# CHAPTER I.

## GENERAL VIEW OF SOUND.

§1. DEFINITION OF THE WORD ACOUSTICS.—2. NATURE AND PROPAGATION OF SOUND.—7. VELOCITY OF SOUND.—8. INTENSITY OF SOUND.—10. COMPARISON OF MUSIC AND NOISE.—19. MUSICAL PITCH.—22. LENGTH OF THE SONOROUS WAVE.—23. AUDIBILITY OF HIGH NOTES.—24. SOUND APPRECIATED BY DEAF PERSONS.—25. RANGE OF MUSICAL INSTRUMENTS.

**1. Definition of the Word Acoustics.** The science called *Acoustics* embraces not only sound itself but also everything connected with the production and transmission of sound. The word is derived directly from ἀκουστικὸς, *belonging to, or adapted for hearing*. Rousseau says that it was "invented" by Sauveur, but although the latter may have been the first to use the French term, *acoustique* (1697), the English form of the word was familiar to men of science in this country in 1683, and a valuable essay on the subject was then written by the Reverend Dr. Narcissus Marsh, urging its importance as a study. See that date in the chronological list of works.

**2. Nature and Propagation of Sound.** So many excellent writers have failed to find a satisfactory definition of sound, that one may well feel justified in believing it to be not only undefined but undefinable, yet, without going so far as to agree to the common statement that sound is vibration, we may admit that all sound is attended by the peculiar motion called *sound-vibration* and that such vibration may possibly be the immediate cause of the excitation of the sense of hearing. The frequent assertion that sound is sensation appears to have no basis whatever, and it implies the assumption that sound depends, as a condition necessary for its existence, on the accident of the presence of some receptive and appreciative organ, an assumption that is untenable and contrary to reason. The nearest approach to a definition of sound, that can fairly be regarded as incontrovertible, seems to be the mere dictionary meaning of the word: *sound is that which may be heard.* That concussion of some kind is absolutely essential for the production of sound, scarcely admits of doubt.

**3.** Sound is transmitted, or propagated, by means of a wave, or pulse, of alternate condensation and rarefaction, which may traverse either the air alone, or any other medium: it may even be communicated by the air to a solid body, and thence again to the air beyond, this process being repeated until the energy of the original impulse becomes exhausted. Thus, when a wind-instrument is played in a closed room, the sound is conveyed by the air to the walls, ceiling and floor, and by these to the air of any adjoining spaces. It should be clearly understood that the particles of the medium through which the sonorous pulse passes, oscillate through very short distances, and, having imparted their motion to the particles beyond, they return, to be again reflected, as long as the exciting cause may continue.

**4.** The motion of the sound-wave is to a great extent independent of a current of air, for although a strong wind may somewhat increase or diminish the intensity of a sound travelling a long distance, as everyone knows, yet sound-vibrations are constantly transmitted in a direction opposite to that of the air-current.

**5.** As light and heat extend in every direction from the sun, so the sound-rays diverge from a sonorous body which is entirely surrounded by air. When

> "The gentle lark, weary of rest,
> From his moist cabinet mounts up on high,
> And wakes the morning, from whose silver breast
> The sun ariseth in his majesty;"

each mellow note that issues from that tiny throat, as the lovely



bird pours forth his song of praise, forms spherical waves of condensation and rarefaction, expanding further and further in the circumambient atmosphere, until their energy of motion gradually dies away.

**6.** We must, however, take a more prosaic view of the sound-wave in order to gain a clear idea of its action. The following application of a well-known experiment may serve to illustrate this. Take a rod of pine about six feet long, with one end cut nearly to a point and rounded, so that it can easily enter the orifice of the ear. Let an ordinary tuning-fork be struck, and the handle of it applied by an assistant to the broad end of the rod. Let the observer bring the small end of the rod near to his ear, and wait until he can hear no sound from the fork. The small end of the rod should then be applied immediately to the ear, and a distinct musical sound will be audible. It will be at once evident that this sound cannot have been transmitted through the air: the sonorous wave will have passed only through the substance of the wood, by reason of its elasticity, and yet the rod itself will not have moved sensibly. Here then, is a very tangible proof of the minuteness of the excursions backwards and forwards of the particles which form the sound-wave, while the wave itself, assisted by the conducting power of the rod, about ten times that of air, possesses sufficient energy to carry the otherwise inaudible vibrations of the fork to the organ of hearing.

