degree of force, be always alike; and from the same want of elasticity, a thrashing-flail makes less noise than a whip, though it displaces more air.

It may further be remarked, that the sails of a wind-mill, which move with great rapidity and displace much air, create only a rustling sound.

The lightness occasioned by the expansion of the sonorous particle, and its consequent attraction by solid bodies, is an assumed and novel principle. The tread of a footstep upon the earth, of a blow on a wall, or the wheels of a steam-boat upon the water, have long been noticed as conveying sound further and with greater rapidity than through the air; so that within the range of both modes of transmission a double sound is produced. The cause of this difference has not been accounted for; but the theory that the sonorous particle gives off but half its propulsive power to the air when placed on the surface of a solid body, accounts at once for its extended conveyance, while the more direct percussion thus obtained will account for its increased velocity.

We have purposely avoided all allusion to the method by which Sound is associated with Hearing, as it will be better understood after the different parts of the ear and the functions they perform have been explained, when it is hoped that the principles of sound and the formation of the ear will mutually exemplify each other.

PART II.

ON THE

APPLICATION

OF THE

PRINCIPLES OF SOUND

TO THE

CONSTRUCTION OF PUBLIC BUILDINGS.

ON THE

APPLICATION

OF THE

PRINCIPLES OF SOUND

TO THE

CONSTRUCTION OF PUBLIC BUILDINGS.

On the Construction of Buildings for the facility of Hearing.

The theory attempted to be established in the preceding pages, relative to the cause and propagation of sound, would be mere useless disquisition were we unable to render it available to purposes of practical utility; the most prominent of which are the construction of buildings for the facility of hearing, and an illustration of the mechanism of the ear in conformity with these principles. The first of these, however, will form the sole subject of the present division of this treatise, and will embrace,

First, the construction of those buildings in which the position of the speaker is fixed, as in churches, lecture-rooms, &c., and

Secondly, a consideration of those intended for debate, in which the speakers are placed on opposite sides, and their position is undetermined, as in the British Houses of Parliament.

It has been assumed by Palladio, and is generally admitted, that a chamber best adapted for the purposes of hearing, seeing, sufficient ventilation, and elegance of appearance, should be of the following proportions, viz., the breadth two-thirds of the length, and the height four-fifths of the breadth ; thus a room 60 feet long should be 40 feet wide and 32 feet high.

The church of St. Mark, at Kennington, is constructed on nearly these proportions, in respect to length and breadth. When first erected, the reading-desk and pulpit were separated, one being placed on each side of the middle aisle; but it was found that, when either was used, the sound was distributed unequally, and heard imperfectly, but on uniting them in the centre the reflection from the walls on either side was rendered proportionate, and the hearing is now considered very good. This church is 101 feet long, 65 feet 6 inches wide, and 34 feet high, with an end and side galleries, under which the voice is not quite so well heard; the walls are of stucco, painted, and the ceiling, which is slightly concave, is of plaster: the disproportion of the height renders this church unpleasantly hot.

The rotunda at the Bank of England is a circular chamber, 57 feet in diameter, with a lofty dome crowned by a lanthorn; it has several recesses, beside two doors of communication with different offices, and two avenues communicating with the open air. From this irregularity of surface, and the difference of temperature thus produced, as well as from partial echoes from its walls and roof, hearing within it is extremely difficult, and it may be considered as the worst hearing apartment in London.

The hall of Christ's Hospital, Newgate-street, is 157 feet long, 52 feet wide, and 47 feet high. A pulpit is erected against one of the side walls, at an equal distance from each end; and though the orators are generally youths, whose ages range from sixteen to nineteen years, hearing throughout is perfectly good.

The theatre of the Royal Institution, Albemarle-street, is stated by Dr. Faraday, in his examination before the House of Commons, to be "almost perfect for a single speaker; and though often referred to, preparatory to the construction of other theatres in London and elsewhere, none equal it in the facility with which the speaker is heard." It is a building the plan of which is rather more than a semicircle, and is 60 feet from side to side, and 44 feet from back to front. It has a large gallery. The walls are ordinary walls, and the theatre is constructed within them; in many places we pass between the theatre and the walls. The former is wood (fir) all round. It will hold about eight hundred persons.

Many other rooms have been erected upon the model of this, in respect to size; but such a deviation has been permitted in the materials as totally to destroy the effect, particularly by the substitution of stucco or plaster for wood, and the introduction of glass behind the speaker.

In the theatre of King's College, London, I witnessed the effect thus produced by a slight shower of rain falling on the windows at the back of the lecturer. From the resonance of the glass, the rain resembled the "pelting of the pitiless storm;" and the voice of the speaker was completely overpowered by the dissonance of this incongruous accompaniment. These five instances are selected as exhibiting a dissimilarity of effect produced by different causes.

The French Chamber of Deputies was erected on the design of a committee of the most eminent architects of France, who had previously examined the most celebrated ancient and modern buildings to guide them in the plan of its construction. It is of a semicircular form, surmounted by a flat dome, and the chord line is about 96 feet. The chamber is addressed from a rostrum a little in advance of the straight side, and is admitted to be admirably adapted to its purpose; but the principles of its construction are inapplicable in a great degree to the Houses of Parliament, where the speeches are delivered from opposite sides and from no particular position. Under such circumstances, probably the square form is the best; and I have found on inquiry that the late House of Commons, or St. Stephen's Chapel, was of the proportions before detailed, in respect to length and breadth, being 60 feet by 40; but its height was only 26 feet: and every person entering that house must have been struck with the lowness of the ceiling, which resembled rather the proportions of a rabbit-hutch than those of a dignified house of assembly.

The opinion, however, of those persons who have written on the subject, almost uniformly inclines to the recommendation of as low a ceiling as possible; Mr. Alexander, of York, having stated that no room for debate should be higher than 26 or 27 feet; and Dr. Reid, who appears to have considered the subject with great attention, prefers (answer 453) "as low a roof as may be consistent with the size of the building, so that the direct voice of the speaker may be strengthened by the reflection from it." In maintaining, therefore, the opinion that a room of such dimensions should be 32 feet high, I feel it necessary to advert to the dimensions of the American Senate Chamber, which is 75 feet long, 45 feet broad, and 45 high, and is both a good hearing and speaking room; but which, in proportion to its width of 45 feet, should have been only 36 feet in height. In the former House of Lords, which is now used as a temporary House of Commons, the breadth is 36 feet, and the corresponding height should be 28 feet, 9 inches, or 29 feet, which it really is. Its length is greatly disproportionate, as it ought not, on the same scale, to exceed 54 feet, whereas it is 96, or 42 feet too long: but, notwithstanding this disadvantage, the part appropriated to the peers was favourable to hearing, though the walls were covered with tapestry, which is a most non-reverberating material.

Before I venture to express an opinion of the suitable construction of the future Houses, I must be permitted to remark that glass, as far as possible, should be excluded. This substance is more sonorous than any other, and when formed into the shape of a vase or a bell, in which its edges are permitted to vibrate, it prolongs sound for a considerable time, and thus will throw a monotonous character over language which is meant to be varied; and where in other places it is fixed, as in window frames, its vibration being immediately checked by the setting, it produces a dissonant jerking sound, which will be readily perceived on entering a conservatory, where some of the syllables of a sentence will be greatly increased in power, and others much diminished, so that the modulation of language is destroyed.

As glass, however, cannot be excluded, from the necessity of admitting light, I venture to suggest that all its benefits may be secured, without entailing any of its disadvantages.

Presuming that the area of St. Stephen's chapel was sufficient for the members of the House of Commons, the number of which remains the same, I would recommend that its old proportions of length and breadth be preserved, but that the ceiling be elevated 6 feet, thus making it 32 feet; and that the house, to at least the height of 20 feet, should be lined with wood of a durable kind, as its reverberating quality is improved by age and dryness. This lining should not touch the floor, but be separated from it by a marble skirting, to cut off all sonorous communication. Galleries should be erected at each end; that in front of the Speaker, for strangers, should extend from side to side, and might be made 12½ feet deep; while that at the opposite end, behind the Speaker, might be 7½ feet deep, and devoted to the use of members, or select visitors. There would thus remain an arena of 40 feet square, in which no galleries, projecting or retiring, should be permitted. The sides might be decorated with pilasters, panelling, or any ornamental carved work; but in any case, it should be surmounted with a broad cornice, the lower side of which should form such an angle, that if the line were continued it would reach to about 8 feet above the floor on the opposite side. All above this wainscoting or screen, including the ceiling, might be marble, stucco, plaster, or any other substance, at the pleasure of the architect, without having any reference to sound. Twelve feet would then remain for the construction of windows, which should be splayed on both their sides and at the base, to admit the greatest quantity of light (which should not be scanty) through the smallest external opening. Should the space here assigned be larger than is required for the thorough lighting of the House, it might be contracted by extending the wooden lining 2 or 3 feet higher. The lower part of the window aperture should very nearly approach the upper side of the wooden cornice above described, which should be so formed as to admit of cushions of cotton, wool, earth, or other absorbing substances to be placed within it. By this means the noise of wind and rain, proceeding from the lower part of the windows, would be prevented passing into the house, while that which was radiated from the sides would be dispersed among non-reverberating surfaces.

The evils which this arrangement is intended to avoid are the interruption which a double tone would create, and which a second reflecting body, such as a wooden ceiling, would probably occasion. Though reverberation is intended to be produced by the screen I have described, it will be found, by a simple calculation, that it would tend to strengthen but not impede the voice. Sound, according to the admeasurement of Halley and others, passes at the rate of about 1,142 feet in a second; and if we imagine a speaker addressing the House, at the distance of a yard and a half from either side, his voice would have to pass 35½ feet to the wall, and on its return would have extended 71 feet. It will be observed that this distance would be traversed rather above 16 times in a second; $71 \times 16 = 1136$. As the most rapid speaker does not utter above four syllables in a second, the return of each would intervene in one quarter of the time that it requires for distinct delivery and emphasis. Or, to place the calculation in another point of view, let us imagine a second divided into 60 parts, each syllable would then require 15 of these portions of a second, while the reverberation would take place in rather less than four.

This reverberation of sound, though mathematically demonstrable, is quite imperceptible by the ear; while it is as requisite for the support of the speaker's voice, as instrumental music to a singer on the stage.

In the materials which have been suggested for the composition of the ceiling no reverberation would take place; but if it were formed of wood, and the former elevation of 26 feet were adopted, after making allowance of 6 feet for the height of the speaker, the ceiling would reflect sound from the distance of 20 feet only; and thus different degrees of resonance would be produced. The single reverberation from either would be unobjectionable, but the close approximation of the two would render both indistinct.

