Science Lectures at South Kensington.

SOUND AND MUSIC.

BY

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WITH ILLUSTRATIONS.

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LECTURES TO SCIENCE TEACHERS.

INSTRUMENTS FOR EXPERIMENTS ON SOUND.

LECTURE I.

It is my intention to speak this morning on certain modes of eliciting, reinforcing, or distributing sound. Of course we cannot go into every such method—it would be impossible within the time allotted. What, therefore, I propose to consider are the more scientific modes, which are not exactly musical, but such as are employed for experimental and computative purposes. The excellent classification given by Professor Clerk Maxwell in the handbook of this Exhibition will be my guide. He speaks of vibrations and of waves; taking first amongst such vibrations the physical aspect of acoustics.

Vibrations and Waves.

Physical Aspect of Acoustics.

1. Sources. Vibrations of various bodies.
    - Air.—Organ pipes, resonators and other wind instruments.
        - Reed instruments.
        - The Siren.

	Strings	Harp, &c.
	Membranes	Drum, &c.
	Plates	Gong, &c.
	Rods	Tuning-fork, &c.
2. Distributors.	Air	Speaking tubes, stethoscopes, &c.
	Wood	Sounding rods.
	Metal	Wires.

3. Pugging of floors, &c.
4. Reservoirs. Resonators, Organ Pipes, Sounding-boards.
5. Dampers of pianofortes.
6. Regulators. Organ Swell.
7. Detectors, the Ear; Sensitive Flames, Membranes, Phonautographs, &c.
8. Tuning-forks, pitch-pipes, and musical scales.

Now of these we shall consider to-day principally monochords, tuning-forks, and sirens under the former head, that of eliciting; in the second place, that of reinforcing and distributing, resonators of various kinds and telephones. The latter perhaps might have been more distinctly specified in the title of the lecture, as what Professor Clerk Maxwell terms distributors. Before, however, adverting to the means of eliciting sound, we can hardly avoid mentioning something as to vibration in general. We find it proceeding from ordinary pendular vibration up to the most delicate vibration of ether on which rests the fundamental hypothesis of light, and we can observe this vibration in various ways.

A very ingenious instrument is here contributed from abroad which enables you to combine one or more harmonic motions. The string is strained between two elastic terminals, both of which by means of electro-magnets can be set into oscillatory motion. By putting the first alone into motion we get single vibration; by joining and coupling up with it that at the other end, which can be rotated round its axis, we can combine another harmonic motion, either in the same direction making complex vibrations, or at right angles, or indeed at any given angle; thus compounding it into various regular figures, ellipses, circles, and other curves such as were produced by Lissajous.

Taking this end of the vibrating string first, I bring the battery in connection; then straining the string to the right tension you will see very distinctly that it is vibrating in two segments forming a node at the middle point. The string is studded with small white points to enable it to be seen. Now if I put on the second magnet at the other end, joining it into the same circuit, and combine the vibrations of those two, the figure becomes much more complicated. There are three or four ventral segments, two different vibrations being thrown into the string at the same time. I can compound them still more by turning the second magnet round upon its axis and setting them in two rectangular directions. A beautiful elliptical figure is formed here by the vibrations in a horizontal direction at one end and in a vertical direction at the other. This apparatus shows the vibration of a string; I will next demonstrate another means of combining the vibrations of reeds. This is a very pretty contrivance, contributed by Mr. Pichler, who kindly comes to assist me in exhibiting it. The instrument consists of a wind-chest with means of blowing, above it there are two reeds; one fixed in the vertical and the other in a horizontal position; by shifting the bearing of one reed it can be made to double its length, so that the vibrations shall be to each other in any ratio from that of unison down to an octave below. We can pass through all the intermediate figures. On each reed is placed a small mirror, and here is a limelight, the beam from which falls first on the mirror of the upper reed, it returns and is reflected on the second, whence it is thrown on the screen. Whilst the mirrors are still, the spot of light on the screen is motionless; when we set them vibrating, the one in a vertical direction gives a vertical line of light, when the other in a horizontal direction is added they combine their two harmonic motions and give beautiful curves, which I have already named. The circle denotes unison; the varied figures are produced by varying phases and velocities at the two reeds.

Strings were the earliest sources of sound and were the first used for acoustical experiments; indeed, in ancient Greek times determinations were made of the laws of sound from strings, which are generally attributed to Pythagoras, though Mr. Chappell in his erudite work concludes that Pythagoras's information came originally from Egypt or even can be traced back to Babylon. At any rate, by Euclid's time a very perfect knowledge of the laws of strings had been attained. Euclid wrote a work called *Sectio Canonis*, the division of the string or monochord by which all these ratios are obtained.

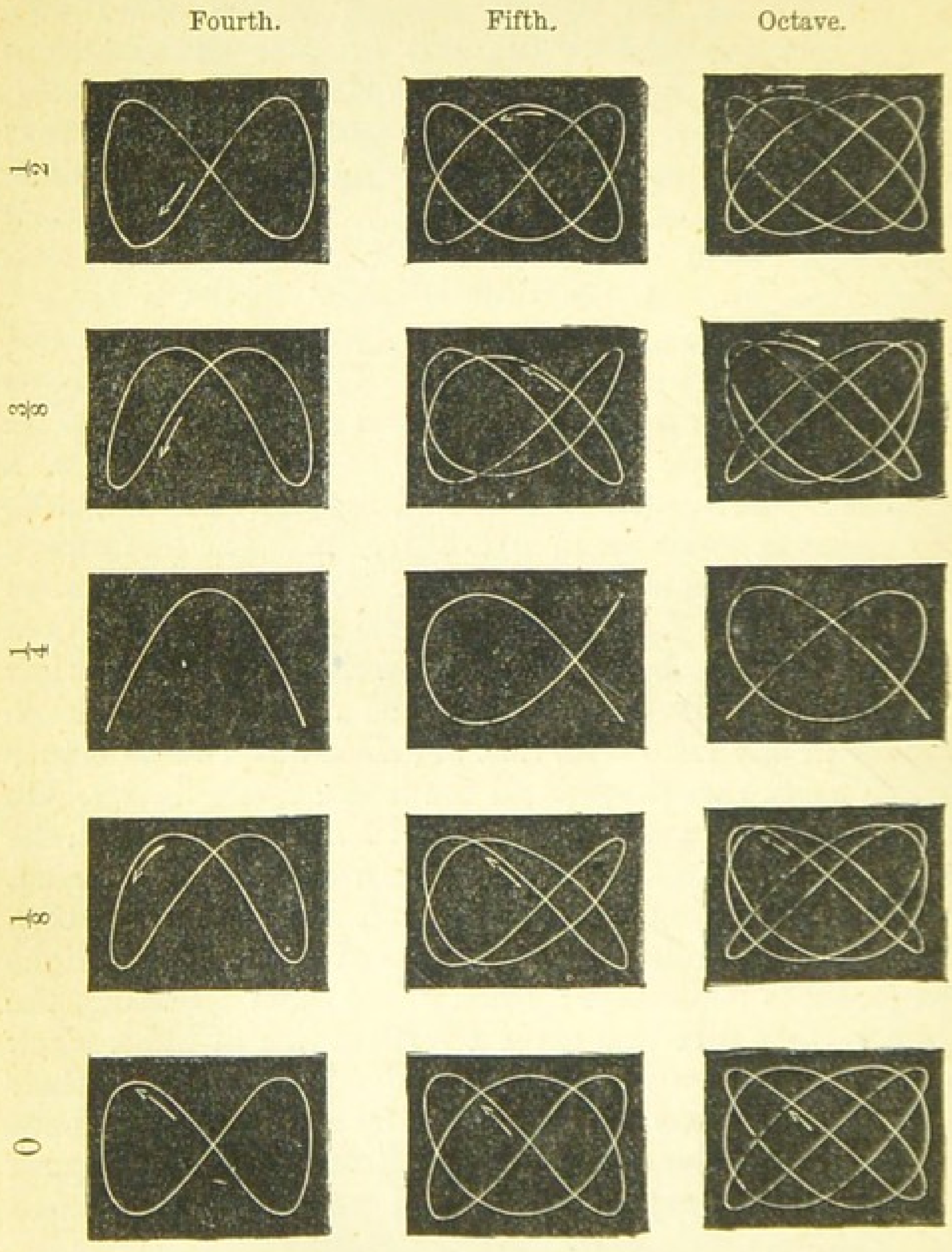

FIG. 1.—Optical curves. The octave, fourth, and fifth.

From this time we have a long gap until we come to the age of Galileo; but even in Greek times the simple ratios and parts of the string were well known. I have placed these on a diagram there just as a reminder, because we shall have to speak again to-morrow of a different form of numerical calculation not involving ratios; to-day I wish to bring before you the ratios and nothing more. You can see how these ratios would have produced by a geometrical method those beautiful figures projected on the screen. The principal ratios are:—

the octave	2 to 1
fifth	3 ,, 2
fourth	4 ,, 3
major third	5 ,, 4
minor third	6 ,, 5
major tone	9 ,, 8
minor tone	10 ,, 9
major semitone	16 ,, 15

I have also written down in small figures below (I do not wish to confuse you with them to-day, as I shall have to say more about it to-morrow), the ratio of the comma, a computational interval, 81 to 80: this at present I will pass over.

