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contrasted with exact thirds, the harmonic seventh compared with other forms of minor seventh, and numerous other theoretical results reduced to practical knowledge.

Of the applications of the various systems, I will only say that in my opinion it is a mistake to apply ordinary music to them indiscriminately. Just systems especially, which have both thirds and fifths nearly perfect, must be studied and written for before they can be used with advantage. I need hardly say that I think, when this is done, the advantage will be great.

Dr. Guthrie here took the chair.

The CHAIRMAN: I am sure you will all thank Mr. Bosanquet for his communication, and I am sure we are very glad to hear that there is some practical prospect of this very desirable end being brought about. We have now the subject of the limits of audible sounds, and if Dr. Stone will introduce the subject, I hope Mr. Galton will illustrate it by one or two practical results.

THE LIMITS OF AUDIBLE SOUND.

Dr. STONE: At the risk of the accusation of irrepressibility perhaps you will allow me to occupy one or two minutes in the way of the Roman nomenclator of old, to start a subject rather than to complete it. I wish to mention the limits of audible and musical sound. Of course we have them both above and below, at either extreme. We have, also, I am proud to say, a very fine collection of illustrative instruments in the exhibition, and I would name three at the upper limit and three at the lower. The first is a curious instrument of Mr. Griesbach's which is interesting, not only on account of the perfect way in which he illustrates the upper limits of audibility, but because he contrived it so as to show many principles of musical sound which are considered to be of recent discovery. This is the instrument. It is to all intents and purposes a small organ with a key-board, the pipes of which are exceedingly small. They look rather long, but the greater part of the pipe is foot, and the real acting part is very short indeed. Here is a note which would astonish modern pianists to play. It is so

fine that I am afraid you will not hear it. Here is the semitone below it on the same scale, and although many persons are not able to hear these pipes separately, yet the resulting tone produced by blowing two together is perfectly audible to most people. This was made many years ago, and it is historically interesting as being an anticipation of modern research on the subject. Among the many discoveries of Professor Wheatstone was one of this kind. He produced the same effect by using two very small harmonium reeds; reeds of the same kind are here in this small box. These are made by Mr. Griesbach, but as to priority between the two I am unable to speak. Unluckily, that is the condition of these small reeds also: they are unable to speak, but there they are. Time has damaged them, but the same things were certainly contrived as early, if not earlier, by Professor Wheatstone. Then as to the lower limit of sound. Helmholtz may have erred from erroneous information given to him, and perhaps the appreciation of musical sound might be rather different in other persons than those he had to experiment with. I believe he is a violin player, but I do not think he pretends to be a musician of a practical kind. He says the deepest tone of musical character which can be heard is about forty-one vibrations in the second, in the upper half of the thirty-two feet octave he says the perception of the separate pulse is clear, but practically he does not admit that you can get any musical note below E or F on the common German double bass. Now what seems to be wanting, if I may use the term, in these investigations, is that the mass upon which he experimented was rather small. He used pianoforte strings weighted with a kreutzer in the middle. That is a very feeble source of sound. If we are to produce these low tones, the amplitude of the vibrations must be enormously increased. Whether he has quite utilized the effect of a consonant body or of a resonant case, on a vibrating string, to the extent to which it might be done, is a point on which I have some little doubt, because it has been done here. Here is Elliott's apparatus, originally invented by Chladni, a sort of wand passed through a slit. This Helmholtz alludes to, and declares it produces a false result, because the upper partial tones are very strong compared with the fundamental. No doubt they are. I should be delighted to find him correct, and he is probably speaking only of simple pendular vibrations such as you get in the lowest stopped diapason pipes of an organ; but if this is what he means by saying that you cannot hear simple pendular vibrations below forty-one, he is simply saying that you cannot carry the stopped diapason down below forty-one vibrations, a much less extensive statement than to say that the ear cannot distinguish sounds below that. As a matter of fact, all the extreme bass instruments we make use of, perhaps unfortunately, have the upper partials very strong; strong compared to the foundation note, but you can intensify the fundamental note by certain contrivances, especially those of consonance. On this I have spent a great deal of time myself. I have tried on a double bass. The double bass has been often before made to produce very low notes, and there is one, quite gigantic, on the other side of the building, which requires giant to play it; the present race of pigmies had to stand on a a table. It produces a very fine tone in the low notes, but it would not suit this generation; it needs sons of Anak to play upon it. Other attempts have been made to produce the low tone, by making the strings thicker; but then you cannot get at the centre of gravity of a cylindrical string; you must strike at the outer circumference, and these large strings rotate and produce false notes, not at all the tone that is wanted. There remained one thing which had not been done, and that is to work by weight. By covering the string very heavily with copper wire, and placing it on the double bass, I succeeded in getting a sound which I thought satisfactory. The tone contains a great predominance of 16-foot vibration. I had to strengthen the double bass very considerably by what I term elliptical tension bars, so as to give it, in the first place, force enough to resist the enormous pull of this heavy string, and secondly to give it a sound-conductor. There was already a bar from end to end which tended to counteract the dumbing effect of the "S" holes, which are necessary, however, for letting out the air vibrations. If you will permit me to add presently to my unmusical illustrations, I think I can obtain a note from the double bass, which you will say is musical. Another attempt was in the wind department. We have here an instrument which some of you may know I habitually play, especially with Sir Michael Costa's orchestra. I played it the other night at the Albert Hall. It is a reed instrument of 16 feet in length, the octave