Should either the walls or the ceiling fail to produce the resonance required, it may be obtained by the introduction of a sheet of water under the floor. Every person must have remarked, on entering a bath-room, in which the water occupied the largest portion of the floor, that the voice appears greatly augmented in loudness; and Dr. Hutton relates that when a canal of water was laid under the pit-floor of the theatre Del Argentino at Rome, a surprising difference was observed: the voice has since been heard very distinctly, when it was before scarcely distinguishable. In the introduction of so powerful a reflecting body no necessity exists for the water being deep; a leaden cistern two or three inches in depth, but as wide as the area of that part of the House occupied for the purpose of debate, would be sufficient; and this could be easily regulated, so as to prevent congelation or great evaporation. Nor need this arrangement interfere with warmth or ventilation, as a space may be permitted between the surface of the water and the under-side of the floor. The preceding part of this work will have explained, that sound causes no permanent displacement of the air, but is diffused by the alternate contraction and expansion of its particles; and as these pervade the wood of the floor, if a non-absorbing surface were placed below it, reverberation would be increased by this mode of reflection.

Such appears a general result from the consideration of this theory; but the most skilful plan is liable to derangement from numerous and apparently trivial causes, and it will be impossible in any experimental building to determine what may answer in another; for, although it is easy to construct the model of a chamber, the properties of sound will not admit of reduction or imitation.

Fig: 1.

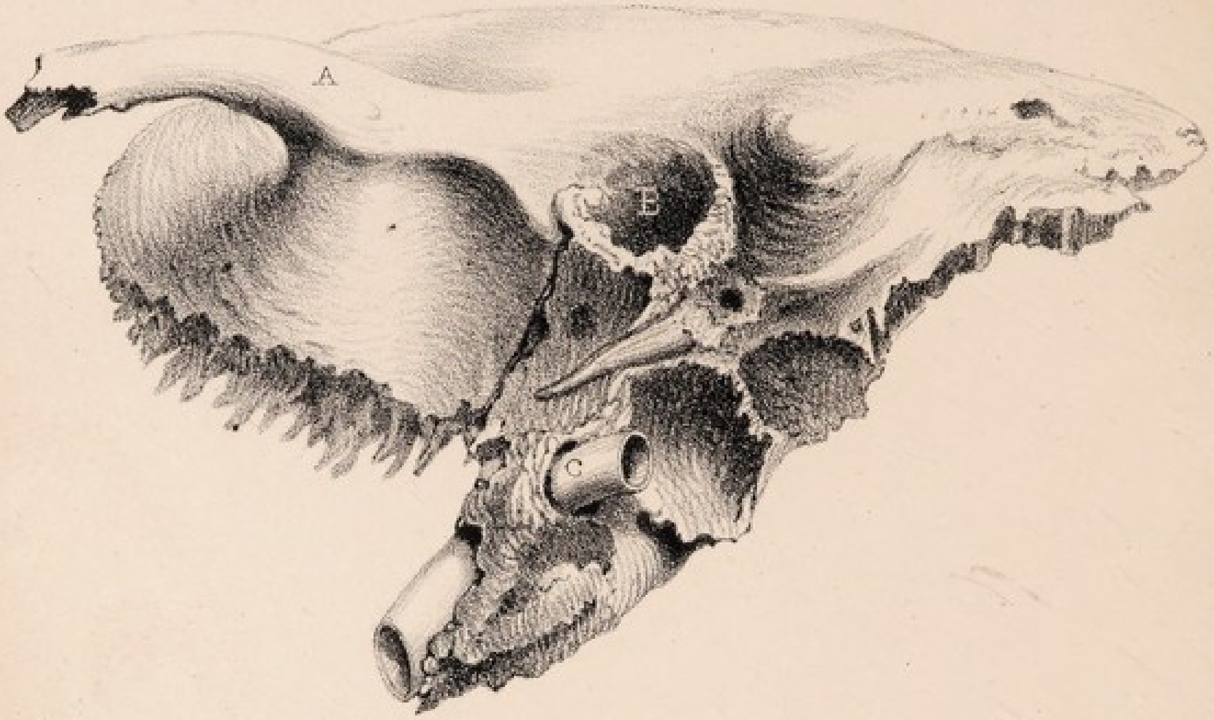

Fig: 2.

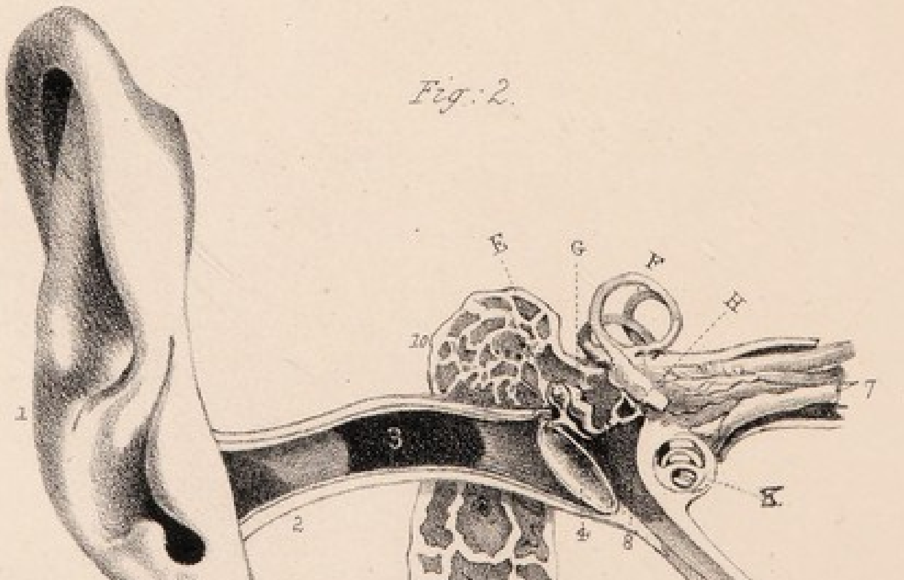

Fig: 3.

Fig: 4.

Fig: 5.

Fig: 6.

Fig: 7.

PART III.

CONSISTING OF TWO CHAPTERS.

CHAPTER I.—Containing an Enumeration of the Parts of the Ear, a Description of their Structure, and Notices of the Period and the Persons at and by whom they were discovered.

CHAPTER II.—The Adaptation of the different Parts for the Facility of Hearing, or the Physiology of the Ear.

CHAPTER I.

The Anatomy of the Human Ear.

Few persons, except those whose attention has been directed to the structure of the ear, can form from general observation any adequate idea of its extensive ramifications. The outward appendage to which the general name has been assigned forms perhaps its least important portion; for, in numerous instances, this part has been destroyed, by accident, disease, or design; but where the internal organs have been uninjured, the hearing, after a few days, has been found to be nearly as perfect as before. Besides the passage into the head, to which the visible part of the ear may be considered the vestibule or entrance, there is another passage of equal importance, the Eustachian tube, proceeding from the back of the nose, and leading to the central cavity of the ear, called the tympanum, into which the skull is perpetually conducting sound from an opposite quarter; and it is only by such a happy adaptation of mechanical contrivances as the Almighty alone could design, that sound proceeding in such different directions could harmonize, and work together for good.

Before we proceed to enter into a minute detail of the separate parts of which this organ is constructed, it will be necessary to premise that its most delicate and important machinery, is included in the temporal bone, of which a representation, of the natural size, is given. Fig. 1.

It will be seen that this bone is formed of two very dissimilar portions, and resembles, in its entire state, an ill made nail, with a broad head and crooked prong. The flat part forms a portion of the external skull, and is denominated the squamous portion of the temporal bone, from its overlapping the surrounding parts, like the scales of a fish; while that part which may be said to resemble the prong of the nail, is called the petrous portion, from its stony hardness, in which quality it exceeds that of any other bone of the body. A considerable part of it is not required for the necessities of the ear, but for other purposes in the animal economy. The temporal bones of each side proceed directly inward, and their extremities approach each other within the distance of an inch and a quarter. This interval is occupied by the sphenoid bone, which approaches each termination of the temporal bone within the sixteenth of an inch, thus avoiding positive contact. The auditory nerve enters the petrous portion about the middle of its length, but the aperture cannot be seen in this position of the bone. The posterior part appears to be required for the formation of the base of the skull; while the aperture at its farther extremity, C, is adapted to one of the most singular and important purposes of life. Through this bony ring the carotid artery on each side of the head passes. Its lower diameter is larger than its superior one, by which means the quantity of blood admitted into the head is regulated; and this canal during its very short continuance takes an angular direction, by which the arterial pressure is still further restrained. In consequence of this arrangement, noises in the head, according with the beating of the pulse, become sensible to the ear, and are often attributed to a derangement of its functions; whereas this perception solely arises from the excited action of the heart, which the peculiar facility of bone for the conveyance of sound transmits, and thus occasions a throbbing sensation in the ear. B represents the commencement of the bony meatus, A the broken portion of the zygomatic process or yoke, which unites the temporal with the superior maxillary bone constituting the cheek bone.

We now proceed to a description of the different parts of the Ear, which are as follow :—

Name.	Purpose.
1. The Auricle or Visible Ear. (*Auricula*)	To collect sound.
2. The Auditory Passage. (*Meatus auditorius externus*)	To convey sound inward.
3. The Ear-wax. (*Cerumen*)	To press the sonorous particles against the sides of the auditory passage, and restore their strength.
4. The Membrane of the Tympanum. (*Membrana Tympani*)	To intercept sound and transmit it on a different principle.
5. The small bones of the Tympanum, four in number. (*Ossicula Auditûs*)	To connect the external with the inner ear: and concentrate sound upon a single point.
6. The Inner Ear. (*Labyrinth*)	To affect the acoustic nerve by hydrostatic pressure.
7. The Auditory Nerve. (*Portio Mollis* of the seventh pair of nerves)	To communicate the sonorous impression to the mind.

These parts are all employed in the direct transmission of sound; but there are three others, without which the functions of the preceding could not be performed: these are—

8. The Ear-drum, or Cavity of the Tympanum. (*Cavitas Tympani*)	To receive external air, and neutralize opposing sounds.
9. The Eustachian Tube. (*Canalis Eustachianus*)	To convey air and sound into the tympanum.
10. The Mastoid Cells. (*Cellulæ Mastoideæ*)	To disperse within the tympanum, the sound collected by the scull.

Some of these parts admit of minute subdivision, as the auricle, which will be hereafter specified. The small bones of the ear consist of four, viz., the *malleus* or hammer (E), the *incus* or anvil (G), the *os orbiculare* or

F 2

round bone (shown at the bottom of figure 4), and the *stapes* or stirrup-bone (H).

The inner ear also consists of three important divisions, viz., the *vestibulum* or central cavity; the three semicircular canals (F), and the *cochlea* or shell (K). The ear is likewise furnished with the ordinary constituents of animal life, as blood vessels, nerves, muscles, &c.

To render these parts and their relative position more easily understood, a diagram is given (Fig. 2), in which they are defined by the numbers and letters under which they have already been described.