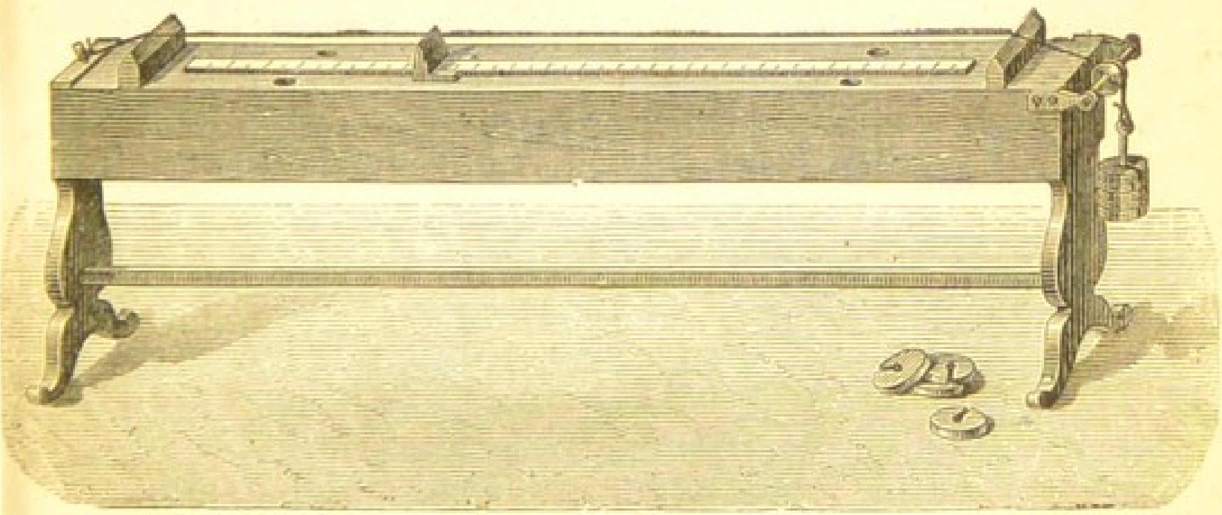

FIG. 2.—Monochord.

I will now proceed to show the monochord and the different ways of using it. There is in the South Kensington Museum an old monochord by Broderip and Longman, which was intended for persons to tune their harpsichords. It consists of a small string with definite marks placed under it to which you can set a fret or stop to check the vibrations. There is also a little harpsichord "jack" by the side, a piece of quill, the predecessor of the pianoforte hammer, by which the string was plucked. Here I have a monochord a metre long divided into decimetres and centimetres with bridges at the end and pegs by which these strings can be strained, either by twisting wrest pins, or by adding weights. Now adding weights is very much the better plan for experimental purposes, and it was the plan employed by the father of all enharmonic instruments, Col. Perronet Thompson, whose organ is exhibited in the Loan Exhibition and of which I propose to speak to-morrow. Weights have a great advantage in a monochord, because the raising of the note of the string is not in simple ratio to the weights you add, but in that of their square. For instance, if I load the string with a certain weight, two of these separate blocks, and then add two more I do not raise it to its octave or anything like it. The advantage, is that accidental variation in the stretching weight causes only a comparatively small error. A monochord of this kind was used by Perronet Thompson for tuning the pipes of his enharmonic organ. He chose stouter wire and very heavy weights, sometimes more than 250 lbs. since the best steel wire will stand that weight; against the notes so produced he cut the pipes of his organ the right length by getting unison. Some considerable time ago, an ingenious gentlemen of the name of Griesbach carried this contrivance of the monochord still further. He not only measured the ratios of tones but contrived a method of drawing and printing them; this instrument we have in the Exhibition. We have also several smaller monochords of Mr. Griesbach's. Here is one with a scale of aliquot parts very elaborately made to measure. Here is a string with fixed points upon it by which the tempered scale of the octave can be accurately obtained. It is an independent reproduction of Broderip's instrument. I wish to call your attention particularly to this large instrument. It has a double-bass string, stretched along this bar of wood, with a sounding box, and there is a means of tightening it by a screw. Here is a very ingenious rotating bow; somewhat damaged by time, but of which the principle can still be seen. A piece of vulcanized India rubber is covered with horsehair and then, being passed by means of rollers over the string, it gets rid of the great difficulty experienced in using strings for tuning, namely, the evanescence of their tone. It is curious to see later discoveries anticipated by an ingenious man whose labours have been somewhat overlooked. He did more; here again anticipating modern instruments, he placed a paper and a tracing point, with blackened tissue behind, so that when the string vibrated, the point pressed against the paper and produced curves. You thus can not only measure the string and get the ratios, but you secure permanent vibrations by means of the rotating bow, and you can also print them off on a strip of paper which travels slowly in front by means of the hand or as here, by means of a weight, so as to bring it gradually past the vibrator.

There are other modes of exciting strings besides striking them, such as by bowing; of course many instruments act in this way. For observations of an acoustical character bowing is not so good; it is apt to produce partial vibrations. We may also excite strings by the impact of the air. There are specimens of struck strings in the pianoforte actions which are exhibited. Bowing you are all probably familiar with. The impact of air, if not entirely a new discovery, has only lately been put to practical use. I do not propose to go into it to-day, because my friend Mr. Baillie Hamilton will deliver a separate lecture upon what he terms "æolian" modes of producing sound, in which the combination of a string with a reed brings out new and beautiful characters of tone. Strings when struck produce many upper partial tones, according to the place where they are struck, according to the nature of the stroke, and according to the density, rigidity, and elasticity of the string. I must refer you to Helmholtz's great work for further details on that point; only noticing what pianoforte makers have discovered by experience, and what Helmholtz has explained theoretically, that if the hammer strike the string in the pianoforte at about one-eighth or one-ninth from one end certain dissonant upper partial tones are excluded and a much finer effect is secured. The second form, of bowing the string, as illustrated in violins and other instruments, was examined by Helmholtz by means of what he terms the vibration microscope, an ingenious plan for producing to the eye of a single observer exactly what I have shown you on the screen. He sets a string into vibration, fixing a small grain of some white substance, generally starch, on it, and looks at it through a microscope which, instead of having a fixed object-glass, has the object-glass mounted on the prong of a tuning-fork. That tuning-fork is made to vibrate in the transverse direction to the string. Here again we have the same composition of harmonic motions which I have already shown you, one instrument deflecting the ray laterally, and the other vertically; so you get regular figures, which become steady when unison or concord is going on, but which flicker into innumerable changing lines when dissonance is present. In this way he was enabled to analyze the vibrations of a violin string in motion, and remarked that regular figures, free from jumps, starts, and abrupt changes—smooth vibrations, in fact, such as you saw just now—were more easily obtained from fine old instruments than from raw modern fiddles. This is very curious, because it has always been a great question of doubt and difficulty why old violins produce so much finer tone than modern ones. I have endeavoured myself to utilize this observation of Helmholtz by rendering the soundboard of the fiddle more homogeneous. Here is an instrument to which the contrivance is applied so as to get the sound transmitted more nearly like that of a fine old instrument. I cannot go fully into the question of tension bars, but I find better effect is produced by putting strengthening bars along the belly of the fiddle, so as to make it more homogeneous without adding materially to its weight. Helmholtz also found that the interior of an old fiddle adds resonance by the body of wind it contains; I have here an old violin, and an old tenor; if we blow into the body as into a wind-chest we can repeat his observation; we can use it, in fact, as a sort of whistle or organ-pipe; of course it gives a rough note, but still you can hear the pitch of it. The tenor is rather clearer, and there is quite the difference of a tone between the two. The result of Helmholtz's experience was that a Straduarius violin gives C, tenors a note lower, and violoncellos generally give F, or G, in the bass.

I proceed next to speak of rods, bars, and tuning-forks, which are only exceptionally used in artistic music; although there is an instrument employed by Mozart in the *Flauto Magico* to imitate the sistrum, with which Papagino is supposed to be gifted, consisting of metal bars which strike a scale of high notes—it is called a *glockenspiel*. This is only an exceptional case to produce a particular effect, but I can show you the character of such notes by means of a steel bar. If I take this bar of cast steel and strike it on one end, you hear first of all rather faintly the fundamental note such as I get by striking it across, but you hear also intensely high upper partial notes which sound very persistently, so that even in this large room it will be possible to hear an excessively high note above the range of the highest piccolo that ever sounded; and it will continue for several seconds after the blow. If the bar or rod be supported at more than one point it forms the usual harmonicon. We have here two very remarkable instruments of this character; one is on the plan of a musical-box. It is very singular that this should have been contrived so well by a half-savage tribe in Angola, that you can get a perfect scale out of it; the bars of metal are supported at one end on a resonance-box of wood, there are also feathers under them, but they are connected with some fetish superstition. Passable music might have been got out of this. Here is another which I find in the Exhibition, which may be recognized as one of the various attempts at wood harmonicons. These instruments have been formed of all sorts of things, of wood, stone, glass, and metal. A clever little boy was brought forward some years since to play what was called a "xylophone," which consisted of pieces of hard wood; on which he really performed very creditably. Then there was the "rock harmonicon" which I can remember in my early days, and the glass harmonicon you must know very well. The one I show is a wood harmonicon. It is formed by adding resonators of a very ingenious kind to bamboo blocks. One of these has unfortunately been broken in carrying it over, but that same accident enables us to look at the mechanism. The resonators are formed of gourds or calabashes, outside which is put a little ear-trumpet to act the function of the pinna of the human ear, to collect the sound; in the hollow of this I discover a small membrane, a piece of thin material resembling goldbeater's skin, intended to reinforce the sound. Here then is one of the last discoveries of Helmholtz anticipated and utilized in the wildest parts of Africa. We have other more developed forms of this instrument, such as the musical-box, which is excited by mechanism. We have the vibrating bar partially producing the sound in the Jew's-harp, and regulating the vibration of a column of air in the harmonium. The form I wish to speak of to-day is the tuning-fork.