of a bassoon. It is not a new instrument, but it is on a new scale This, as I hope to demonstrate afterwards, brings out the CCC, the lowest note of the 16 feet octave, with a tone which you people may call musical or not, but I think it is. At any rate it is not wanting in power or in intensity. I have intentionally omitted to speak of one excellent set of investigations on the upper limit of musical sound, because Mr. Galton, the author, is here present himself, and will explain them.

The CHAIRMAN: I have to ask you to again express your thanks to Dr. Stone for these few supplementary remarks; but I think before we have any discussion on these communications, we had better complete this branch of the subject, and I will therefore call on Mr. F. Galton, F.R.S.

Mr. GALTON: I thought it would be of convenience to experimenters, that I should exhibit some little instruments I have combined for ascertaining what the upper limits of audible sound may be in different persons of the same race, and in individuals of different races, and in different kinds of animals. It is, of course, a matter of great interest to know whether insects and such small creatures can hear sounds, and can in any sense of the word, converse in language which to our ears is utterly inaudible. When I first devised to make experiments, I was checked by the great difficulty of finding instruments that vibrated with sufficient rapidity for the purpose in question. Dr. Wollaston (to whom we are indebted for the first experiments ever made on this subject, and for the fact that vibrations exist which the ear is incompetent to seize and render into sound) found very great difficulty in making his small pipes. I tried several plans for obtaining acute notes, and the one I finally adopted was this: I made a very small whistle, whose internal diameter was much less than one-tenth of an inch—I have many such here, made for me by Massrs. Tisley and Spiller, Opticians, 172, Brompton-road, —with a plug at the bottom, which plug is screwed up by a graduated screw. The graduations are marked on the side, so that when you use the instrument you know the depth of the tube, and knowing what that is, it is a matter of calculation to learn the rate of vibration. There is, however, a good deal of uncertainty in the matter, because there must be some fair proportion between the length and width of the tube in order that the calculations should give a correct result. A short whistle with a diameter exceeding two-thirds of its length, will certainly not give a note whose shrillness is governed wholly by its shortness. Therefore in some of my experiments I was driven to use very fine tubes indeed, not wider than those little glass tubes that hold the smallest leads for Mordan's pencils. It occurred to me, in order to produce a note that should be both shrill and powerful, and so correspond to a battery of small whistles, that a simple plan would be to take a piece of brass tube and flatten it, and pass another sheet of brass up it, and thus form a whistle the whole width of the sheet, but of very small diameter from front to back. I have such a whistle here, it makes a powerful note, but not a very pure one. I also made an annular whistle by means of three cylinders, one sliding within the other two, and graduated as before. I find that when the limits of audibility are approached, the sound becomes much fainter, and when that limit is reached, the sound usually gives place to a peculiar sensation, which is not sound but more like dizziness, and which some persons experience to a high degree. I am afraid it is of little use attempting to make the audience hear these small instruments; but I will try, beginning by making rather a low note. It was found that there was great variability in the audience, in their powers of hearing high notes, some few persons who were in no way deaf in the ordinary meaning of the word, being wholly insensible to shrill sounds that were piercingly heard by others. I find that young people hear shriller sounds than older people, and I am told there is a proverb in Dorsetshire, that no agricultural labourer who is more than forty years old, can hear a bat squeak. The power of hearing shrill notes has nothing to do with sharpness of hearing, any more than a wide range of the key-board of a piano has to do with the goodness of the sound of the individual strings. We all have our limits, and that limit may be quickly found in every case. The facility of hearing shrill sounds depends in some degree on the position of the whistle, for it is highest when the whistle is held exactly opposite the opening of the ear. Any roughness of the lining of the auditory canal appears to have a marked effect in checking rapid vibrations of the ear. For my part, I feel this in a marked degree, and I have long noted the effects in respect to the buzz of a mosquito. I do not hear the