Although this enumeration may at first appear formidable, it is rendered as simple as the nature of the subject will admit: the classification is new; and the purposes of some of the parts have never before been attributed to them.

To render the names of the different parts of the Ear still more familiar, the following attempt is made, as far as typography will admit, to represent them in the relative position they bear to each other:—

EXTERNAL EAR. MIDDLE EAR. INNER EAR.

Eustachian Tube.

Auricle. Auditory Passage. Cerumen. Membrane of the Tympanum. Malleus. Incus CAVITY OF THE Os orbiculare Stapes. TYMPANUM. Semi-circular Canals. Vestibule. Auditory Nerve. Cochlea. The Brain.

Mastoid Cells.

PNEUMATIC APPARATUS. HYDROSTATIC APPARATUS.

1. The Auricle or Visible Ear. (*Auricula.*)

The auricle or visible ear (*fig.* 2, 1), is composed, with the exception of the lobe, of cartilage, a gristly substance harder than flesh, by which sonorous vibrations would be absorbed; and softer than bone, from which they would reverberate. It is covered with a very thin skin, which is lubricated by small glands placed beneath it; and in health has all the smoothness of polished ivory. It is attached to the temporal bone by three ligaments, and has on its surface several muscles, seven of which have received names, but which the design of this work renders it unnecessary to enumerate; it is also plentifully supplied with nerves, blood-vessels, and lymphatics.

The outer rim takes the name of the *helix,* as far as its curved margin extends, the remaining outer portion being the *lobe.* The small cavity caused by the turning over of the helix, is called the *cavitas innominata,* and separates the helix from the *anti-helix.* A small depression next adjoining towards the top of the ear, is called the *scapha.* These parts surround the upper part of the *concha,* in which all the other channels for collecting sound terminate. About the middle of the concha, on the facial side, is the entrance to the head, called the *meatus auditorius externus,* or external auditory passage, which is nearly imperceptible on looking direct at the ear. The part which obscures it from view is the *tragus,* opposite to which is the *anti-tragus.* The concha is unequally divided into an upper and lower part by a strong ligament, which may be called the root or origin of the helix.

2. The external Auditory Passage. (*Meatus auditorius externus.*)

This passage (*fig.* 2, 2) commences at the deepest depression of the auricle, called the *concha,* and is about one inch and a quarter to an inch and a half in length; the external part being formed of cartilage, and the internal part in the thickened projection of the temporal bone. Its extent is an eighth of an inch greater at the floor of the passage, than at the upper part. In its ordinary state it is contracted at its commencement; but on the auricle being pulled upwards and backwards, and the *tragus* pressed towards the face, it exhibits considerable dimensions. Its position is rather inclined upwards till about the centre; on which account that part of the tube becomes rather diminished, but again declining, it widens till the junction of the cartilaginous with the bony part of the passage. As the aperture on which the membrane of the tympanum is fixed, is larger than the meatus at this contracted part, it follows that the diameter of the passage must in this very limited space again increase. A representation of the orifice at its narrowest part, and of the figure of the membrane taken from the same ear, are given in figures 6 and 7.

3. The Ear-Wax. (*Cerumen.*)

This secretion (*fig.* 2, 3) forms one of the most important mechanical offices of the ear; but it will be sufficient at present to state that it is of an acrid taste, and of a consistence to render it impervious to sound: at the same time it is possessed of such a degree of fluidity as to admit of its constant propulsion outwards, from the action of the cerumenous glands, by which it is secreted.

4. The Membrane of the Tympanum. (*Membrana Tympani.*)

The membrane of the tympanum (*fig.* 2, 4, also *fig.* 7) is situated at the farther end of the auditory passage behind the cerumen, between which, in a healthy condition of the ear, there is a small unoccupied space. It is placed in a groove of the bone entering into the tympanic cavity, to which, however, it does not adhere throughout, there being in numerous instances a small portion towards the top, amounting to about the twentieth part of the whole circumference, in which this groove is imperfect; and it is through the aperture thus formed that persons are enabled to pass smoke by the mouth, so that it shall escape by the external ear.

The shape of the membrane is most frequently oval, but it is sometimes nearly round, and in some instances it has been found to have its longest diameter horizontally. Its colour among northern nations is a deep blue; but in persons of the southern countries of Europe, it is of a deep olive brown. This colouring matter becomes absorbed when a deposit takes place within the tympanum, when the membrane partakes of the colour of such deposit, which is generally yellow; while at other times from the injection of stimulating fluids, its absorbent vessels become impaired, and it then assumes a chalky whiteness. The membrane is rather larger than the aperture in which it is placed, and is either projected inward or outward. The opinion that is almost generally entertained is, that such inclination is inward; but from my own observation in many hundred cases, it has always appeared to present a bead-like or convex appearance, when viewed through the meatus; from which I am led to conclude that its position, in a state of perfect repose, is outward. The reasons, of a physiological character, which strengthen this opinion will be found at a subsequent part of this treatise, page 86, where we proceed to a consideration of its purposes and action. It has three well-defined muscles in the inner side, by which it is attached to the first of the small bones; but some modern anatomists have described five, and even seven. Much controversy has arisen, whether the membrane itself is purely muscular, or merely of a fibrous construction; in which Sir Everard Home and Sir Charles Bell have advocated opposite opinions.

The membrane of the tympanum, and the three anterior parts of the ear, being open to ordinary observation, their discovery must have been coincident with the earliest examination of the organ; but the sloping direction or obliquity of the membrane was first made known by G. Fallopius, in the year 1558; and J. Mery first described the groove in which the membrane of the tympanum is affixed upon the *os annulare,* which at birth forms a detached ring, but afterwards becomes consolidated with the temporal bone.

5. The small bones of the Tympanum (*Ossicula Auditûs.*)

These consist of four, and extend across the cavity of the tympanum, connecting its large external membrane with the smaller one, communicating with the inner ear at the *fenestra ovalis.* The first or most external of these bones has been called the *malleus* (*fig.* 2 E and also *fig.* 3) from its resemblance to an ancient hammer or mallet. It consists of five parts; a head, neck, two processes or arms, and the *manubrium* or handle, which extends in an oblique direction rather beyond the centre of the membrane of the tympanum to which it is attached. It is supported on the outer rim of the aperture on which the membrane is placed, by its processes called *brevis* and *gracilis,* by which it acquires great freedom of action; while its head, which projects a little inward, is articulated into a dent or depression formed in the broadest part of the adjoining bone, called the *incus,* from its assumed resemblance to an anvil.

The *incus* (*fig.* 2 G, and also *fig.* 4) consists of two limbs, one short and thick, having no attachment; the other long and slender, called the *processus longus ;* but the space between them is occupied by a membrane which invests them both. The position of the longer limb of the incus and the manubrium of the malleus are nearly parallel, and a nerve, called the *chorda tympani,* passes between them. The discovery of the malleus and incus is hid in obscurity, but they are first alluded to by Berenger in 1521, and described by Vesalius in 1555, who gave them their present names.

Towards the extremity of the longer limb of the incus is placed the *os orbiculare,* or round bone, which is by far the smallest bone of the body, not exceeding in size a small pin's head; it is a little flattened, and forms the attachment between the incus and the stapes, and is represented in *fig.* 4 both as attached and separate.

The *stapes* (*fig.* 2 H, and also *fig.* 5) has been so called from its very correct resemblance to a stirrup-iron. It consists of a head, neck, two sides, or *cruræ,* a little disproportionate in length, and a basis, which latter is fitted into the small aperture called the *fenestra ovalis,* in which it acts like the piston of a pump; it is also, as well as the incus, covered with a membrane that unites and envelopes its sides, and attaches its base with the membrane of the inner ear on which it is fixed. It was accidentally discovered by Ingrassias at a public lecture about the year 1560. Its base is represented separately in *fig.* 5. The *malleus* is supplied with three muscles; a tensor, to draw the membrane inwards, and two laxator muscles, to extend its surface outwards; and the *stapes* is supplied with one muscle, called the *stapedius.*

6. The Inner Ear (*Labyrinth*)

Is composed of three very distinct parts.

1. The *vestibule,* which is a small semi-circular cavity formed immediately behind the *fenestra ovalis,* to which the stapes is attached. It has opening into it upon the

inner side, five small apertures, called *ampullæ*, and which form the termination of the three semi-circular canals; two of these in their progress unite, thus having but one common exit.

2. The semi-circular canals (*fig.* 2 F) are three in number, but are rather elliptical than circular, the largest being the horizontal one. There is a second lying nearly at right angles with it, and hence called the vertical; while the third, from its direction in relation to the others, has been termed the oblique; and these two latter uniting before the termination of their course have separate entrances, but one common terminus.

3. The third division of the inner ear is called the *cochlea* (*fig.* 2 K) from its resemblance to a shell. It consists of two separate passages winding round a central column or newel; the entrance to one of these passages being from the vestibule, and the termination of the other leading into a passage communicating with the tympanum, which aperture is called the *fenestra-rotunda*, or *foramen rotundum*. These passages take two turns and a half before they reach the apex of the cochlea, the external covering of which has been called the *cupola;* and the part beneath it, where these two passages unite, is termed the *infundibulum*, from its funnel-shaped appearance, which extends halfway down the central column, of which the lower half is called the *modiolus*.

The whole of the cavities in the inner ear are filled with a fluid possessed of a little gelatinous matter, and hence of a density rather greater than water, which in the semi-circular canals is contained in delicate membranous sacs fitted to the varying orifices of their different parts, and upon these membranes the acoustic nerve is divided and spread, having a small portion also of this fluid between these sacs and the sides of the canal.

To Duverney is due the merit of first delineating, in 1683, the structure of the inner ear. He discovered that the semi-circular canals were sometimes round and sometimes oval, widening at their mouths, and described with admirable exactness the structure of the cochlea.

The existence of the fluid pervading the inner ear was unknown till the year 1760, when Contugo, a Neapolitan, at the age of 25, commenced a new era in the knowledge of the structure of this organ, by the discovery that the parts lying beyond the fenestra ovalis were filled with fluid; adding the hydrostatic principle to the pneumatic mechanism of the ear. This discovery, which affected the opinions of all anatomists from Aristotle downwards, with the exception of Valsalva, naturally led to considerable scepticism on the part of his contemporaries. Chaldani, in 1773, supported these discoveries by new experiments, which were still more successfully prosecuted by Meckel in 1777. To elucidate this subject he made an opening into the cochlea, and on pressing the stapes in the same manner as is performed during life, the fluid flowed out with considerable force; and the same result occurred on leaving the cochlea uninjured, and making the opening in one of the semi-circular canals. The experiment was afterwards repeated on another subject, by leaving all the parts before mentioned entire, and removing the membrane of the fenestra rotunda. But to demonstrate still more clearly the existence of the fluid, which he compares to the aqueous humour of the eye, he caused a head to be frozen, which presented afterwards a structure of ice filling all these cavities; and he proved the non-existence of air between them by opening the largest cavity, the vestibule, under water, when no gaseous bubble was seen to arise, which, it is presumed, must have appeared had any air been contained within it.