Tuning-forks form a great portion of the experimental apparatus of acoustics. They may be looked upon simply as double rods vibrating in opposite directions, and thus dispensing with a firm fixture; because one vibration counterbalances the other. A single rod of course transmits its vibration to the support, unless it be very solid, but in a double rod this is not so. When they are struck alone like the bar of steel which I showed you just now, they give very

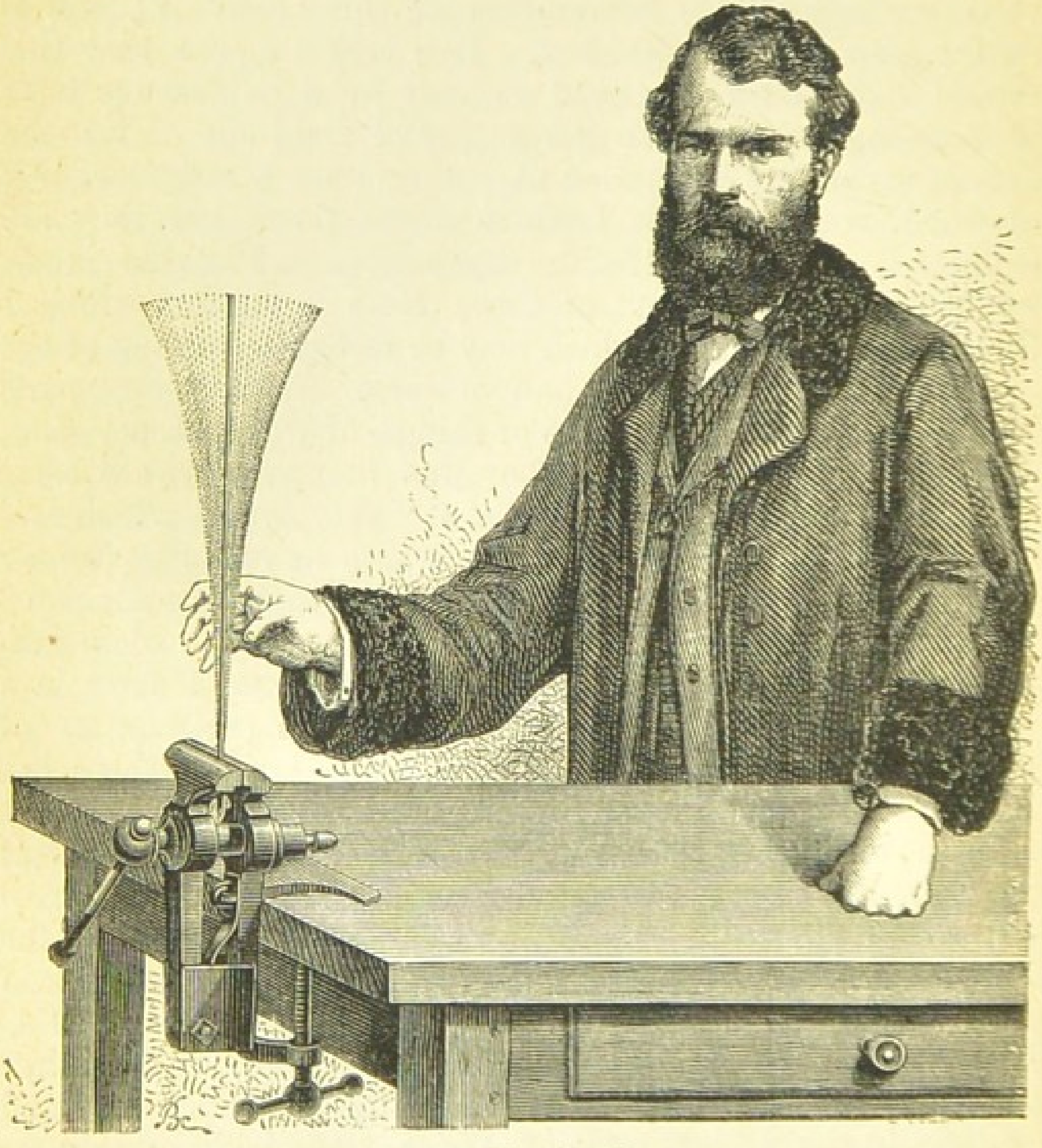

FIG. 3.—Vibrating Bar.

high secondary tones. When I hold this and strike it, you do not hear more than a high "*ping*," though there is here a slight sound of the fundamental note. This we can reinforce till it becomes of considerable value. Tuning-forks are amongst the instruments whose use has extended from sound into other branches of physics, after a pleasant fashion of reciprocity. They have been employed of late years as a measure of time; their pendular vibrations are so regular, so accurate, and so easily adjusted to any one period of vibration, that they furnish an admirable means of measuring small intervals. Here is a beautiful instrument contributed by the French *Conservatoire des Arts et Métiers*, in which a tuning-fork has been constructed for that purpose. It has little styles attached to the prongs, and as it vibrates they touch a piece of blackened paper which runs slowly past them. The tuning-fork makes an undulatory line upon it, which is the harmonic motion as it were unfolded. Another style beside the first enables you to mark any instant of time; for example, the passage of a star across the wires of a telescope, and to measure the exact period at which this took place by counting the number of pendular vibrations which the tuning-fork has made since a given period, previously marked on the paper. Acoustical instruments have also been found useful even for the measurement of the rapidity of light; the coarser form of vibration serving to measure the quicker and more ethereal. Foucault's beautiful instrument for measuring the rapidity of light is in the Loan Exhibition, and you will find that it is worked by the instrument which I shall speak of presently, namely, a small siren. He found that the best plan to make a mirror rotate at the enormous speed required, was to attach it to a small turbine or siren played by steam at a high pressure; as it rotated more quickly so the note went up. The number of vibrations is easily known from the pitch of the note; and he could thereby say how many times in a second the rapidly rotating mirror was revolving, simply by taking the pitch of the siren which was going round with it.

When tuning-forks are struck alone, as I said, they give a very feeble note, but we can alter this by combining them with some resonator. The usual resonator is a box containing a body of air; but Helmholtz has pointed out that a string can be made to perform the same function. The arrangement of the string is a little elaborate, but everybody knows the plan by which tuning-forks are fastened on a resonance-box, and the moment it touches it, it gives the tone; of that I shall speak again. The weak point musically of tuning-forks is, the very evanescent character of their sound. It is troublesome, the moment you have struck it, and are fully occupied in tuning your instrument, for the note to fade away and die out. We may partially get over this difficulty by bowing them with a double-bass bow, but the highest tuning-forks are difficult to bow, and the best plan, which has been carried to a great pitch of