mosquito much as it flies about, but when it passes close by my ear I hear a sudden "ping," which is very striking. Mr. Dalby, the aurist, to whom I gave one of these instruments, tells me he uses it for diagnoses. When the power of hearing high notes is lost, the loss is commonly owing to failure in the nerves. On the other hand we may find very deaf people who can hear shrill notes, in which case the nerves are usually all right, but the fault is in the auditory canal. I have tried experiments with all kinds of animals on their powers of hearing shrill notes. I have gone through the whole of the Zoological Gardens using a machine of the kind that I hold in my hand. It consists of one of my little whistles at the end of a walking stick, that is in reality a long tube; it has a bit of india-rubber pipe under the handle, a sudden squeeze upon which forces a little air into the whistle and makes it sound. I hold it, as near as is safe, to the ears of the animals, and when they are quite accustomed to its presence and heedless of it, I make it sound, then if they prick their ears it shows that they hear the whistle, if they do not, it is probably inaudible to them. Still, it is very possible that in some cases they may hear but not heed the sound. Of all creatures, I have found none superior to cats in the power of hearing sharp sounds. It is perfectly remarkable what a faculty they have in this way. Cats, of course, have to deal in the dark with mice, and to find them out by their squealing. Many people cannot hear any notes in the squeal of a mouse. Some time ago, singing mice were exhibited in London, and of the people who went to hear them, some could hear nothing, whilst others could hear a little, and others again could hear much. Cats are differentiated by natural selection until they have a power of hearing all the high notes made by mice and other little creatures that they have to catch. You can make a cat, who is at a very considerable distance, turn its ear round by sounding a note that is too shrill to be audible by any human ear. Small dogs also hear very shrill notes, but large ones do not. You may pass through the streets of a town with an instrument like that which I used in the Zoological Gardens, and make nearly all the little dogs turn round, but not the large ones. At Berne, where there are more large dogs lying idly about the streets than in any other town in Europe, I tried this method for hours together, on a great many large dogs, but could not find one that heard it. Ponies and cattle, too, are sometimes able to hear very high notes—much more than horses; I once frightened a pony with one of these whistles in the middle of a large field. I can produce no effect on ants, nor on the great majority of insects, though there are some apparent exceptions about which, however, I am not yet prepared to speak.

The CHAIRMAN: I am sure I need not ask you to thank Mr. Galton for his very interesting remarks. Time is getting on, and I will now invite those who have anything to say upon the general subject of Just Intonation and the Limits of Audible Sound to do so. There was only one remark which occurred to me specially during Dr. Stone's last communication, and that was the able way in which he pointed out the bearing which the mass of the air which is set in motion has upon audibility. It has nothing to do with wave-length or wave amplitude but with the quantity of air, which you may compare to the end-length of sea waves. That seems to have great power and effect on the auditory nerves. Perhaps the lowest audible note which we have heard, at least, is that which you hear when you are outside a tunnel, and you hear the actual throbbing of the piston of the engine. You have an immense mass of air in the tunnel set in vibration. It has nothing whatever to do with the length of the tunnel; it does not act as an organ pipe establishing stationary waves, but you have an immense mass of air set in deliberate motion with slower vibrations even than sixteen in a second, and the sound is perfectly audible.