7. The Acoustic Nerve.

The acoustic (*fig.* 2, 7), or sentient nerve of hearing, is the *portio mollis* of the seventh pair of nerves, according to the arrangement of Willis, and of many of the most celebrated modern anatomists, and its only function is to convey the perception of sound to the mind. The *portio dura,* or harder portion, possesses a different office, being a nerve of voluntary motion, contributing to the action of the lips, cheeks, nostrils, and eye-lids, and ramifying upon the external ear, as well as on the muscles within it. These two parts have recently been considered as separate nerves, the portio dura being termed the seventh pair, or facial nerve; and the portio mollis the eighth pair, or the acoustic. Both arise from the same portion of the brain, and for a short distance are enveloped in the same sheath; and this difference in their modern classification is noticed to avoid the misapprehension of the particular nerve alluded to in the perusal of these pages, as the succeeding observations will be confined to the acoustic portion, or portio mollis.

This nerve enters the petrous portion of the temporal bone, about the middle of its length, where it speedily divides, and supplies delicate filaments to each of the three grand divisions of the inner ear before enumerated. In the semi-circular canals it is spread upon the membranous sacs, and receives its constriction by the fluid which exists in the canal in which the sacs are placed. In the vestibule it expands upon its lining membrane, and in the cochlea it not only lines the spiral column before described but penetrates the bone, and appears to be spread in every direction in which it can obtain support. The nerve is supplied with blood-vessels, and hence its sensitiveness is frequently affected from constitutional causes.

Eustachius, about the year 1580, gave the first definite account of the acoustic nerve, which he divided into three branches. In 1591, Varolius assigned the position of the origin of the auditory nerve in the brain. Spigel subsequently added to the knowledge previously acquired, by defining the two portions of the seventh pair of nerves, which were then called the fifth; and in 1664, our countryman, Willis, described more clearly than had been done by Spigel the different functions of these nerves. Duverney, in 1683, demonstrated the division of the soft portion of the seventh pair into three branches; the subject also attracted the attention of several other able writers, and in 1806, Sœmmerring published his exquisite engravings, particularly exhibiting the expansion of the acoustic nerve within the labyrinth.

We have departed from the mode usually adopted, in uniting the external with the inner ear, leaving the intermediate tympanic cavity for subsequent consideration, the portions already described being those alone which are actively engaged in transmitting the external sonorous impression to its ultimate recipient, the mind.

8. The Tympanum, or Ear-drum. (*Cavitas Tympani.*)

This cavity in the temporal bone, represented in *fig.* 2, 8, when all the internal parts are removed, is found to be rather less than half an inch in depth, and nearly of the same width, but of irregular proportions. It has been called the tympanum, from its supposed resemblance to a drum; its largest external membrane being considered the drum-head; while it is supplied with external air through the medium of the Eustachian tube, which enters it upon the facial side.

The purpose of this cavity is twofold; first, to admit the common atmospheric air, by which the freedom of the action of its larger membrane is secured; and, secondly, to constitute a chamber in which the sound conveyed by the Eustachian tube, and that supplied by the skull, and projected into the tympanum through the mastoid cells, that bound it on the external side, may be antagonised and destroyed.

G. Fallopius, whose work was published in 1558, first gave the name of tympanum to the cavity in which the small bones are contained. He remarked on the singular phenomenon of their having attained their full size at the period of birth, but without assigning any reason for it.

9. The Eustachian Tube. (*Canalis Eustachianus.*)

The Eustachian tubes, one of which is attempted to be shown in *fig.* 2, 9, (though its real position is such as to prevent its being represented in this view,) are two passages which convey air, and some degree of sound, which is inseparable from it, into the cavity of the tympanum. One proceeds from the back of each nostril, in that part of the *fauces* called the *pharynx,* where these tubes have their largest diameter; being nearly oval, and having a small thickened extremity constituting a rim or lip. They are about an inch and a half long; the first inch being formed of cartilage covered with a smooth mucous membrane, and lessening in diameter till it unites with the farther extremity, which is constructed for the space of half an inch in a bony canal of the temporal bone. The passage in this part is not circular, but rather resembling the shape of the letter D, the round side being outwards. At its entrance into the tympanum the orifice becomes round and rather expands. Its general figure greatly resembles that of a post-boy's horn.

These guttural orifices derive their appellation from their discoverer Eustachius, the contemporary of Fallopius; but it is assumed by Fabricius that they were known, though not named, by Aristotle.

10. The Mastoid Cells. (*Cellulæ Mastoideæ.*)

These cells, which are but partially shown in *fig.* 2, 10, as the larger portion has been removed to expose the inner parts of the ear, form the external boundary of the tympanum, and appear to be an enlargement of the spongy bony substance which separates the internal from the external surface, or plates of the skull, which is called the *diploe* of the cranium. These cells are lined with a delicate membrane, and are generally supposed to have communication with each other.

Valsalva, whose elaborate researches and geometrical precision have acquired for him the reputation, during the last century, of being the best authority relative to the anatomy of the ear, was induced, by some isolated cases, to imagine that apertures existed between the brain and the mastoid process, by which the latter acted as a drain to the former organ. These holes he describes as consisting in number, sometimes of three and sometimes only one; their situation, form, and size no less varying. In the case of a person who died of apoplexy, the large flow of blood which proceeded through the Eustachian tube into the mouth he attributed to this source. The existence of these apertures is now wholly disbelieved.

The parts thus enumerated and simply described are those which possess a distinctive character in the machinery of the ear, the functions of which will be hereafter separately and conjointly explained. There are others of less importance of an auxiliary character, which have been purposely omitted in this brief sketch, as needlessly embarrassing a subject which cannot be rendered too plain.

CHAPTER II.

Of the adaptation of the Structure of the Ear to the principles of Sound, or the Physiology of the Ear.

THE principles which we have endeavoured to establish respecting the origin of Sound, the mode of its diffusion, and the causes of the different phenomena it exhibits, will be found to have parts applicable or corresponding to each in the structure of the human ear; and we shall proceed to enumerate their functions in the order in which they have been previously described.

Of the Auricle, Auditory Passage, and Cerumen.

The *Auricle,* or Visible Ear, is peculiarly adapted to a variety of these principles. I.—From its irregular surface, by which a larger proportion of sound is received than could be obtained by an even surface of the same extent. II.—This superficial enlargement is bounded by a narrow curve called the Helix, by which the sonorous particles are prevented from flying off, and are returned into the deepest depression of the ear, called the Concha, on the principle of Echo. As the helix becomes more perfect, the quantity of sound thus preserved is greater; and it was remarked in the ear of Mozart, that the helix extended all round; and this great peculiarity of structure was accompanied by as unusual a developement of the sense; it being recorded that " at the age of six years he could distinguish and point out the slightest differences of sound; and every false or rough note, not softened by some chord, was a torture to him. At ten years of age the most numerous orchestra did not prevent him from observing the slightest false note, and he immediately pointed out, with surprising precision, by what instrument the fault had been committed, and the note which should have been made." It is not contended that this extraordinary perception proceeded wholly from the shape of the auricle, but was the result of equal perfection in the construction of every other part.

In a well formed ordinary ear, the helix does not generally extend beyond five-eighths of its circumference, and therefore the sound impinging upon the lobe is wholly lost. When the auricle is fully developed, as in early life, all its various inequalities lead towards the auditory passage, the aperture of which is covered by the tragus, to prevent its escape. Many animals possess a facility of moving the auricle in the direction whence sound proceeds; and the hare and other timid animals possess this power in the greatest degree; while beasts of prey, as the lion, have theirs firmly fixed in a forward position, to collect the sound of the fugitive objects of their pursuit. A moveable power of the ear has in some few instances been possessed by man, but only in cases where some internal defect or unusual necessity for the most perfect hearing, has been the occasion: the only two instances brought within my own observation have been those of a newspaper reporter and of a judge. Some savage people have been said to possess this faculty; but the great facility of movement of the head in man appears to render it unnecessary.

The *Auditory Passage,* or Meatus Externus, is lined throughout with a continuation of the delicate epidermis which covers the auricle, and becomes thinner as it approaches the membrane at the end, over which it is spread. In the floor of this passage are longitudinal grooves, which further tend to conduct the sound inwards; and its concentration by this and the preceding part, may be partly illustrated by the wind-sail, an invention used on board ships to convey fresh air into the holds and cabins. It is a long tube, formed of three breadths of canvas, one of which is omitted at the upper end, to admit of its distention; and it is placed opposite the wind, by which its mouth becomes extended; and from this expanded surface the air is condensed and forced through the dependent tube.

The principal use of the *Cerumen*, or Ear-wax, appears hitherto to have been wholly misunderstood, as those assigned to it constitute the least important of its purposes. These have been supposed to consist in affording protection to the membrane from the variableness of the climate, and the barrier it presents against the inroad of insects; while its appellation in the French language (*ordure de l'oreille*) clearly denotes that it has been considered as merely excrementitious matter.

To render the use we are about to attribute to it the more apparent, it will be requisite to revert to the mode already described for the propagation of Sound. The first act in the formation of speech, is the compression of the air within the lungs, which after its modulation by the organs of voice is converted into language, when it is projected upon the atmosphere. Those particles of the air, however, which first receive the sonorous impression, communicate it to adjoining ones, and thus it proceeds until those lying upon and within the ear of the auditor become affected. This method of transmission is effected by the successive expansion of all the intervening particles, and their enlargement tends to render comparatively less the density of each particular atom, which thus becomes in a greater degree subject to the attraction of solid bodies.

The Auricle presenting an extent of surface, probably twenty times greater than the opening into the Meatus, into which all its sinuosities tend, a considerable condensation of sound here takes place, and the lower part of this passage in a healthy state being closed by the cerumen, the progress of sound would be prevented were there not some opening by which it could be further conveyed. The wax of itself affords no such facility, being different in its composition from all those substances through which sound is propelled, its oleaginous and plastic nature being unlike the friability of metals, the graduated deposit of wood, or the concretion of stone. It is, therefore, perfectly impervious to sound; but the glands by which it is produced propel it forward, and thus leave a small chasm for the passage of air between the walls of the meatus and this flexible secretion. In this intervening space particles of air are placed, and, becoming expanded by communication with the sonorous molecules within the meatus, they here undergo considerable constriction, and thus acquire that primitive intonation and renovated strength, which transmission from a distance diminishes.

The contraction before described of the auditory passage at this part, not only forms a shoulder or base for the support of the cerumen, but afterwards widening till it reaches the groove upon which the membrane is fixed, affords a space for its subsequent expansion. See *Figures* 6 and 7. It may be objected, that on the inspection of some ears the wax is found to open and form a passage, through which the membrane may be seen; and such is undoubtedly the case; but it generally happens that this view is obtained only where defective hearing exists, of which this diminished secretion is frequently the cause; and the separation observable may be attributable to the want of due proportion in its component parts, from which cause it adheres with tenacity to the sides of the meatus rather than preserve its cohesion.