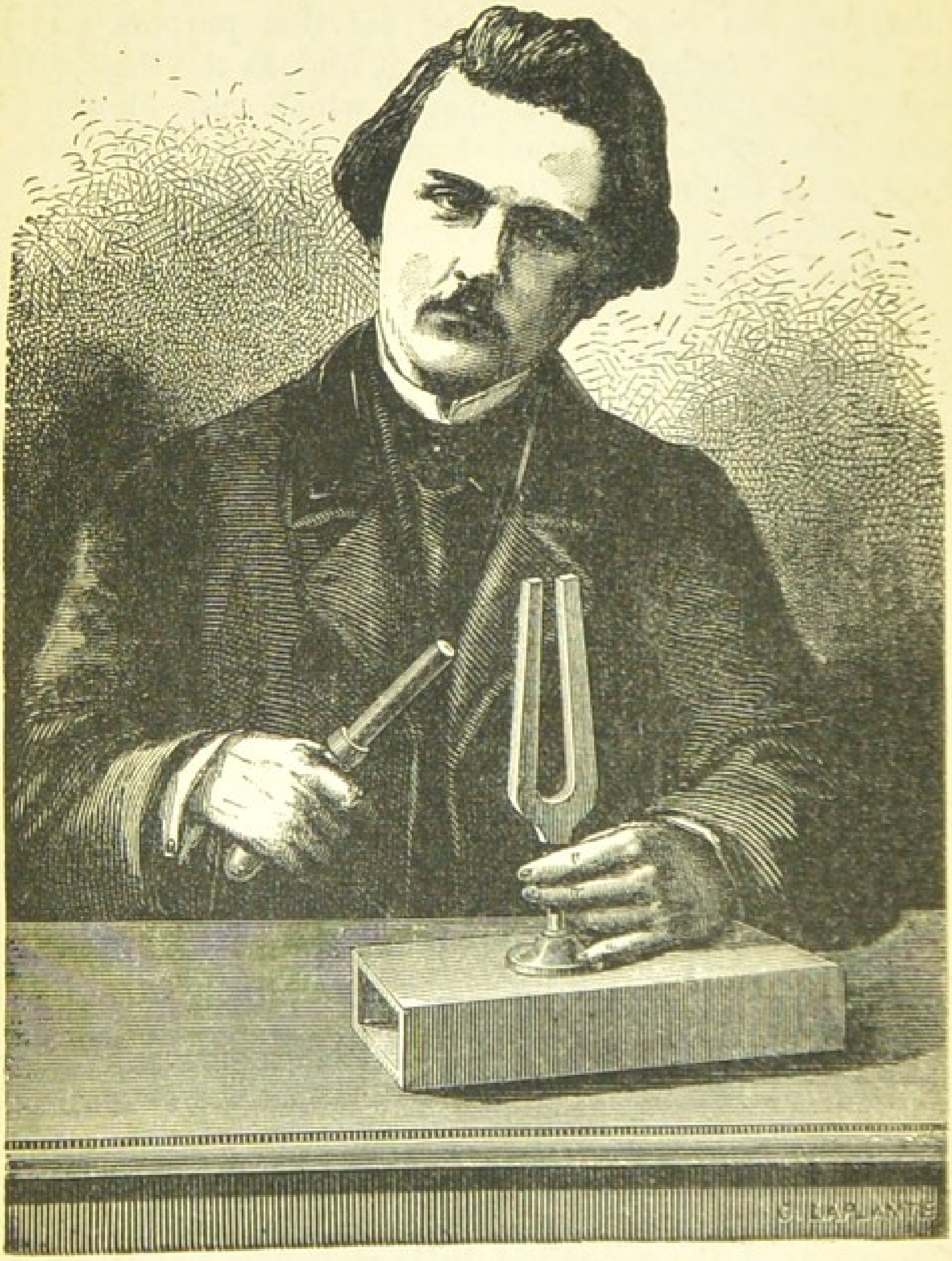

Fig. 4.—Tuning-fork on box.

accuracy by Helmholtz, is to excite them by electricity. An intermittent current is made to pass through one prong of the fork by means of a style and mercury cup, enabling the prong to close the circuit. An electro-magnet pulls by its attraction on the prong of the fork, breaking contact by so doing; a fresh contact is thus made, and so the fork is kept in permanent vibration. I have here an apparatus which I have made for this purpose; (you will excuse my mentioning that much here shown is the work of my own hands). When the magnet is formed, it separates the prong and lifts the style out of the mercury cup in so doing; the fork is now in vigorous vibration and produces a note, which at present you cannot hear, but by bringing a suitable resonator

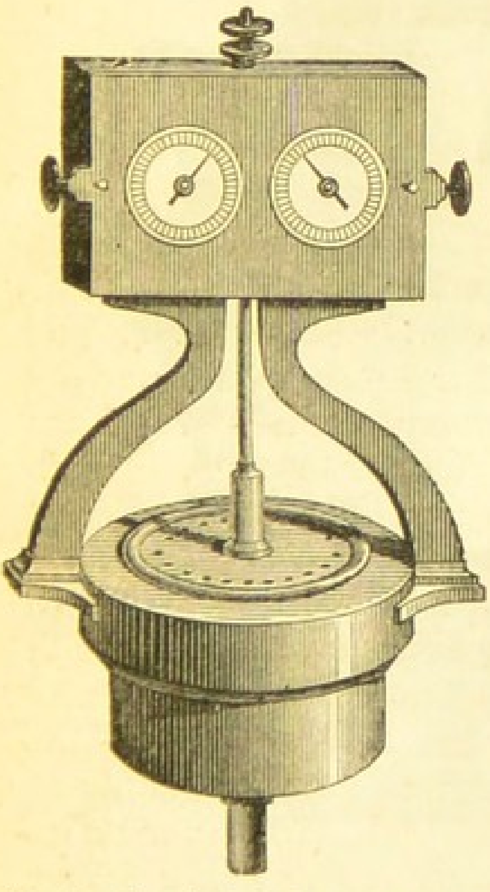

Fig. 5.—Cagniard de la Latour's Siren.

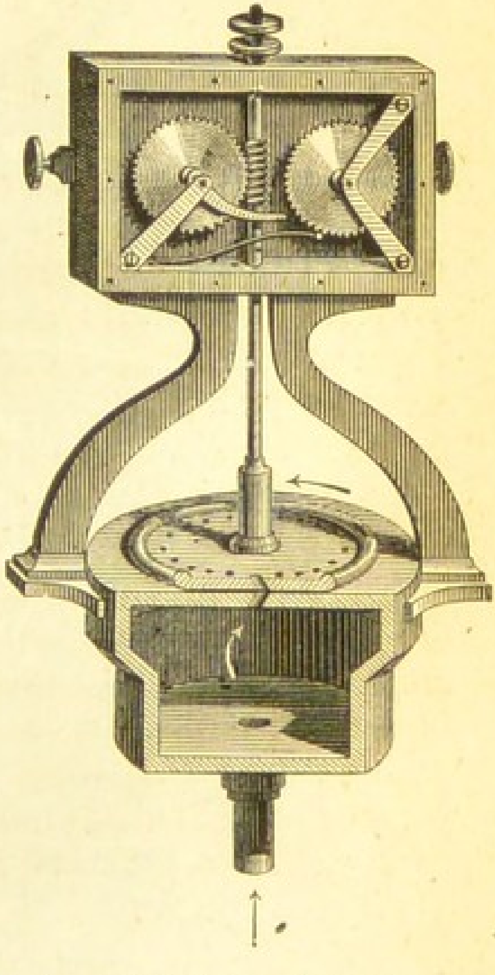

Fig. 6.—Interior view of the Siren.

to it you will hear it distinctly. In that way Helmholtz has been able to keep eight or ten forks all vibrating from one principal fork. Here is one of these principal forks, sent from Paris, having a mercury contact upon it, and there is also a series of secondary forks which have only the electro-magnet and which can be thrown into secondary vibration from this; you can thus reproduce the various vowel sounds which have been explained and demonstrated by Helmholtz.

I have next to speak of sirens. This fanciful name given to these instruments by Cagniard de la Tour, because it is said to sound under water. I never heard myself, although I have read the *Odyssey*, that those charming though dangerous young ladies named Σείρηνες did sing under water, but I believe that is the derivation of the word, and I leave it as I find it. Sirens are entirely unknown as musical instruments, though they have played an important part, not only in

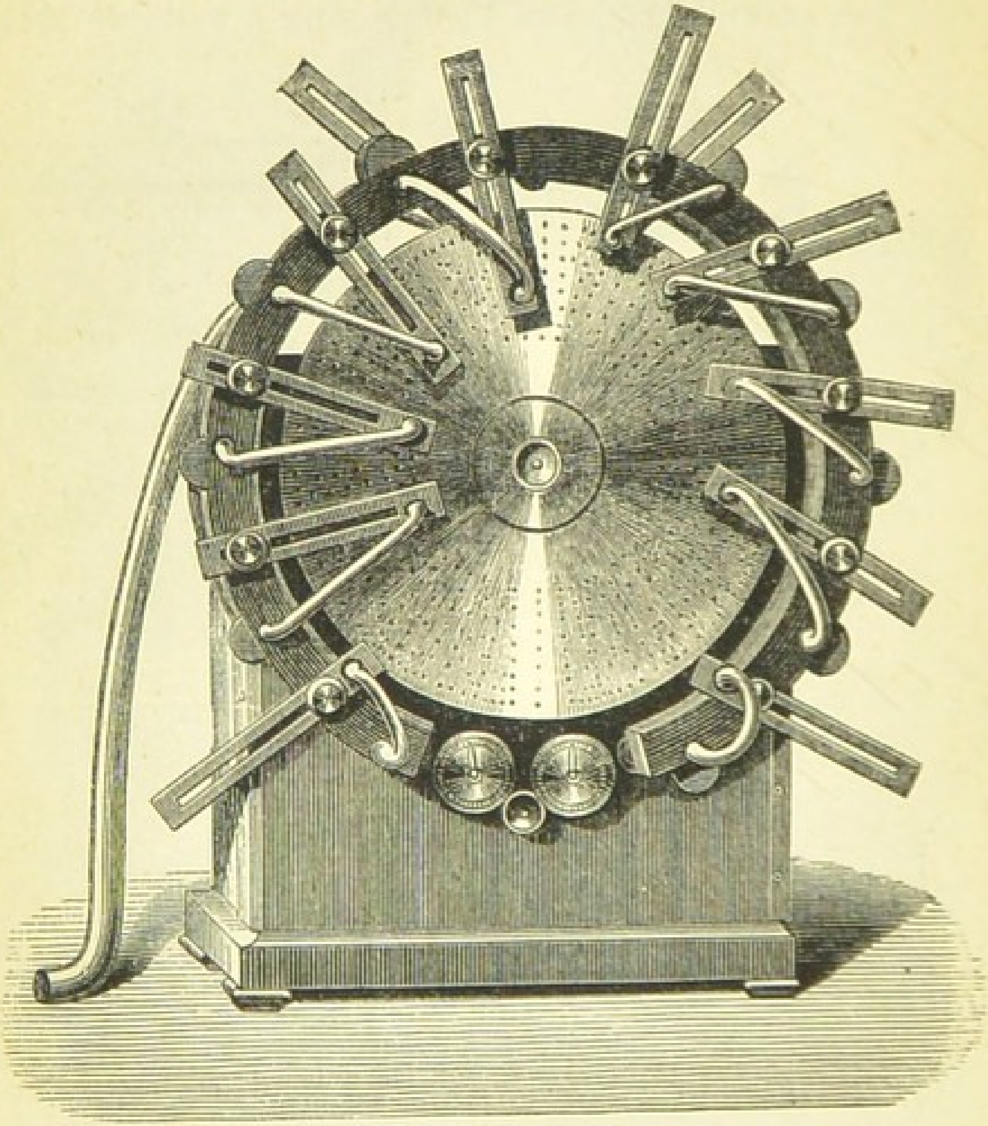

FIG. 7.—Seebeck's Siren.