**7. Velocity of Sound** varies considerably, according to the nature and condition of the conducting medium. Since the time of Newton, whose results were corrected by Laplace, various estimates have been made of the velocity of sound in air, as well as in different fluids and solids. There is now a general agreement amongst scientific men, that the velocity of sound in air at a temperature of 32° Fahrenheit, is about 1090 feet in a second. The velocity increases at the rate of very nearly 1.09 foot in a second, for each degree of rise in the temperature. The accepted laws concerning velocity are as follows: *The velocity of sound varies directly as the square root* *of the elasticity and inversely as the square root of the density of the medium*, but as long as the temperature remains the same, the density and the elasticity vary in the same proportion, and therefore neutralize each other.

**8. Intensity of Sound** depends on the *amplitude* of vibration, that is, the distance through which the vibrating particles move, and the amplitude decreases as the distance of the observer from the point of sound production increases. In more precise language: *the intensity of sound varies directly as the square of the amplitude and inversely as the square of the distance*, but these laws, like others of similar nature, are subject to interference; in this case the disturbing influences are variation of the density of the medium; motion of the atmosphere, and the conversion of a part of the energy of the vibrations into heat.

**9.** Lord Rayleigh (1877) remarks that "it is a direct consequence of observation that, within certain wide limits, the velocity of sound is independent, or at least very nearly independent, of its intensity, and also of its pitch [that is, its rate of vibration]. Were this otherwise, a quick piece of music would be heard at a little distance hopelessly confused and discordant."

**10. Comparison of Music and Noise.** Many writers have exercised their ingenuity by endeavouring to draw an exact line of demarcation between music and noise; the two, however, so blend together that it is impossible to separate them, and the question often becomes simply one of taste.

**11.** It is amusing, if not always instructive, to read the various opinions on these two subjects. The poet Waller evidently considered musical sound to be a species of noise, or he could not have written these well-known lines in praise of the singing of his mistress:

> "While I listen to thy voice,
> Chloris! I feel my life decay:
> That pow'rful noise
> Calls my fleeting soul away."

**12.** Perrault, in his celebrated *Essai du Bruit* (1680), states



that "all tone is noise, but all noise is not tone." The late Professor Donkin (1870) says: "Few, if any noises are perfectly unmusical, that is, absolutely without pitch. Two noises of the same general character often differ from one another in a way which we describe by calling one of them more acute or sharp, and the other more grave or flat; for example, the reports of a pistol and of a cannon. On the other hand, few, if any sounds are perfectly musical, that is, absolutely unmixed with noise. Hence the question presents itself whether there is, after all, a real distinction in kind between noises and notes."

**13.** When audible vibrations occur with sufficient rapidity to prevent their being distinguished by the ear as separate shocks, the resulting continuous sound always possesses more or less musical character. The peculiar faculty of the ear for the combination of sounds is thus explained by Sir John Herschel (1830): "The ear, like the eye, retains for a moment of time, after the impulse on it has ceased, a perception of excitement. In consequence, if a sudden short impulse be repeated beyond a certain degree of quickness, the ear loses the intervals of silence, and the sound appears continuous."

**14.** It may be well to mention here, that in Great Britain and in Germany, the word vibration is always understood to mean two motions in opposite directions. In France a vibration is generally considered as one motion, to or fro. Delezenne of Lille (1857) makes the following useful distinction, which will be adopted in these pages: "Each movement backwards or forwards will be an *oscillation;* the two successive movements will constitute a *vibration.*"

**15.** About sixteen of these vibrations in a second of time are generally supposed to be the lowest number that can so coalesce as to produce a musical sound, but the illustrious Savart constructed, and described in a lucid paper (1831), an ingenious machine which gave a note with only eight vibrations in a second. Professor Helmholtz (1857 and 1863) has emphatically denied the possibility of the production of such a note, and he asserts that Savart must have been mistaken as to the note he heard, but, after carefully reading the above mentioned paper, I can find no reason to doubt the conclusions at which Savart arrived. It is difficult indeed to believe that such a man as he, and "a great number of persons" besides, could have been so deceived as to have taken one note for another, as Professor Helmholtz supposes. Johannes Mueller (1840) goes so far as to suggest that even lower notes than that of Savart, might be audible.

**16.** Sufficient notice does not appear to have been generally taken of the probability that different ears may possess different powers of definition. There is a condition of the eye, by no means uncommon, which prevents a row of spots from being distinguished as such, a more or less blurred line being all that can be seen. It may well be that the ear is liable to a similar defect, and that while one person can hear, and even count, single taps or blows, another may be unable to distinguish any separation between them, and be only conscious of a continuous sound, just as *astigmatic* persons are unable to distinguish spots within a certain distance apart. This is merely hypothesis, but it may perhaps account for much of the diversity of opinion that prevails. "*Valeat quantum valere potest.*"

**17.** It is well known that grave sounds are rendered more appreciable by their union with certain higher ones. Des Cartes (1618) writes: "With the thicker strings of a lute, which give the graver sounds, other smaller strings are associated, [which sound] an octave higher. These are always touched at the same time, and thus cause the graver sounds to be heard more distinctly."