If, however, a single instance can be found in which this impervious barrier exists, connected with perfect and acute hearing, no other mode than the one I have assigned for the passage of sound can be the medium of it; while cases of diminished secretion, though they lessen will not destroy the perception of language, as it can still be distinguished when the secretion is altogether wanting, the sides of the passage, as in the case of aqueducts mentioned in page 37, being one mode of conduction.

The ear-wax, however, forms the great mechanical power by which the renovation of sound is produced, and without it no ear can be said to be effective. It is the almost universal custom to remove this secretion when deafness arises, but the experience of nineteen persons out of twenty, on whom this operation has been performed, has proved the injurious tendency of the practice.

This application of the ear-wax has some resemblance to a very common domestic arrangement. When a chimney smokes, it is usually occasioned from the aperture being too large, by which the rarefied air is not sufficiently condensed to raise the smoke. To remedy this, a bladder is frequently fixed up the chimney, at a short distance from the fire, around which the air must necessarily pass, and by the constriction it thus undergoes it acquires such a degree of force on its subsequent expansion, as to expel the smoke, which without this contrivance it would not be able to effect.

The three external parts of the Ear, already described, act upon the same principle as an ear-trumpet, which consists of an expanded mouth, a conducting passage, lessening as it proceeds, and a small contracted aperture at the end. The auricle and meatus of the human ear resemble the two former parts of this instrument; but instead of having a minute terminus, which the economy of the subsequent parts of the ear would not allow, the condensation is effected by closing the passage with the cerumen, by which the same degree of power is obtained, but in a manner more consonant to the general mechanism of the organ.

In the year 1836 the author constructed an instrument called an Otophone, for the elevation of a depressed ear, and being an original invention obtained a patent for it. It is formed on models of the back of the ear, which it restores to its original form and capacity, and fitting all its inequalities requires no support from the hand. It is invisible when looking at the face, and entirely unseen when worn by females.

The Otophone does not weigh above a quarter of an ounce, and being of metal (gilt) promotes a degree of warmth favourable to the secretion of cerumen; while in particular instances its metallic composition alone, has promoted the apprehension of sound. Where the internal organs are unimpaired, it has restored imperfect hearing, and increased the perception to those who hear well.

Of the Membrane and Small Bones of the Tympanum.

In the preceding division of this treatise I have remarked that I would defer, till the present occasion, the consideration of the position of the membrane of the tympanum in its ordinary state of repose. It is almost universally described as being drawn inward; though Mr. Shrapnel, who paid considerable attention to this subject, admits that a small portion of it is protuberant; confirming in some degree my own observation made in numerous instances, in which it has always assumed a convex appearance, when viewed through the meatus; and the following physiological considerations induce me to believe that such is its natural position. First, by this arrangement the cavity of the tympanum becomes enlarged, and the small bones extended, by which means they acquire greater freedom of action; while, on the contrary supposition, they would always be compressed, and afford but little facility of adjustment to the varying pressure of sound. Secondly, when the Eustachian tube is obstructed, the hearing is greatly impaired, or totally lost. By forcing air through this tube into the tympanum, a loud noise is perceived, like the report of a gun, which arises from the compressed membrane being driven outward; and as good hearing is obtained while this position is preserved, it is reasonable to infer that such is its natural or proper one. Thirdly, as the groove in which the membrane is fixed is not perpendicular, but slopes inward from the top, it follows, that the membrane, if at all larger than the opening (which is the case), by the laws of gravitation would project outward, were it not counteracted by some internal force. This power is assumed to be obtained by one tensor and two laxator muscles; the former constantly drawing the membrane inward, but the latter, though effecting generally the same purpose, permitting occasional relaxation, from which their appellation is derived. Müller, who has considered this subject with particular attention, gives the following description of the tympanic muscles. "We have now to inquire whether the *tensor tympani* is subject to voluntary influence. Like the *stapedius*, it presents under the microscope, according to my observations, the characters common to all muscles of animal life; its primitive *fasciculi* are regularly marked with the cross *striæ*. The so-named *laxatores tympani* are, on the contrary, not muscles. In the *musculus mallei externus*, I could recognise none of the characters of muscle, which are so evident in the *tensor tympani*; it is a mere ligament." Although the above writer is inclined to consider the position of the membrane, according to the general opinion, as permanently concave, this definition of the dissimilarity of its muscles by no means bears out his conclusion.

The space which I have described as existing between the base of the cerumen and the bony ring of the membrane, affords room for the outward projection for which I contend; but whatever position be the correct one, neither of them affect the three modes of propulsion subsequently described, by which sound is conveyed from the external to the inner ear.

The transmission of sound inward is effected by the impression made on the membrane of the tympanum, on the following principles:—I. By the positive motion of the membrane upon its osseous attachments. II. By the constriction sound undergoes in passing through the ossicula: and III. By the superficial attraction which the membranes investing the small bones afford.

The membrane of the tympanum receives the sonorous impression, and transmits it on the principles applied in hydraulics for the elevation of water. In this office it may be considered to represent the arm, having its inner surface attached to the handle of the malleus, as the hand is applied to a lever. The rim of the bony cavity, over which the membrane is stretched, supplies the fulcrum, on which the two processes of the malleus are supported; while the long process of the incus, the os orbiculare, and the stapes are portions of the connecting rod, which is thus divided to obtain increased length in a contracted space, and accommodate the different parts to the varying pressure of sound: the base of the stapes performs the part of the piston. But here the analogy ends between these parts and a pump, as the pressure of the stapes causes no escape of the fluid; and we must therefore rather consider its further action to resemble that of a hydrostatic machine, the pressure on the fluid being supplied by the power of a lever instead of the more common method by a screw.

In this arrangement we perceive the necessity for the ossicula being at the time of birth of unalterable proportions. Their action is purely mechanical; and as the power of a lever wholly depends upon its length, shorter proportions subject to growth would render the hearing imperfect till its proper length should be obtained; and any subsequent elongation would be equally unsuitable to the transmission of an elementary property which is undeviating.

The second mode by which sound is conveyed has been previously illustrated in the manner by which all substances are more or less favourable to its transmission, but which is particularly exhibited in wood, and will be subsequently shown to be as effectively conveyed through the bones.

The third method by which sound is conducted across the tympanum, is by superficial attraction, for which purpose the two processes of the incus are united by a membrane resembling a narrow sail; and the crura of the stapes are similarly united; so that sounds which permeate the membrane of the tympanum become attracted by this membrano-osseous band, and are impressed upon the inner ear at the *foramen ovale,* by the base of the stapes, which is interposed between the lining membrane of the tympanum and the proper membrane of this opening. Should it be objected that these membranous surfaces are not continuous, it will be found that they closely approximate, and direct continuity is not required: a whisper in one of the alcoves of Westminster Bridge is audible in the opposite one, although there is an open intervening space of above forty feet.

Dr. Wollaston contributed to the Philosophical Transactions of the Royal Society, a most valuable communication, on the effects produced by the preternatural distension and depression of the *membrana tympani*, in which he attributed the increased perception of acute sounds to the former, and of grave ones to the latter; while others are of opinion, and among them Müller, that acute sounds alone are increased by either of these positions. As both these conditions are the frequent result of disease, they will be fully considered when the Pathological division of this work is published.

An opinion has been expressed by the most eminent writers, that the sense of hearing can be preserved after the malleus and incus are lost, if the stapes remain; and though doubted by some, the disputants in this case are not

> ——— " each claiming Truth,
> And Truth disclaiming both ;"

as within certain limitations both are right. The perception of sound, as has been already described, is perfectly audible when it proceeds from internal motion as in the excited action of the carotid artery, where it passes through the *foramen* at the inner extremity of the temporal bone; and while the auditory nerve is entire, which the retention of the stapes preserves, many degrees of sound, and almost all its measured states, as in music, may be made sensible through the conduction of the bones of the head: but the perception of language is altogether different, and without the antecedent membrane and ossicula, is certainly lost. There are, however, so many accessories to our perceptions, that a quick apprehension of the meaning of words is often obtained by those who in fact cannot distinguish them.

When a person has enjoyed the sense of hearing for many years, and becomes deprived of the parts previously alluded to, the general intonation of the sound leads to a conclusion of the meaning of words; and in this he is assisted by the anticipation of the subject upon which he is to be addressed, as well as by the movement of the lips of the speaker; and these three corroboratives greatly aid in the apprehension of language.

Indeed, far less injury than the loss of parts will occasion this defect in perception; any temporary disarrangement will cause an obliteration of the sound of the consonants, which are dependant on the most artificial modulation of the organs of speech, while the vowels which are produced by the open mouth, and but a slight alteration of the throat, will be readily understood; and the first indication of approaching deafness is an inability to distinguish Proper Names, to which those auxiliaries to hearing previously described afford no indication.

The Inner Ear.

The whole of the preceding parts of the ear appertain only to those animals which exist in the air, and are accessory to organs purely pneumatic. The inner ear belongs equally to terrestrial and aquatic animals; but in respect to the latter it is found of a far less elaborate construction than in the superior classes. In both it is filled with an aqueous fluid, which being of 800 times greater density than atmospheric air may be supposed to impress the nerve distributed within it in a proportionable degree. In fishes this is contained in a simple sac or bag, having no other external approach than through the common integuments of the fish, while the acoustic nerve is disposed in a small gelatinous fluid at the further end, in which also otolithes, small earthy concretions, are sometimes found. This portion of the inner ear in man is represented by the vestibule, upon the opening into which the stapes is affixed, at the fenestra ovalis; but this cavity, which in the human race is smaller than in aquatic animals generally, is more than compensated by other parts which communicate with it. On the left or internal side are placed the three semi-circular, or rather semi-elliptical canals, the purposes of which appear not to be satisfactorily defined. Some physiologists have surmised, that as they extend in three distinct radiations, viz., the horizontal, vertical, and oblique, they correspond with the general influence of the air, and receive impressions in every direction. Without attempting an elucidation free from all objection, even to my own mind, I venture to suggest that they may owe their importance merely to their tubular construction, and that their prolongation in different directions has been determined by reference to the economy of the osseous structure in which they are imbedded. The conveyance of sound through the medium of tubes is unquestionably great; as on applying the ear to the orifice of a water-pipe, which had burst in one of the suburbs of London, it was found to convey with great distinctness the sound of each stroke of the propelling steam engine, which was placed at above four miles distance. The constriction therefore which the nerve of hearing may undergo in these comparatively long canals, from being spread upon a membranous sac, filled with fluid, and receiving the compression of the fluid in which these sacs themselves are placed, may be considerable.