acoustics, but in the investigation of light; singularly enough they are used for saving life. In going over the Exhibition galleries you will see some enormous steam sirens wherein you can study the arrangements. They are intended to be blown on the coast by means of steam, and to send out to sea a powerful sound warning mariners away from dangerous rocks. The simplest form used in the laboratory is a rotating disc of cardboard pierced with a number of holes at regular intervals. It is made to rotate in front of a small windchest in which there are keys so that a stream of air can be directed against any particular ring of holes. The form adopted by Cagniard de la Tour merely makes these holes vertical, and has a little pipe coming up. A still more perfect form is Dove's polyphonic siren, which has been perfected by Helmholtz. Here is Seebeck's siren. I make it rotate, and open the little keys, and you hear the different tones. As I drive faster the notes rise up sharper and sharper. It gives, however, a very feeble and wretched note; the object in the latter instrument has been to produce a more powerful one. This double siren cannot be said to err on the side of lack of power. It has two perforated rotating discs on one axis, each connected with windchests, which are covered by outside boxes, so as to give more purity to the sound. The lower windchest is fixed, but the upper can be rotated upon its axis. Each of them contains four rows of oblique holes, and each of these four rows of holes can be brought into operation by touching a valve which draws in and out. These instruments require very great wind pressure; we have now a pressure on the bellows of more than one hundredweight; equal to a column of twenty-six inches of water. When this high-pressure wind is allowed to pass through the oblique holes in the windchest against the corresponding holes in the rotating disc, the latter is soon set into rapid motion. At first a series of puffs is heard, as the two sets of holes coincide and interfere, but these soon merge into a continuous hum, and mount into a note, which rises steadily in pitch as the rotation becomes more rapid. An attached counter enables the speed to be measured by means of a watch. If you examine the ratios as I have written them down on the black board, you will find that on the lower disc there is a row of eight holes, outside that a row of ten, then a row of twelve, and then a row of eighteen. These give us, if you take *c* for the lower note, *e*, *g*, and *d*. On the upper disc there are 9, 12, 15, and 16, which give *d*, *g*, *b*, and the upper *c*. We can thus get unison by taking the two *g's*; an octave by taking two *c's*, a 5th by taking *c* and *g*, and so we can work through the various consonant intervals. I have not time to demonstrate these facts fully, but I will consider one or two. Starting with unison on the two discs, I rotate the handle moving the top box, whilst the lower one is sounding; you will hear that the sound rises and falls according as the phase of the vibration on the top disc is similar to the lower one and reinforcing it, or opposite to it, and antagonizing it. In each rotation you thus get eight spaces, four of the loud, and four of the feeble sound. I can also show you the beats which arise from slightly altering the pitch of the upper tone by slowly rotating the upper box by means of the handle, the tone becoming flatter when the direction of revolution is the same as the disc, and sharper when it is opposite. You hear the beats very distinctly. These beats involve a most important question of acoustics which must be reserved to the next lecture. We thus reach the second part of the subject, namely, reinforcement and distribution.

Now reinforcement is common to all kinds of vibrations, it even occurs in the child's swing. When a child swings itself it reinforces the action of the swing by slight muscular exertion. It occurs when peals of bells are ringing. Any one who has been at the top of Magdalen Tower at Oxford on the 1st of May, will have noticed that when the bells begin to ring the top of the tower rocks like a ship in a storm, people have even felt as if sea-sick. Although there is this pendulum motion, like that of a rod or tuning-fork, the tower is particularly safe, for it shows the foundation to be solid, the vibration occurring in the limestone which is elastic. The same reinforcement occurs when soldiers cross a suspension bridge. The rule is that when a regiment has to go over a light bridge they break step. If they march together the effect has been to injure or throw down the bridge. Reinforcement may be defined essentially as a gentle force, acting periodically, as when one pulls a heavy bell; each individual pull will not raise the mass or anything like it, even with your whole weight; but you keep on, reinforcing the vibrations of the bell, taking the period of the swing and giving each time a gentle impulse, and this gentle force acting periodically becomes magnified into a very great one. Generally speaking reinforcement in sound is correlative with the power of producing sound. All sounding bodies also reinforce, but some have been divided off by Clerk Maxwell into what he terms distributors. Others again have the power of singling out particular sounds for reinforcement. You may hear this going on in many places. If you take up one of these forks even while I am speaking to you, you can feel the particular notes that I speak of; it seems to vibrate when a certain note occurs. The same with a drum—while I was speaking I could feel distinct vibrations in the drum as each word came out of my mouth. The same with a piano—if you take off the dampers and speak into it, and then stop suddenly, you hear the piano singing out loudly with a sort of hum, the notes which you have been speaking or singing. Or even more simply than that. If any of you happen to be at a musical performance such as the opera, and put your finger on the top of the crown of your hat, you will find it acts like a membrane to reinforce particular sounds, giving a regular vibration; and then another note to which it

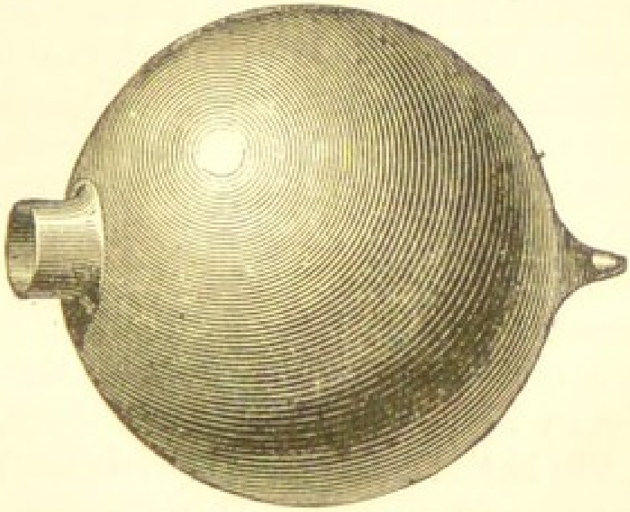

Fig. 8.—Helmholtz's Resonator.

does not consonate comes up, and the hat is still; so that the hat itself seems to be enjoying the music after its fashion. This propensity for singling out sound has been utilized by Helmholtz in making his resonators. He originally made the resonators, of which I have two sets here, with external membranes very much like this old marimba, but afterwards he found he could use the drum of the ear for the same purpose by making the cavity of a particular size, so that themselves speaking a certain note, they will single out that note from all others and reinforce it largely. Here is one which is sufficiently vibratile to give when struck a note like that of a bell, corresponding to the tone of E with 320 vibrations. When I speak that note you will hear it, and when I go down another note it ceases altogether. Here is another answering to G, and another to the upper C with 512 vibrations, and so on. Here are others arranged for all sounds. Even as I am speaking, if you take a few and try them, you will hear as I fall on the particular note in the inflexions of speech the tube reinforces it. The human voice is very full of harmonics, and if I sing the low C different persons holding these resonators will hear the upper partial notes that I unconsciously produce at the same time as the grave note that I am consciously singing. In this way Helmholtz accomplished that wonderful feat of analyzing the tones of different instruments and showing what musical quality depends upon, a fact which was never appreciated or understood before.

Now I have to speak of distributors. These are mentioned by Clerk Maxwell as air, wood, and metal. The third form, the metal, has lately been revived in a very pretty toy which is being sold about the streets, and is called a telegraph. It is merely a couple of resonators made of pill-boxes or little boxes of tin, with a wire-thread passing between them. Any words spoken into one of these are perfectly audible at the other end. The first mode of distribution by means of air hardly needs much said about it, because it is happening at the present moment as I am speaking to you.

The second deserves a little illustration; the more so as it was studied by an illustrious man lately dead, Sir Charles Wheatstone. We have the original mechanism here by which he performed the experiment. This curious, classical-lyre-looking thing is the instrument he used in his form of the telephone. His distributors were simply bars of light deal. I have constructed a long bar of the kind with four pantile laths, along the side of the room, and I find even in this considerable length, they convey the sound of a tuning-fork to this resonator very well. I will ask my assistant to strike the fork in the air and you will not hear it at all, but when he applies it to one end of the wooden rod, and I apply the other end to this resonator, you all hear it distinctly. The lyre down here is speaking the note produced at the top of the room. More than this, tactile sensation, as I have always contended, is shown to be continuous with aural sensation, for if I take hold of this rod while the tuning-fork is sounding, I can not only hear the vibration but I can feel it perfectly well at the same time; thus it is sensible to my auditory and tactile nerves transmitted through the length of wood. It is very singular that this apparatus should not only reproduce pitch but also quality. When it was tried many years ago at the Polytechnic, some of you may recollect a band of players was placed in a lower room, each playing his own instrument, and to each instrument was attached a long rod of deal. These rods, after passing through the floor, were fixed to harps in an upper room, and when the players played, one harp, standing before you by itself, seemed to play a violin, another a clarionet, another a double-bass, another a piano, the sounds being conveyed through the rods of wood and giving not only the pitch, but actually the musical quality of the generating instrument.