**18.** Be the rate of vibration necessary for the production of continuous sound what it may, it can easily be proved that when that rate is attained, whatever may be the means employed, a sound of decidedly musical character will be the result, though it by no means follows that the sound will be an agreeable one. Professor Tyndall (1883) observes that Galileo produced a musical sound by passing a knife over the serrated edge of a coin, thus causing "a succession of taps quick enough to produce sonorous continuity." A flexible plate, such as a card, held against the edge of a revolving toothed wheel, is a common means of producing musical sound by taps. Savart conducted some important experiments with a machine so contrived as to register the number of collisions in a given time.



**19. Musical Pitch.** If the vibrations of which a musical sound is composed, maintain an equal rate for an appreciable time, the note is said to have a definite *pitch* or musical identity, which is considered to be high or low, according to the greater or lesser number of the vibrations in a certain time. Euclid (4th Century, B.C.) says: "Musical notes must be considered to consist of parts, as they are capable of being tuned precisely, either by increasing or reducing the numbers of their vibrations. Therefore, as all things which consist of numerical parts are governed, when compared together, by numerical ratios, musical sounds must always be in some numerical ratio to each other."

**20.** Chladni (1802-9) states as a general law, that "the air by which the sound is propagated, makes neither more nor less vibrations than the body which produces the sound." It is, however, well-known that when, during the production of sound, the distance between the source and the recipient increases or decreases, owing to the motion of either or both, the rapidity of the vibrations varies inversely as the distance. The whistle of a receding or approaching locomotive engine is commonly cited as an illustration of this fact, which also may be proved by moving a sounding tuning-fork from or towards the ear.

**21.** The present average pitch of *a'* in England, may be estimated at from 450 to 452 vibrations in a second. Further details of this subject will be found in chapters VIII. and IX.

**22. The Length of the Sonorous Wave** caused by a sound of a given pitch, may be found by dividing the number of feet through which the sound passes in a given time, by the number of the vibrations performed in that time. The velocity of sound in air at a temperature of 53.6° Fahrenheit, is about 1113 feet in a second, hence a sound with 452 vibrations in that time, and at that temperature, causes an aerial wave of nearly 2 feet 5.55 inches in length.

**23. Audibility of High Notes.** The sense of perception with regard to notes of high pitch is extremely variable in different individuals. As an instance of this, the following experience of my own may be found interesting. I was walking one fine summer evening, through Battersea Fields, the site of the present Battersea Park, with a friend who drew my attention to the chirping of the grasshoppers. I had not noticed it, but on listening attentively, I found that I could hear an occasional note, while he heard, as he said, "quite a concert." After careful comparison we found, as I had expected, that he was able to hear much higher notes than I, and that the only sounds audible to me were a few of the comparatively low ones. Dr. Wollaston, in *Philosophical Transactions* for 1820, and Professor Tyndall (1883) have described similar incidents.

The most extraordinary case of limited capacity in this respect, that ever came under my notice, was that of an amateur pianoforte-player, who was utterly deaf to all sound higher than $g''$.

**24. Sound appreciated by Deaf Persons.** While we hear of many persons, supposed to be in full possession of the sense of hearing, who are unable to hear extremely high sounds, we have, on the other hand, many instances of the appreciation of musical pitch by persons considered to be deaf. Athanasius Kircher (1650) and Johannes Mueller (1840) mention cases of persons reputed deaf, and really so as regarded aerial vibration, being able to *feel* musical sounds, which were transmitted to them by means of the actual contact of parts of their bodies with the sounding instrument or with some solid body in connection with it. I recently heard of a well authenticated instance of a deaf man who was able to tune a church organ.



**25. Range of Musical Instruments.** Most persons are able to hear all the notes employed in music, if not to estimate exactly the pitch of the very highest. Savart's grave note, which would be rather more than two octaves below the $C_{,}$ of our present pianofortes, and which would have, in air at a temperature of 53.6° Fahrenheit, a wave length of about 139 feet 1.5 inch, as also the exceedingly acute sounds given by certain insects, which probably extend many octaves above the highest note of the pianoforte, far exceed the limits of musical instruments. These range from the $C$ of the largest organs, with nearly 16.8 vibrations in a second, at our present English pitch, and a wave length, at the before mentioned temperature, of about 66 feet 3 inches, to the $c'''''$ of the piccolo, with nearly 4300.2 vibrations, and a wave length of about 3.1 inches. These extremes embrace eight octaves, but not more than seven octaves are in general use, and these are included in the compass of the modern pianoforte.