Comparative anatomy also furnishes some faint elucidation on this point. The semi-circular canals are found in quadrupeds, in birds, and some reptiles, in which they generally consist of three; in some of the latter, however, they are reduced to two, and in a few instances the canal exists but as a simple ring. In all the osseous fishes they are wanting, but in some of the cartilaginous ones, as the ray and shark, are fully developed; from which we must infer that bony structures are sufficiently favourable for the conduction of sound in fishes generally without their aid, but that the gristly substance of the species described renders this further mechanical developement necessary.

The purpose of the cochlea has been equally a subject of doubt and disputation. It is the most vitreous bone of the body, and thereby approximates to the most sonorous substance, glass; while its convoluted figure is equally favourable for the condensation of sound. The intricate windings of which it is composed afford a favourable surface for the expansion of the acoustic nerve, through a continuity of passages in a limited space; but except these general analogies, little more can be deduced from its structure. The opening of one of its passages into the vestibule, near the fenestra ovalis, and the termination of the other in the cavity of the tympanum, at the foramen rotundum, has given rise to the most ample discussion, whether the fluid in the labyrinth is affected by sound through one or both of these channels.

Sir Charles Bell, who upon this subject differs from Scarpa, and whose opinions, in common with those of other eminent writers, we feel obliged to abridge, observes, " It is contended that the sound passes in both ways; that is, along the solid bones and through the air of the tympanum. Did it pass through the air, why is there all this expense of apparatus? why a membrane of the tympanum? for unless the impressions of sound were to be conveyed as powerfully through the air as by the bones, why are they there at all? If the air were the medium then the chamber containing it should be direct and regular. * * * Besides, the air in the tympanum has a free egress, and cannot therefore strike the membrane on the foramen rotundum forcibly.

" In the labyrinth there is no air, but only an aqueous fluid: now this we have seen conveys a stronger impulse than the atmosphere; stronger in proportion to its greater specific gravity and want of elasticity; for an elastic fluid, like air, may be compressed by concussion, but an inelastic fluid must transmit fairly every degree of motion it receives. But if the fluid of the labyrinth be surrounded on all sides, if, as is really the case, there can be no free space in the labyrinth, it can partake of no motion, and is ill suited to receive the oscillations of sound. Against this perfect inertia of the fluids of the labyrinth I conceive the foramen rotundum to be a provision. It has a membrane spread over it, similar to that which closes the foramen ovale. As the foramen ovale receives the vibrations from the bones of the tympanum, they circulate through the intricate windings of the labyrinth, and are again transmitted to the air in the tympanum by the foramen rotundum.

" Without such an opening there could be no circulation of the vibration in the labyrinth; no motion of the fluids communicated through the contiguous sacculi, nor through the scalæ of the cochlea; because there would be an absolute and uniform resistance to the motion of the fluids. But as it is, the provision is beautiful. The membrane of the foramen rotundum alone gives way of all the surfaces within the labyrinth, and this leads the course of the undulations of the fluid in the labyrinth in a certain unchangeable direction.

" To me it appears that to give a double direction to the motion of the fluids, or to the vibration in the labyrinth, far from increasing the effect, would tend to annihilate the vibrations of both foramina by antagonising them."

Dr. Roget observes, " With regard to the purposes which are answered by the winding passages of the semicircular canals and the cochlea, hardly any plausible conjecture has been offered. It is not an improbable supposition, that the return into the vestibule of undulations which have passed through these canals, has the effect of at once putting a stop to all farther motion of the fluid, and preventing the continuance of the impression which has been made already on the nerves. The same use may be assigned to the double spiral convolutions of the tubes of the cochlea; for the undulations of the fluid in the tympanic tube, received from the membrane of the fenestra rotunda, will meet those proceeding along the vestibular tube derived from the membrane of the fenestra ovalis, and like two opposing waves will tend to destroy one another. Thus each external sound will produce but a single momentary impression; the prolongation of the undulations of the fluid of the labyrinth being prevented by their mutual collision and neutralization."

Muncke, who, according to the account of Müller, "has reviewed the various opinions relative to this question, and the arguments on which they are founded, decides in favour of the chain of ossicula being the principal means of conducting sound."

Müller, with the view to the illustration of this subject, imitated the structure of the tympanum in the following ingenious manner. He took a cylinder of glass six inches long, and into the upper end inserted a tense membrane of pig's bladder fixed upon a short wooden tube, the other end of the cylinder was closed by a thick lamina of cork, through which were two openings made at equal distances from the sides of the cylinder, and into these holes were inserted short tubes projecting on both sides beyond the cork, but furthest externally; these two ends were also covered with tense membranes. A wooden rod was affixed from the centre of the upper membrane, representing the membrana tympani, to one of these tubular openings representing the fenestra ovalis, at which part it was terminated by a broad piece of wood, so as to cover nearly the whole surface of the membrane, to the same extent as the stapes covers the natural aperture; and this rod was of such a length as to keep both the membranes somewhat tense. To the other opening through the cork, representing the fenestra rotunda, no connexion with the upper membrane was permitted. Having fitted a metallic flute-pipe into the wooden tube at the upper end of the cylinder, and immersed the two tubes representing the fenestræ in water, Müller gives the following description of the effect produced.

"My ears being stopped with plugs," (to obtain, as expressed in preceding experiments, the more powerful conduction of sound through bone,) "I could by means of a conducting rod, held in connexion with one ear, ascertain the relative intensity of the sonorous vibrations communicated to the water through the two openings corresponding to the fenestra rotunda and the fenestra ovalis; while another person sounded the pipe. The difference was very striking. The sound transmitted by the wooden rod to the opening of the foramen ovalis was in a remarkable degree louder than that propagated through the air of the cavity, and the membrane of the foramen rotundum. The loud sound issuing from the former was heard even opposite the latter; hence, to ascertain the strength of the sound issuing from the latter separately, it was necessary to remove the rod from the apparatus, and to close completely the fenestra ovalis by means of a solid plug. It was then found that the sound was transmitted by the fenestra rotunda *with but little more intensity than by the solid lamina of cork itself.*"

Notwithstanding the very clear result here exhibited, the reader will be surprised to find this experienced physiologist expressing the following opinion:—

"When both fenestræ exist together with a tympanum, the sound is transmitted to the fluid of the internal ear two ways, namely, by solid bodies and by membrane; by both of which conducting media sonorous vibrations are, as my experiments have shown, communicated to water with considerable intensity. The sound being conducted to the labyrinth by two paths will, of course, produce so much the stronger impression, for undulations will be thus excited in the fluid of the labyrinth from two different, though contiguous, points; and by the crossing of these undulations stationary waves of increased intensity will be produced in the fluid."

The fenestra rotunda, having no sonorous accessories, does not, in my opinion, communicate sound to the labyrinth, of which the experiment of Müller seems decisive, while its membrane appears to be required for another purpose. The fluid within the inner ear being incompressible, and yet subject to a varying degree of force, unless some yielding substance had been provided for these inequalities, would re-act upon the structure by which it was impressed, and thus produce a rebound of acoustic machinery; but the fenestra rotunda possessing an elastic quality this difficulty is avoided. It may, indeed, be considered to perform an office similar to that of a valve to a steam engine, which on excessive pressure opens, and relieves the machine; an office in the animal economy generally performed by the sphincters. But as such an arrangement would permit the escape of the fluid, on which all sonorous susceptibility depends, the hearing would necessarily be impaired till the deficiency should be restored; while by the present arrangement such inconvenience is avoided, by the relaxation of this membrane. Other considerations of greater weight contribute to support this opinion, arising from the functions of the cavity of the tympanum; but as these have not hitherto been explained, and form the subject of succeeding pages, it will be unnecessary to insert them here.

Of the connection of the Acoustic Nerve with the Mind no satisfactory explanation can be given. At this point of the enquiry we appear to have arrived at the boundary which separates the material from the immaterial world; we have carried investigation, if not discovery, to the limits of the first, and into the other our finite capacities will not permit us to enter.

Of the Tympanum, Eustachian Tube, and Mastoid Cells.

The seven parts of the ear previously described are those which are subservient to the active principle of sound, and may be considered as the working parts of the ear. The three above enumerated which intervene between the external and inner ear possess a passive character, but they will be found, notwithstanding, to be no less important.

The tympanum is the central cavity of the ear, to which the purpose has always been assigned of contributing to the free action of its membrane, by the communication maintained between it and the outer air through the Eustachian tube. But another equally important purpose has been hitherto overlooked, viz., its constituting a chamber for the neutralization of that portion of sound, resulting from the peculiar construction of the Eustachian tube on the one side, and that collected by the osseous structure of the cranium on the other. The circumstance which first led me to ascribe this additional purpose to the tympanum arose from having taken cold, attended with sore throat, by which the Eustachian tube on one side became closed, and deafness of that ear ensued; in about three days afterwards inflammatory action attacked the other side, but less violently, as it did not wholly obliterate hearing. In this state I had occasion to walk to the house of a friend about a mile distant, and found that every footstep occasioned a dull and heavy noise in the head. By taking prompt measures the Eustachian tubes were soon restored to their original healthy state, when the noise I had previously experienced in walking ceased; and I was afterwards led to consider from what cause a sensation that must always be produced by the same act, was discoverable only in a diseased state of the organ. The unpleasant noise described was evidently conveyed from the feet, through the osseous column to the head, where it appeared condensed by the cavernous structure of the skull, and was communicated to the ear. It therefore appeared that the Eustachian tube might possess a counteracting property, and in a healthy state neutralize that sound, of which, when it was impaired, I became sensible.

On considering, therefore, the shape of this canal, I at once perceived it was constructed to convey sound as well as air, being formed on the principle of an ear-trumpet, with an open mouth to collect sound, and a contractile passage to condense it; and that if its purpose had been solely for the conveyance of air, an aperture of uniform diameter would have been sufficient. As Nature has formed nothing in vain, this construction evidently evinced its double purpose; and as it would project the sound at right angles upon the osseous band, by which the external and inner ear are united, it must necessarily create an injurious effect. The noise I had perceived when the Eustachian tubes were closed, convinced me, that sound must be projected from the other side, and that their antagonizing forces were requisite to cause that neutralization of sound, which their separate structures produced.

The effect of this counteracting principle has been recently exemplified in some experiments publicly exhibited. Two glass vases of the same note (for example A), on being struck will sound alike, but if one be held about a foot distance over the other, their uniform radiations will so act as to produce silence. If their mouths are removed, so as to be out of the range of each other's influence, their original sound will continue ; and which by the preceding means may be again obliterated But if a glass vase of note C, be held over the one A, and both be rendered sonorous, sound by the preceding means will not be prevented, but an inharmonious tone, the result of their intermixture, will be produced.