Mr. ALEX. J. ELLIS, F.R.S.: I only wish to say a few words with regard to the experiment of Helmholtz which was alluded to, for trying to determine the lowest limit of tone. His object in operating on a piano string loaded with a kreutzer was to render the upper partials inharmonic to the fundamental, so that he should be quite sure that he heard a simple pendular vibration. His object was to determine the lowest audible limits of such vibrations. The subject is one which has been very recently investigated, and accounts of the experiments have been given by Professor Preyer, of Jena, one of the members of the general committee. There are the pipes here which he experimented upon. He found that the best way to hear these sounds, was to obtain them first from a reed attached to a pipe, and then to shut off the air, and listen to the tone as it vanished, when he heard the fundamental or lowest tone quite distinct from all the others, as a simple pendular vibration. As the result of a great number of experiments he found that ears differed very much as to what was really a musical tone, defining that to be one in which we hear no throbs, but only a continuity of sensation. He has also published a work on the limits of sensational power, and, in fact, that was his great point, to determine the limit of continuity of sensation. He found that he himself could hear continuous tone from as few as 14 vibrations to the second, but that most ears perceived sensation to be continuous when the number of vibrations reached 23. Therefore, somewhere between 14 and 23 vibrations must be fixed as the lowest limit of continuous simple pendular vibrational tone produced in the human ear, as far as it has yet been investigated. He also has gone very much into the question of the upper limits of tone, but his especial investigations were to determine the smallest amount of error in a melodic interval, which the most practised ears could hear. For this purpose he made use of some of these instruments of Herr Appun, of Hanau. There is one which gives a complete series of partial tones up to the 32nd, and there is another one in the next room which gives tones from 128 to 256 vibrations, proceeding by two beats at a time. With that instrument Herr Preyer experimented, and the investigation has a very important bearing on the method of representing just intonation by means such as that of Mr. Bosanquet, who uses an approximative scale, obtained by dividing the octave into 53 equal parts, which I consider to be really perfect enough. I have not calculated all Herr Preyer's results out completely, but I may state that no ear seems to detect an error in an interval melodically—not in a chord—which amounts to the hundredth part of an equal semitone, but that the fiftieth part (double that) may be detected by very fine ears indeed. With regard to just intonation and key-boards, I may say that key-boards like Mr. Brown's and Mr. Poole's (which is very good if we reject the natural sevenths), go upon the principle of carrying out a series of tones proceeding by perfect fifths, in three columns, so to speak, each column being a comma lower than the preceding. Guéroult uses only two. Guéroult and Helmholtz's plan is the one Dr. Stone said I wanted to simplify, using a single key-board by means of compound stops, and that was the instrument which was to have been exhibited; but he was a little in error. That instrument was one with single, not compound, stops, and was intended to exhibit the old organ tuning continued so as to play 21 notes to the octave. It was invented by Mr. T. Saunders, who subsequently declined to exhibit it. But the principle of Helmholtz's and Guéroult's instruments is to have two rows of 12 notes forming perfect fifths, one row being a comma flatter than the other. This would give the full succession of major keys, but only five minor keys complete. The other minor keys are quite imperfect, whereas with Mr. Bosanquet's instrument which, although it has only 53 tones to the octave, has actually 84 finger-keys to the octave, so as to be able to go round and round, all the keys, minor as well as major, are practically perfect. This instrument is really almost as simple to play as an ordinary harmonium when you understand that the major thirds are taken in a series below, and the minor thirds in a series above; whilst the oblique arrangement of the finger-keys obviates the necessity of jumping from one row to another and allows of playing each scale in one line. I consider Mr. Bosanquet's arrangement to be the acme of perfection in this respect, and I do not think that we are likely to arrive at anything which is simpler. I hope Mr. Bosanquet will give us an opportunity of hearing some of the effects of it afterwards, because until persons have heard music played in just intonation they cannot at all appreciate what it is that persons want to obtain as contra-distinguished from that which we are generally obliged to hear. I had an opportunity only last Christmas of hearing a well trained and educated choir of the Tonic Sol-fa College, accustomed to sing in perfect intonation, and, when they were singing unaccompanied, the chords in just intonation were perfectly divine, but when they sang immediately afterwards to a pianoforte which was almost inaudible, the chords were all torn to pieces in such an extraordinary way by the accommodation of the voices to the instrument that it was perfectly painful to listen to them. With regard to the upper limits of audible tone, although I am rather an old boy, I may say that I heard all the high tones produced by Captain Douglas Galton perfectly.

The late Sir Charles Wheatstone's Acoustical Discoveries.

Professor W. G. Adams, M.A., F.R.S.: If I were to speak of all the instruments—or even of all the musical instruments—which may be connected in some way or other with the name of Sir Charles Wheatstone, I am afraid I should occupy a very considerable time, weary you, and shut out those who have to come after me; but I propose to draw your attention to three classes of instruments with which Sir Charles Wheatstone was specially connected. First of all, if we consider the vibration of reeds, we may start from the very ancient instrument the Marimba, which has iron rods fixed into a sounding body in the same way as the iron fiddle, which consists of rods fixed at one end to a sounding board; from the iron fiddle, by lengthening the rods, we get to the kaleidophone, which is so well known, and the figures traced out by which are so familiar, that it will not be necessary for me to describe them in detail. If we take a cylindrical rod with one end fixed, and cause it to vibrate, being cylindrical, it will vibrate transversely at the same rate in all directions, but it may be put in vibration so as to give not only a simple figure, the ellipse, circle, or straight line, but by dividing it by nodes or points of rest into separate vibrating segments we may get also the super-position of the partial vibration figures combined with the original simple figures.

The simple figures are obtained by causing the rod to vibrate as a whole, and the partial vibrations are obtained by producing one or more nodes on the rod. The ratio of the number of partial vibrations to the number of fundamental vibrations is given by the number of indentations produced in the original figure traced out by the free end of the rod. The number of vibrations when there is one node on the rod is about $6\frac{1}{4}$ times the original number of vibrations of the rod when it vibrates as a whole. With one, two, three or more nodes the number of vibrations is as the squares of the second, third, or higher odd numbers. No. of nodes, 1, 2, 3, 4, &c.; No. of vibrations, 9, 25, 49, 81, &c. With a rectangular rod, when its section is a square, the curves traced out are the circle, the ellipse, or the straight line,