Lastly, I have to mention a perfectly new and very remarkable distributor of sound in the shape of electricity. It has long been known that a rod of iron when magnetized by a galvanic current gives a peculiar clink; that I propose to show you first.

I have put the clinking apparatus in the middle of the room. It is a rod of iron surrounded by a long coil, and here I have the means of passing a current through the coil; the current first passes through a harmonium reed, a wire attached to the vibrating end of which dips into a mercury cup, so that rapid vibrations can be produced. I can transmit the vibrations of the reed up into the coil and thus intermittently magnetize the bar of iron. Those who are near it can hear the clinking no doubt, though it is faint. That clinking rises to a musical sound when the intermissions become more rapid.

Some years ago Reuss utilized this. His plan was to have a small box, such as I have here, with the vibrating membrane at the top connected with a battery. If you speak into the box and the membrane vibrates, making an intermittent contact; the vibration is reproduced at the other end of the circuit, as you will hear when I sing into the instrument. The tone is now reciprocated by the receiving instrument at the other end. That is an early stage of the telephone. I am proud of being able to show (through the kindness of Mr. Latimer Clark) the new instrument invented by Mr. Elisha Gray, of Chicago, which has come over for this Exhibition. There are four springs, vibrating like tuning-forks, which are kept in motion by electricity. They give the common chord. Then there is an arrangement by which the vibrations that each of them sends off can be transmitted through the line of wire to the distant receiving instrument. There are the four notes of the chord, and you can distinctly hear the pitch of each particular note sent from one end by means of a key, repeated at the other end of the wire. This is a very remarkable transformation of energy. What we have done before is comparatively easy to understand. We have sent the actual vibrations of a sounding body through thin pieces of wood; but in this instrument we have transformed vibrational energy into another form of molecular force, electricity, one which we consider to be probably vibratory, though the point is still *sub judice;* then we transmit the force along a metal wire miles away, and at the further end we are able to re-analyze it back into sound vibrations once more. It is likely to prove of very great value practically. For instance, certain receiving instruments will only respond to their own forks, and in telegraphing you will easily understand how it would keep perfect secrecy. In military service it would be possible to have a telegraph set up like this, so that you, carrying the right receiving instrument, would not be liable to what was often done in the American War, namely to have a wire "tapped" and the messages carried off by the enemy.

ON TEMPERAMENT.

TO-DAY I have, at the request of the authorities, undertaken to give a brief analysis of a more difficult and more theoretical but certainly a not less important subject. You must excuse me if it is a little dry. Yesterday we had abundance of experimental assistance; to-day much of our time must be occupied, in even giving an outline of the subject, with figures and diagrams.

The subject is musical instruments and temperament, or rather, temperament as applied to musical instruments; and here at the very beginning I must notice that there has been much difference of opinion on the question. I find statements as opposite as these. Col. Perronet Thompson, of whom I shall have to speak further on, in his work on *Just Intonation* says, "The temptation under the old systematic teaching to play out of tune, was that performers might play with perfect freedom in all keys, by playing in none; hence the rivalry in the magnitude of organs, and sleight of hand and foot to conceal; but a reaction is setting in, and the world is finding out that music is not in noise, but in the concord of sweet sounds." On the other hand Dr. Stainer, a most competent musician and theorist, who has published an excellent work on harmony, writes in this way, "When musical mathematicians shall have agreed amongst themselves on the exact number of the divisions necessary in the octave; when mechanicians shall have constructed instruments on which the new scale can be played; when mathematical musicians shall have framed a new notation which shall point out to the performer the ratio of the note that he is to sound to the generator; when genius shall have used all this new material to the glory of art, then it will be time enough to found a new theory of harmony on a mathematical basis." Now I have once before demurred very strongly to this mode of treating the subject, and since my original remarks at the conference, I have had a little conversation with Dr. Stainer. Dr. Stainer, who I need not say, is not only a most able, but a most unbiassed judge in the matter, quite admits that he does not hold those views so strongly as he did; that he is beginning to think there is a possibility of just intonation, although he sees very clearly the mechanical difficulties which we all admit, and which stand in the way of its production.

Going into detail as to what temperament is, we may define the object of it as being the division of the octave into a number of intervals, such that the notes which separate them shall be suitable in number and arrangement for the purposes of practical harmony. This will be probably new to many persons. The old form of harmonium, piano, and every keyed instrument is so engraven on our minds from use, that most persons are quite unaware that there is any other possible arrangement. They may perhaps in a museum have occasionally seen a strange-looking instrument, stranger even than the one I have here, but they have passed it by, under the impression that it was incomprehensible or worse. Now the usual instrument which we are accustomed to, has of course its own system of temperament, and that temperament although not the oldest is certainly the simplest, and is generally called the equal temperament. It divides the octave, as you see in the harmonium, into 12 equal parts, or semitones. If it so happened that the octave could be divided into 12 equal semitones, such that the other divisions, the 5th and the 3rd, should be in tune, it would be a very great boon, but unfortunately nature has not so ordained it, and the first point which I wish to insist upon is what probably has not been conceived by everybody, that the discrepancy, the difficulties, the errors which we have to get over, lie, not in our system of music, but in nature itself. Just as the diameter and the circumference of a circle are not commensurable to one another; so the 5th, the 3rd, and the octave are not commensurable. They do not come to actual agreement in an arithmetical way, and this is so very well given in Mr. Ellis's translation of Helmholtz's great work, that I will ask your leave to quote a few words. When speaking of temperament he says, "It is impossible to form octaves by just 5ths or just 3rds or of both combined, or to form just 3rds by just 5ths, because it is impossible by multiplying any one of the numbers $\frac{3}{2}$, or $\frac{5}{4}$ by two, or either by itself or one by the other any number of times, to produce the same result as by multiplying any other of those numbers by itself any number of times." The ratios if you recollect, of the different notes of the octave to one another were briefly mentioned yesterday, and I have left the diagram up there; of course those ratios can be put in the form of fractions by putting the antecedent as numerator, and the consequent as denominator, so you easily form $\frac{3}{2}$ $\frac{5}{4}$ &c. as stated in Mr. Ellis's book. It is perhaps the simplest way of making you understand this incommensurability, to take a case. If we divide the octave into 12 equal semitones, of course the 5th ought to be seven of those; but it was found out very early in the history of music that the 5th is a little more than seven of these. As a matter of fact a 5th is 7·01955 and consequently taking 12 of these 5ths, they give rather more than 7 octaves. They do not come back again to the corresponding octave of the note from which you started. This difference, or departure as it is termed, is the former figure multiplied by twelve. I will give you the multiplication by twelve for simplicity's sake. We have ·23460 of a semitone as the excess. This is an old discovery generally attributed to Pythagoras, and the figure is commonly called "the comma of Pythagoras." What a comma is, I shall presently show you. But it is questionable as I mentioned before, whether Pythagoras deserves entirely the credit of this discovery, or whether he merely imported it from Egypt or Babylon. At any rate the Greeks knew, as I told you yesterday, of the monochord, the ratios to be derived from it, and of the divisions of the scale. Euclid wrote a work called the *Sectio Canonis*, or the division of the string, which contains all these given in very full detail. The 3rd of their scale was made in a similar way by four 5ths taken upwards, and that is still called a Pythagorean 3rd. There is then an incommensurability between the octave and the 5th which is in nature, and this incommensurability when multiplied gives the interval we term the comma. The error of the Pythagorean 5th has been said, and is still said by some persons, to be too trifling to be noticeable; that human ears are unable to appreciate it, and that you can overlook it. I believe I can show you distinctly the opposite in two ways. I can shew it on this harmonium where I can play two notes differing by a comma, or by a smaller interval which I shall have to speak of presently, a schisma; and I am going to ask a friend of mine who has a fine tenor voice to sing a true interval, and then we will compare it with the tempered interval, as given by the common harmonium.

Here is Helmholtz's harmonium on which I can show you very clearly what is a comma—it seems to me very audible, and perhaps Mr. Colin Brown will kindly play us a comma on his instrument, and a schisma also. The schisma is only $\frac{1}{11}$ of a comma, but I think you will agree with me, it can be distinctly heard. Now if my friend Mr. Jones will sing a perfect 5th we will have the note sounded on the harmonium, and I think you will notice the difference distinctly. I admit the experiment is difficult, indeed only last night I heard it denied by a great authority that it could be shown. (*A true fifth above tenor G was sung, and the D of the tempered harmonium was shown to be distinctly flat to it.*) Now the question occurs, what is the best mode of getting over, of covering up, or in some way retrieving these inherent errors of the scale. Ever since the early times of harmonic music different plans have been suggested, some of them of considerable historical interest. The principal was what is termed the unequal temperament. It was used for organs in former times, and is now termed mean tone, or meso-tonic. English cathedral organs up to a recent period were tuned by this system, and traces of it can be found in the music written for them. Until lately I could have pointed out many organs, and I believe there are some still, tuned on this system. The organ of Canterbury Cathedral, with which I am somewhat connected, has only lately been shifted from the old unequal temperament, and the large organ in the Moorfields Roman Catholic Chapel was only a few years ago tuned on the unequal temperament. If you look carefully at the music of the time, Purcell's anthems, for instance, in Boyce's Cathedral music, you will be able to notice that he palpably shirks certain notes; he avoids G♯ for instance, because he knew G♯ to be a treacherous note on this old temperament. When the organ was altered at Canterbury a few years ago, some pipes had to be cut, and others had to be lengthened; the lengthening was very considerable, the larger pipes had to have no less than two feet of metal stuck on to them, so as to bring them into tune. What was this unequal temperament then? It was an attempt at getting the more common scales accurate ; scales in common use were tuned perfectly true, or very nearly true, and the error was accumulated in other keys which were supposed to be less needed ; they were termed wolves. Of course, there was a consequent condition in dealing with this old tuning that the player should limit himself to a prescribed circle, and should never modulate into these forbidden keys ; A♭ and B♮ were wolves ; I speak from memory, as it does not matter which, so long as you understand that some were excluded. This temperament had many merits, and some organists even of the present time prefer it to the equitonic. I am not at all sure that I should not prefer it myself. It specially had the advantage of retaining the third of the scale correct ; but it had on the other hand the fault of flattening the very sensitive fifth to its injury. Of this I shall speak again, but I may show you a table which I abbreviated from Mr. Curwen's work, who I believe derived it originally from Mr. Ellis, wherein I have put down the numbers respectively of the three temperaments. In the middle is the true temperament, there is the ordinary equal temperament on one side as used for pianofortes and harmoniums, and the unequal temperament on the other.