This effect of antagonizing sounds has been noticed by Dr. Thomas Young, in his "Lectures on Natural Philosophy," &c., vol. i. page 390, where he observes, "When two equal undulations, of equal frequency, coincide, and when the particular motions are directed the same way, at the same time, the velocities in each direction are added together, and the joint effect is doubled, or perhaps quadrupled; since it appears that the strength of sound ought to be estimated from the squares of the velocities of the particles: but when the particular motions of the two sounds counteract each other, both their effects are wholly destroyed."

The cavity of the tympanum forms the intermediate space between the Eustachian tube and the Mastoid cells, which form its external boundaries; and their collected sound is so exactly proportioned by the hand of nature, that the slightest alteration of the structures on either side, will derange it; and hence hearing by the ordinary channel will be impaired.

The disturbing sounds produced within the tympanum as well as others arising from the external ear, have hitherto passed under the general name of *Tinnitus Aurium,* without any attempt having been made to discriminate their different causes and character. In elucidation of this subject it will be necessary to state, that there are four distinct species of tinnitus, two of which arise in the external ear, and two within the cavity of the tympanum.

The first of these has been experienced by every person whose hearing has been perfect; and arises from a slight fissure in the ear-wax, which, assuming a trumpet-like form, projects sound upon the membrane; but the plastic and perpetually moving nature of the cerumen soon closes up the aperture; when this not inharmonious sound which more than any other may be demoninated "singing of the ears," ceases. This sensation, if we may be permitted to compare the perceptions of one sense with those of another, may be likened to that of a falling star to the sight, which is no sooner discovered than it disappears.

The second cause of disturbance arises from the limpid state of the cerumen, causing it to flow inward instead of forward and outward, thus occupying that small chamber behind the ear-wax in which sound is permitted to expand, and where becoming inspissated, it presses upon the membrane, and destroys its freedom of action. This description of tinnitus is characterized by a buzzing noise.

The third impediment to hearing, from structural alteration arises from the manifold accidents to which the Eustachian tubes are liable. By inflammatory action of the throat these orifices become nearly closed, and from its relaxation, or the enlargement of the tonsils, are frequently elongated, while they are also subject to contraction from the involuntary nervous action, which affections of the mind create. They are also affected by polypi, occupying the cavity behind the posterior nasal aperture; by thickening of their mucus membrane, or any accidental tumour formed upon it; all of which, by contracting the passage, increase the sound projected into the tympanum, and are the most frequent causes of deafness.

A fourth obstruction equally fatal to hearing, arises from an alteration of the Mastoid cells. These delicate chambers, which resemble in the thinness of their partitions the cells of the honey-comb, frequently become agglomerated by a dense sanguineous fluid, or ossified, so as to resemble in their whole extent a compact piece of ivory ; in which state scarcely any traces of their primitive cellular structure remain.

Whenever this alteration takes place, the patient is never free from the most distressing noises. The sound collected by the cranial bones, instead of being divided and dispersed, becomes condensed, and the noise thus produced resembles the rushing of a waterfall, the hammering of iron, the roaring of thunder, &c., and is as incessant as it is incurable.

It is stated by Macrobius, in his second Book, that Pythagoras was first induced to investigate Phonics from frequently passing a blacksmith's shop, and observing the variations in sound produced by his large and small hammers ; but though the differences arising from *tinnitus*, before described, are equally distinguishable, I am not aware of any work in which they have been attributed to their proper causes.

These different mechanical obstructions evince the necessity of an exact equipoise in the different parts of the structure of the ear, and with a view to ascertain by the test of experiment whether the theory here advanced, of counteracting sounds, was correct, and particularly to discover whether deafness arising from noises occasioned by obstructions in the Eustachian tube, might not be removed by other sounds projected upon the cranium, I caused a machine to be constructed, which gave twelve strokes upon a bell in a minute ; and by placing a person whose deafness arose from this cause, at a foot distance from the machine, when it was elevated to a level with the head, I found that, after continuing for about three minutes, the party was enabled to quit the apartment, and walk up stairs to another room, where he could hear conversation at the distance of twenty-two feet. This delightful restoration of the sense, however, was but of short duration; for the artificial sound being discontinued, and the noise through the Eustachian tube unremitting, I was after two or three minutes obliged to approach nearer to the patient, till I arrived within two feet of him; which was his original hearing distance. The success of this experiment, in numerous instances, proves the correctness of the theory; and many persons have assured me, that if they proceeded homewards, immediately after rising from the machine, they were enabled to hear well during the continuance of their walk, even though it extended two or three miles.

Dr. Willis, who died in 1675, has left on record two cases, which have ever since been the subject of wonder and misapprehension. They were related to him by an individual worthy of credit, and are as follows:—one instance was that of a woman, who, in spite of her deafness, heard every word that he said as long as she remained in a room in which a drum was beaten; and the other was that of an individual whom he knew whose hearing was defective, but who heard everything during the ringing of a peal of bells in a belfry near his residence. Dr. Willis attributed the effects thus produced, to the increased tension occasioned by these excessive sounds upon a relaxed membrana tympani; but as he had no personal inspection of the cases, his assumption of the cause must be purely hypothetical; and most succeeding writers have attributed it to an affection of the auditory nerve.

Dr. Kramer, of Berlin, who is not only one of the latest but most erudite writers upon the treatment of diseases of the ear, has remarked, that the phrase "nervous deafness has hitherto been frequently misused as a cloak for ignorance and want of skill in any doubtful or obscure disease of the ear;" but, in this instance, he appears to have rendered himself obnoxious to his own reproof. He states, that "if the patient sit in a cart which is rattling quickly over a stone pavement, or press his forehead against the frame of a window whilst a waggon is rattling past, so that the whole house is shaken by it; or if a peal of bells be ringing near the patient, or a drum be beaten, the auditory nerve becomes so excited by these deep-toned uniform noises, that while they continue the patient often hears the human voice better than a sound person, whose ears are stunned by the noise. This deceptive improvement, however, never continues longer than the noise itself which has produced it."

Having thus identified this class of aural affections with those of Dr. Willis, which have been transcribed from Dr. Kramer's work, it will be observed that the beneficial results produced are ascribed to a preternatural state of the acoustic nerve; the derangement of which the above author assigns to two causes "differing essentially from each other. First, attended by augmented irritability (*erethismus*), and secondly, with diminished irritability (*torpor*). *Tinnitus* forms the essential point of difference between the two; it belongs, without exception, to the erethetic form, while to the torpid form it is altogether foreign." And he further adds, "It is only when the tinnitus is for the most part of a very feeble kind that it seems to be drowned by surrounding bustle and noise, and returns again in the midst of domestic quiet. * * * The noises are at first of a deep toned character, resembling the roaring and foaming of the sea; the descent of rain; the rustling of the wind among the leaves, or the humming and buzzing of insects. Subsequently (and especially when the disease is more fully established) the tones are of an acute, singing, tingling kind; like the chirping of birds, whistling, or the singing of a kettle of boiling water."

It will thus be seen that Dr. Kramer employs *tinnitus* as a generic term, without specifying any of those subdivisions which his own acute observation had remarked. That which he first describes comprehends those of a loud and grave character, and such as would be produced by the transmission of sound through wood, stone, or bone; while the latter resembles that shrill and hissing noise occasioned by the passage of air through contracted apertures. These two varieties are perfectly identified with those I have previously described, page 101, as the fourth and third, the former resulting from ossification of the mastoid cells, and the latter from partial obstruction of the Eustachian tube; and they are therefore dependant upon mechanical causes, having no relation whatever to the acoustic nerve, which merely receives the sonorous impression, as a mirror reflects the image presented to it.

It is certain that tinnitus frequently accompanies an irritable state of the acoustic nerve, as the inflammation by which it is produced generally extends to the throat, and by contracting the mouths and passages of the Eustachian tubes, will produce this effect; but the diseases are perfectly distinct in their cause and character, though sometimes associated.

Dr. Müller also, of Berlin, has referred to the preceding cases of Willis, which he has classified as *paracusis Willisiana;* and remarks, that "similar ones have been observed by Holder, Bachmann, and Fielitz; they are perhaps to be attributed to a state of *torpor of the auditory nerve,* which requires to be roused before it can exercise its functions. Sometimes, however, the circumstance of a person hearing particular sounds during a great noise, as well as other people who are not deaf, may arise from his being much less disturbed by the noise than they."

I have selected the opinions of these two authors as affording the strongest contrast and severest test to my own; their elaborate researches in all that relates to the ear having entitled them to a just pre-eminence; but in this particular they appear to be equally wrong; Dr. Kramer attributing the restoration of hearing to those cases only in which an irritable state of the acoustic nerve exists, of which tinnitus, in his opinion, forms the diagnosis; while Müller attributes it to the torpid state which is unaccompanied by tinnitus.

So far from Dr. Kramer's opinion being correct, every one must have remarked, that in the erethetic form of nervous deafness ordinary sounds are distressing, and become more painful in proportion to their loudness; so that, instead of restoring impaired hearing by additional noise, persons labouring under this affection have straw strewed before their houses to diminish it; while, on the other hand, torpidity of the acoustic nerve is generally produced by cerebral congestion, tumours, or aneurismal enlargement, compressing the nerve; which accelerated motion would only tend to increase.

The reason attributed by Dr. Willis, for the restoration of hearing by counteracting noises increasing the tension of the membrane being generally rejected, and those assigned by the most recent writers being not only reconcileable with each other, but involving also a physiological incongruity, in attributing effects produced by the mechanical parts of the ear to the sentient,—it remains to be considered to what cause can be attributed a sensation in itself undeniable. This improved perception is most generally experienced in carriages, by those whose hearing is impaired by tinnitus arising from contraction of the Eustachian tube. The acknowledged transmission of sound through metal, wood, and bone, which all combine to produce this counteracting noise, appears to act upon such persons by antagonizing the sound by which their hearing was previously disturbed; while this accession, to those who hear well, by destroying the natural equilibrium renders their hearing worse. Each party, however, after alighting, in two or three minutes recovers his pristine state, the artificial sound no longer controlling the disturbing one in the deaf, and ceasing to annoy those who hear well. We must, therefore, attribute this change in the perception to the circumstance which has produced it, and not to the state of the nerve, which appears in both cases to be unimpaired, and duly responds to the mechanical organization. Even should this explanation be deemed incorrect, the opposite one of Kramer and Müller is evidently erroneous, as affections of the acoustic nerve, whether erethetic or torpid, are not with such facility removed.

Although imperfect hearing, in cases of the above description, does not appear dependant on the state of the acoustic nerves, yet deafness is often produced by injuries affecting them; sometimes by affections of the mind acting on the nerves of involuntary motion; at others by affections of the stomach, probably communicated to the ear through the *otic ganglion,* (discovered by Dr. Arnold of Naples, in the year 1826); and also by the derangement of organs still more remote; but as these causes arise from constitutional disturbance, and have reference to the pathological branch of the subject, their further consideration is necessarily excluded from the present treatise.

Conclusion.

Some of the parts of the ear, either in their composition or development, are peculiar to this organ, as the cerumen, the principal purpose of which has not been hitherto assigned to it, and the small bones of the tympanum, which, after the period of birth, are restrained from further growth. The other parts, though partaking of the general character of all vital organs, are adapted to general principles, applicable to aerial or liquid pressure; but the uses of the whole appear to be comprised in the promotion of four separate functions, namely—

1. The auricle, auditory passage, and cerumen, to the collection, concentration, and restoration of sound to the primitive strength which its transmission to a distance impairs.

2. The membrane of the tympanum, and the small bones within it, by the combination of mechanical pressure, osseous conduction, and superficial attraction, convey sound securely across an open chasm in which it is exposed to interruption from opposite sides.

3. The acoustic nerve, being spread within the inner ear upon a fluid eight hundred times more dense than air, receives the impression which is thus rendered more powerful and communicates the sonorous sensation to the mind.

4. The cavity of the tympanum, eustachian tube, and mastoid cells, but slightly increase the strength of sound, and appear designed to prevent its interruption from physical causes.

It will be observed, in this arrangement, that the three latter parts do not greatly add to the intensity of sound, while their derangement is the most frequent cause of deafness; and it may therefore be inquired, under what necessity are they created? In fishes they do not exist, and appear not to be required in some of the amphibia, which, by withdrawing the skin that covers the membrane while under water, are enabled to expose the inner ear to the pulses of sound; and if we consider the power of the three external parts of the ear for its renovation, it would seem that a direct communication between the external and inner ear, without the intervention of the tympanic parts, might be effected; but as we find that, with the exceptions above stated, almost every other class of animals is furnished with a tympanum, which in every case is provided with an eustachian tube or canal, and an enlargement of bone, analogous to the mastoid cells, the adoption of such an apparatus can arise only from some general principle; and such we consider to be the susceptibility of all substances to sonorous impressions. Few possess this property in a greater degree than bone; and hence the necessity for an organisation which will counteract this tendency when it leads to evil, and render it available in the production of good.

It is not difficult to imagine that, had the ear been placed in some less osseous part of the frame, the construction of the tympanic mechanism might have been avoided; but though our limited faculties permit us to discover only a few of those links in existence on which the order and harmony of nature depend, yet perhaps it is not impossible to discover, in the present instance, reasons sufficient for the complicated mechanism we observe. By the ear being placed on the head, it approaches nearer to the brain, the common seat of perception, and is on a part which, for other purposes, must be necessarily uncovered, as for sight, smell, and respiration; while, in a different situation, it might be associated with functions that impose the necessity of external protection. It is also placed in the most favourable position for the apprehension of language, its most important purpose, the transmission of sound being most perfect in a level direction; while, from the great facility of the head for movement, the ear can be directed, without any material change of position of the body, to the source of sound.

Doubtless, many other advantages which its situation presents could be enumerated, and the inconveniences which its attachment to any other part would occasion might be pointed out; but, in those alluded to, we perceive sufficient to counterbalance the disadvantages which its liability to derangement occasions.

Similar objections have been made respecting the construction of the eye, which are thus stated by Dr. Paley:—"Why should not the Deity have given to the animal the faculty of vision *at once?* Why this circuitous perception, the ministry of so many means; an element provided for the purpose, reflected from opaque substances, refracted through transparent ones, and both according to precise laws; then a complex organ, an intricate and artificial apparatus, in order, by the operation of this element, and in conformity with the restrictions of these laws, to produce an image upon a membrane communicating with the brain? Wherefore all this? Why make the difficulty in order to surmount it? Why resort to contrivance where power is omnipotent?" To this Dr. Paley makes the following forcible reply, which is equally applicable to the construction of the ear:—"It is only by the display of contrivance that the existence, the agency, and the wisdom of the Deity could be testified to his rational creatures. God, therefore, has been pleased to prescribe limits to his own power, *and to work* *his ends within those limits;* and when a particular purpose is to be effected, it is not by making a new law, nor by the suspension of the old ones, nor by making them wind and bend and yield to the occasion (for Nature, with great steadiness, adheres to and supports them), but by the interposition of an apparatus, corresponding with these laws, and suited to the exigency that results from them, that the purpose is at length attained."

In attempting to demonstrate new principles respecting Sound, and assign additional functions to the structure of the Ear, the author is aware he has undertaken a task of hardihood, if not of temerity, particularly as his difficulties have been increased by a rapid declension of sight, which it is supposed these studies have principally occasioned, and have obliged him to compose this treatise by dictation to his daughter. This great affliction has also prevented him consulting many works by which the elucidation of his theory might have been promoted, and performing several experiments which for the present must be deferred. A strong desire, however, which it was out of his power to resist, impelled him to the completion of the performance, influenced by the hope that, at its termination, his mind being relieved from the long-continued pressure, his sight might be improved; and it is under the expectation arising from this impression that the work, in its present form, is presented to the public.

THE END.

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THE following Observations, selected from above one hundred others, appeared in different Journals on the publication, in 1836, of the Author's "TREATISE UPON THE EAR AND DEAFNESS :"—

At the present period, the volume before us is the only one which is worthy of being consulted, either by the general reader or by the medical student. Those heretofore published, savoured too much of quackery, the principal object being to puff the authors into practice, instead of instructing the reader. This work is illustrated by a number of beautiful engravings, exhibiting very clearly the anatomy of the ear, one of which represents that organ in Mozart. Mr. W. has treated the subject of his work in a truly scientific manner. We cordially recommend it to our readers. —*Parthenon.*

Nothing has tended more to advance useful knowledge than the production of scientific works, in a style suited to all classes of readers, and investing the facts which nature exhibits with that interest which necessarily arises from a due discrimination of their uses. Among the many such works which have emanated from the press in this age of enlightenment and zealous inquiry, we have to place the one now under consideration. The author has treated his subject, with which he is thoroughly acquainted, in such a manner as cannot fail to convey clearly and distinctly to his readers the variety of information his book contains. There is no part of anatomy more deeply interesting than that of the eye or ear; the latter is now *for the first time* treated in that full and lucid manner which is desirable. The writer enters into the minutest particulars, with a view of philosophically pointing out the wisdom of their design. The book may be justly considered a complete treatise on the ear as to its anatomical organization, with valuable pathological deductions, indisputably authenticated.—*Keene's Bath Journal.*

Perhaps there is no science in which so much progress has lately been made in the attempt to render the public familiar with its principles, as Physiology. The first efforts were of course imperfect, and their authors were confounded with the Buchans and Reeces of the profession; their motives were misunderstood, and their intentions misrepresented. Fortunately, however, they persevered, and now the works of Combe, Dunglison, Hodgkin, Caldwell, &c., afford proofs at the same time of the deepest acquaintance with the laws of the animal economy, of an anxious desire to benefit humanity, and of a perfect contempt of all the disgusting arts of quackery. The work before us has a similar object in view; it gives the soundest and best ascertained doctrines on the physiology of hearing, and endeavours to clear up some points which have, as yet, been involved in obscurity.—*Coventry Standard.*

A happy mixture of the popular and the scientific characterises this work, and no method could be more suited to so peculiar a subject: its great importance requires that it should be treated with a skilful and practised hand, and its universality requires that it should be made clear to the apprehension of all. In this view the sense of hearing is even of more consequence than that of vision: there being but few persons, living to an advanced age, who are not more or less subject to deafness. Mr. Webster throws some valuable light upon the subject: his treatise is calculated to make the construction and the functions of the organ better known, and its disorders better guarded against. His own useful inventions, upon which there are some interesting observations in his work, are admirably adapted for facilitating the hearing.—*Liverpool Courier.*

When it is considered that next to the blessing of sight the sense of hearing opens out the greatest source of enjoyment, and contributes most to the safety and comfort of life, every information which enlarges our knowledge of the structure, the mechanism, the diseases, and their remedy, of that complex and delicate organ, must be received as a positive benefit done to the human family at large. In the treatise that we are now noticing, not only is there brought together a vast mass of valuable information, hitherto locked up from the public by professional technicalities, but even that information is communicated under so novel, and at the same time so appropriate, an arrangement, as to render it not unworthy of the notice of those whose physiological pursuits have made them familiar with the organic structure of the ear. As a treatise on aural pathology it is worthy of especial attention, from the plainness of its directions, and the peculiar adaptation of the remedies it recommends.—*York Courant.*

No organ of sense appears to be less understood than that which is the subject of the present work; of the exact uses of the different parts, late physiologists have professed their ignorance; Mr. Webster treats each in a clear and perspicuous manner, and his arrangement differs from that of other anatomists. In each division the author has advanced some new views well deserving of attention.—*Gloucester Chronicle.*

This little work is written in a perspicuous and lively manner. It will be found interesting to the general reader, and contains so much valuable practical information that we earnestly recommend it to the perusal of all whose hearing is imperfect. Mr. Webster is the inventor of the Otaphone, an instrument the efficacy of which is attested by many instances. Amongst others we may mention that of the Lord President of the Court of Session in Scotland, who states to Mr. Webster, in a letter published in the book before us, that he "uses the Otaphones both in Court and in

Church, and finds them of great use; at other times he only puts them on at breakfast time, and wears them for two or three hours, and his hearing is improved for the rest of the day." The invention was suggested to Mr. W., he says, by observing persons at church, and other large assemblies supporting the ear with the hand. We think no one can read the treatise now under our notice without perceiving that Mr. Webster is, beyond any other practitioner, master of the very difficult subject to which he has devoted his researches, and feeling disposed to confide in him, and to consult him in all cases of deafness or disease of the ear.—*Wisbeach Gazette.*

Mr. Webster promises to effect for the disease of deafness what Jenner did for small-pox. The work before us evidences profound pathological skill applied with success to the alleviation of one of those infirmities hitherto deemed all but incurable, and which has proved among the most common of the ills to which flesh is heir. We cannot too highly commend this work, which is popularly and pleasingly written, and we do not hesitate to say is a blessing to the deaf.—*Cheltenham Free Press.*

This treatise, on a physiological subject admitted to be little practically known, is at the same time popular and scientific. Of no physical calamity to which man is exposed to obviate or to remedy which is there less known to the surgical profession than that of deafness. Various and widely different have been the theories of some physiologists, and the experiments of several surgical practitioners; but no fixed theory or no settled and generally admitted remedy has been laid down as authority upon which to rely. Many able treatises on diseases of the ear have been published within a few years, but none of them have the merit which the work now before us can lay claim to. Mr. Webster treats the subject under a different form, and with a different scientific arrangement from those usually followed. His anatomical description of the ear is clear and concise, and calculated to enable the reader to follow him through the exemplifications of his system with ease. It is stripped as much as possible of all technical physiological terms. The work is highly instructive, and at the same time amusing; and to those afflicted with the calamity which it is intended to point out the means of curing or counteracting, it will be deeply interesting and useful.—*Wakefield Journal.*

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