	Old.	Just.	Equal.
C	30103	30103	30103
B	27165	27300	27594
A	22320	22185	22577
G	17474	17609	17560
F	12629	12494	12545
E	9691	9691	10034
D	4846	5115	5017
C	0	0	0

The reason that this system became insufficient for the needs of players dates back as far as the time of Bach, who wrote a great work called the well-tempered, or well-tuned key-board ; he therein aimed at getting perfect freedom of modulation into all keys ; but the geniuses who first made use of this system, and required it, were Mozart and Beethoven.

They were the first to find tempered instruments, which established the possibility of going round from key to key, wandering in beautiful modulations wherever they wished. This perhaps led them into the practice, and the desire for it became so strong that they sacrificed a certain amount of accuracy to obtain freedom of motion.

Before, however, we are in a position to compare the different systems of temperament, we ought to fix on a standard of comparison. You should understand that we are not dealing with ratios in speaking of this standard of comparison, but with absolute numbers; I gave you the ratios yesterday. A ratio may remain large, fixed, and simple, whilst the component numbers upon which that ratio is founded, dwindle down by degrees to infinitesimal smallness and fractional complexity, or they may rise to equally large values at the other extreme. The ratio and the number are different things altogether. It is somewhat singular that in these days the mistake of confusing these two should be made. But it has been made, and is continually being made, therefore I feel bound to give you a warning against it. In dealing with absolute numbers we may employ two principal methods of estimating them. We may use the geometrical method and compare them as magnitudes, or the numerical, and compare them as numbers. The geometrical method can be shown very well in a large diagram kindly lent me by Mr. Ellis. This long column contains the four forms of temperament marked at the head of each column by their first letters. Here is the hemitonic, or equal semitone system; the just, the meso-tonic, or old organ tuning, and the Pythagorean systems follow. You will see that the length of the black, blue, red, and yellow, is made to designate each note, but as you go up and down the scale those lengths do not at all agree in the same place; one overtops another, and in another place falls short, thus exactly measuring the inherent error of the scale which we have somehow or other to get rid of. If they were all accurate to one another, we should not have that locking in of one with the other. That is the geometrical method of showing differences of temperament, but we may do it by means of numbers. That table admits of translation into numbers. I have one which I shall be happy to lend to anyone who is interested to copy. By the numerical method there are a good many different ways of indicating the equal semitone system. We may take decimals, but this involves long and unwieldy figures. Of course there is no reason why long and unwieldy figures should be unmanageable, but some people are afraid of them. I will write out in full that Pythagorean comma of which I gave you before the first few figures. It is 7·019550008654. Taking the third founded on that, it is 3·863137138649. That would be rather difficult to recollect, though we have worse numbers than this to deal with; for instance, the value of π which is not only larger, but goes on to all eternity and never stops. No doubt the first five figures of decimals would be sufficient for many purposes, but that is only an approximation. The question arises, whether we cannot use smaller divisions than 12. Several methods have been adopted which are very convenient. 24 has been used, 31 is good, and also 50; 53 is remarkably good, and so is 118. I mean that instead of dividing the octave into twelve divisions, we may divide it into a larger number, and these are the several denominators or consequents of ratios which produce the best results. 53 is so good that I thought it worth while to make a diagram of it, and here is a scale of 53 divisions to the octave from *C* to *c*:—

5	*c*	octave	53
9	*b*	seventh	48
8	*a*	sixth	39
9	*g*	fifth	31
5	*f*	fourth	22
8	*e*	third	17
9	*d*	second	9
0	*c*		
53			

By adding these together you get the other intervals. For instance, if you take 9 and 8, and 5 and 9 together, they make 31, that is the 5th; or take 9 and 8 = 17, and that is the 3rd, the whole octave being divided into 53. This has another advantage, that you can show by it, in a very simple way, the comma; you will find that the comma comes out to be just one of these divisions, $\frac{1}{53}$rd of the octave. If you want to go to greater nicety, you must take a larger number of divisions, and of that I have also given some illustrations.

One of the best numbers to choose is 30103, which, in the decimal form, is really the logarithm of the number 2. We need not consider it as a logarithm, but simply treat it as a common number. If you separate the octave into this large number of very small divisions you can show all intervals with great accuracy, and even get the interval of a schisma. Taking the octave as 30103 the fifth will be 17609; the comma 539, and the schisma will be 49. Some put it at 48, but 49 has this advantage, that it is just $\frac{1}{11}$th of the comma. The table above is framed on the 30103 system. Now I am in a position to show you the comparison between the new and the old temperaments a little more closely. Here are three columns, one the just intonation, the second the old organ tuning, and the other the modern.[1] The old organ tuning had one advantage, that it keeps the 3rd perfectly correct 9691, the same as in just intonation, but you see how terribly that is thrown out by the equal tuning, being raised to 10034. On the other hand the 5th is a little wrong; it is more out than in the equal temperament. The mode of working this out deserves a little consideration. You divide the octave into any number of intervals, of aliquot parts, which we may call m; v of these make a fifth, t represent the major 3rd, and q represent the comma; taking the logarithm of 2 which I have given in the form of a whole number, and dividing it by these, we get the closest possible cyclic approximation to just intonation. The cycle of 53, which has the advantage of simplicity, was first proposed by Mercator, who is known as the inventor of a plan for charts. This system was employed by Perronet Thompson, and has been fully carried out in that beautiful harmonium of Mr. Bosanquet's, which many of you may have seen in the galleries of the Exhibition on the other side. I did not think it desirable, as it is a bulky, heavy, and delicate instrument, to bring it over here, but you will probably have heard it played and explained by Mr. Bosanquet himself. For practical use there is no doubt that this 53 scale is the most perfect we can get without running on to a most impracticable number of divisions in the octave. Whether it is the best for performance upon a playing instrument is an entirely ulterior consideration of which I shall speak presently. This 53 scale gives you an opportunity of seeing

[1] See table on page 25.

how the comma of Pythagoras is got without unnecessary computation.

$$\begin{array}{lcl} \text{Twelve 5ths} & = 31 \times 12 = & 372 \\ \text{Seven Octaves} & = 53 \times 7 = & 371 \\ \hline \text{Therefore the comma} & = & 1 \end{array}$$

On the larger scale the comma rises to 539, and the schisma to 49 or $\frac{1}{11}$th of the comma.

Having now established our standard, we are in a position to compare the various systems; but before doing so, without intending disrespect to anybody, I must remark on the complex nomenclature with which we have here to deal. It is perfectly astounding. I do not propose to go into all of it, but I may simply mention it to show you what names exist. Amongst them I find, Commatic, Pythagorean or Quintal, Mean or Meso-tonic, Commato-Skhismatic, Hemitonic, Skhismatic, Skhismic, Skhistic, Cyclic, and Skhismo-cyclic. These words of course are of value for investigation, but there are too many, and they are too near to one another in sound for ordinary use.

The difficulty, of course, which all these systems were made to meet, is that the advance of music requires free power of modulation from every key into every other, both of the major and minor forms. We can obtain this in two ways; either by a slight falsifying of the intervals, or by increased mechanism, and an increased number of notes in the octave. These two views are very well represented by the two quotations I gave you, from Perronet Thompson and from Dr. Stainer. Dr. Stainer at the time took, and in a great measure still takes the view, that the organ at present built is as complicated as it will bear being. Indeed in speaking about it the other day he said that he should be very glad to adapt true temperament to the St. Paul's organ, but imagine the St. Paul's organ, which is now very large, with eighty-four keys in each octave; St. Paul's itself would not hold the organ, much less the congregation. There is great truth in that. Mr. Bosanquet's harmonium has eighty-four keys to each octave, and if you multiply that by the number of stops it would become so utterly unwieldy that practically no one could play upon it. In the equal temperament, as I have said before, the octave is divided into twelve semitones, and the result of this is that the fifths are a schisma flat. This is not a great flattening, but the interval of the 5th is very sensitive. It very soon beats, as it is termed; that is to say, the interference of sounds caused by the flattening of the schisma, produces about one beat a second. On the other hand, the equal temperament disfigures the third very much indeed. It makes it seven schismas too sharp. The sixth also, which is a very peculiar and beautiful interval, and which has been called the sorrowful sixth. (If I am not mistaken, the bagpipes derive their peculiar wailing effect from the use of the sixth which occurs in the archaic scale of that instrument), that sixth is disfigured very much. The number is 22185 in just, and 22577 in equal temperament, or eight schismas too sharp. The seventh again, in the old temperament is rather flattened as you see. The numbers are 27165 in the first column, and 27300 in the other; whilst it is terribly wrong in equal temperament, namely, 27594. There is another discrepancy in the tempered scale affecting the second. If I had time I could show you that this is a variable note, and requires to be used in two ways. In the old temperament it is about half way between the two, but in the equal temperament it is ninety-eight divisions too sharp for the acute form, and in the flat form it is nine schismas too sharp. This shows that the equal temperament is about as bad a system as we can employ. It has only one advantage, and that is that it is simple, and everybody can learn it easily. There is another accusation to be brought against it, though perhaps you may look upon this view of the question as rather Hibernian, namely, that we never get it; the tuning of the 5th a schisma flat, which gives one beat a second, is a delicate process, and I firmly believe that very few pianoforte tuners are really able to accomplish it. Mr. De Morgan used to say that he never could manage it, although he separately tuned a number of strings himself to beat one beat a second; for when he compared them together they never were in tune. Now if he could not do it on a single note with his great mathematical ability and mechanical skill, I doubt if the ordinary class of tuners can. However, although I object to equal temperament on these grounds, which you will see are obvious facts of nature, not at all matters of opinion, I must allow that it does afford great facility and simplicity, to have only twelve keys in the octave; it would be of great advantage if this facility could possibly be retained.

How then shall we go on instrumentally to improve matters? For the first method, I have here a form[1] of Helmholtz's harmonium which is really very little complicated. Any person understanding music can very soon master it. There are two keyboards put into the place of one, the lower of which is a comma sharper than the upper; consequently, when you want to lower any note a comma you can do it by putting your finger on the upper keyboard, instead of the lower one. This gets over a great many difficulties, but it is not absolutely true; however, the great fault of equal temperament is the third. If we have the third, sixth, and the seventh approximately true, we have got over the most important errors. Those intervals are to a great extent accurate on this instrument; the dissonance of the sharp third itself is not, I think, beyond the limits of audibility. Those who say so cannot possess very good ears. I will give you the common chord, first on the single keyboard, and then change to the third, a comma flattened, so that you may hear the difference. Now I will take the sixth. When you have heard the true interval you will see that the other is decidedly out of tune, although it might pass muster if you did not hear the correct interval. The first mode then is Helmholtz's double key-board with 24 notes.

Then there is another contrivance equally simple in the keyboard; this is Mr. Ellis's harmonium. He accomplishes his object by shifting the sound not by means of separate notes or keyboards, but by combination stops. I wish I had the instrument here to show you; though if it had been here you would have seen nothing. It is just like a common harmonium, except that it has a few draw-stops which fulfil different functions from those in the ordinary arrangement.

The next is an instrument which you have probably all seen in the Exhibition—that of General Perronet Thompson. Perronet Thompson adopted the system of increasing the digitals up to the full number of sounds, though he did not carry it out quite to the bitter end; and therefore he does not profess that his enharmonic organ plays in all the keys; but even he has about 72 keys to each octave, and he starts on the

[1] Mons. Gueroult's, made by Debain.

cycle of 53 sounds, of which he uses about 40. With all that mass of keys of different kinds, described by differ-

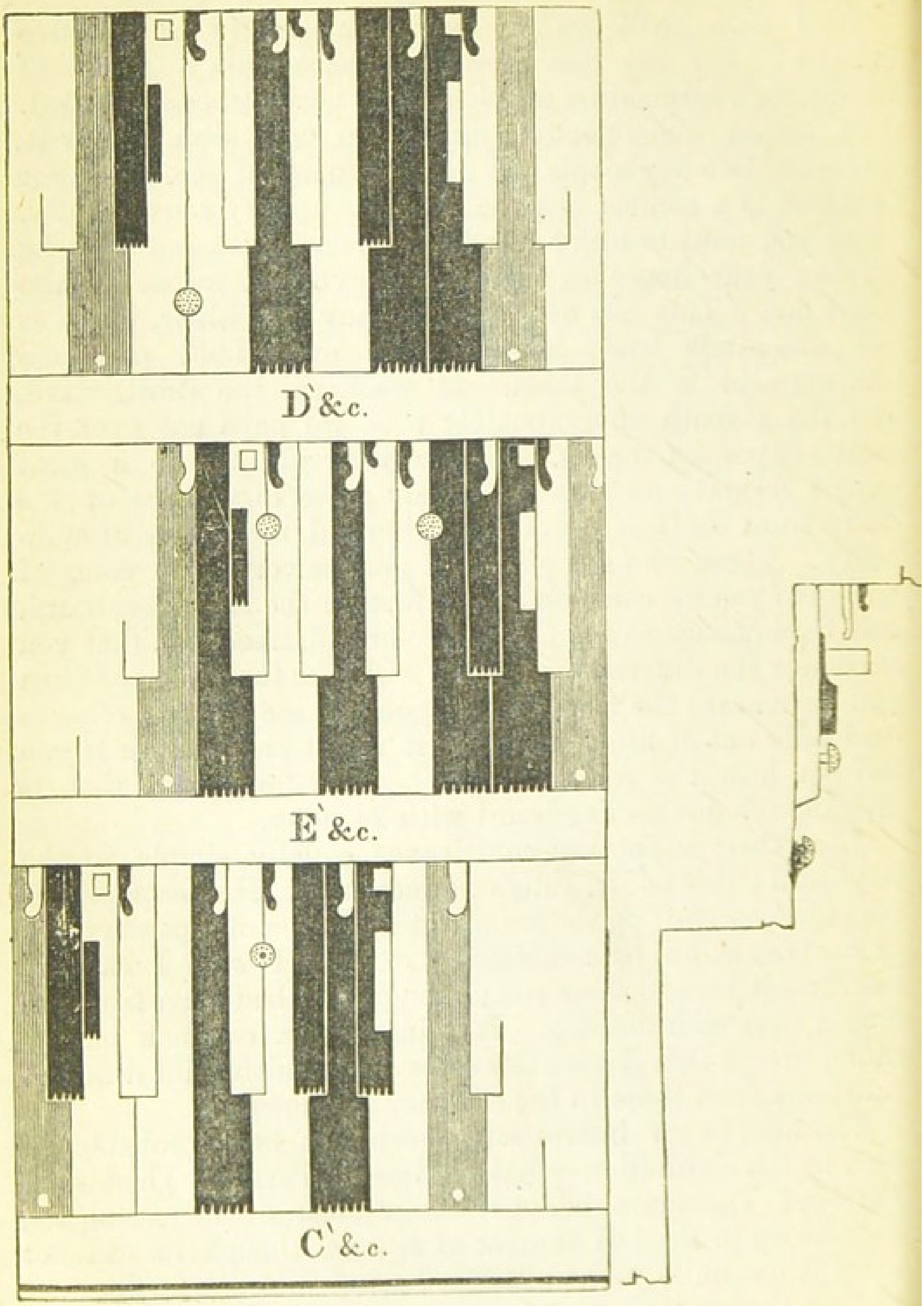

Fig. 9.—Perronet Thompson's Keyboard.

ent names, quarrils, buttons, and flutals, besides the usual twelve keys, it looks a very difficult instrument to play, and has always been found unmanageable. It has the power according to his own statement of performing correctly in twenty-one keys with a minor to each.

If you look at the keyboard in passing, you will see three rows of ordinary keys, coloured in various ways. There are, in fact, three keyboards ; there are also the quarrils, buttons, and flutals named above. With all the mass of mechanism which looks like a large organ, it only possesses one speaking stop. This seems a very small result for such enormous magnitude, and you can now appreciate what St. Paul's or any other large organ, with perhaps eighty speaking stops, besides couplers, would be if it were magnified in the same ratio.

I have now to speak of two harmoniums, first that of Mr. Bosanquet, and secondly one, which I am most happy to be able to show you to-day, of Mr. Colin Brown, Professor of Music in the Andersonian University of Glasgow, who has been kind enough to come all the way from Scotland to play it to you. In both these we seem more within bounds of practicability. Two things are aimed at in both these harmoniums which are not in those I first named ; in the first place to get correct intonation, and in the second to generalize the keyboard. You do away with that distinction between black and white notes which causes so much confusion to learners. Mr. Bosanquet certainly has black and white notes still left after a fashion, so as to guide the eye, but you never play as you do on the common piano in six flats or five sharps and so on. You do not feel your way by the black and white notes as you have to do on the ordinary piano. There is only one key or scale on each ; it is a little complicated, but when you have once learned it all positions are the same, and that is why Mr. Bosanquet terms his instrument a generalized keyboard. I have heard persons say, "I cannot play in five flats, I can play in one flat, five are too difficult." Here there is no such difficulty ; five flats are no more difficult than one flat. You have only to get the right pitch and all scales are in the same position for the hand. I think I have stated that Mr. Bosanquet has fifty-three sounds in the octave, though there are eighty-four keys. This harmonium possesses also some very beautiful characteristics, of which one is the power of getting the harmonic seventh. Nevertheless he does not look upon it as an instrument for great execution. It is more intended as a sort of well-spring and fountain from which can be drawn pure chords, vitiated and made dissonant by more ordinary instruments. I admit that my own sense of hearing was incorrect at first. I did not like these purely consonant untempered instruments. When I first heard Perronet Thompson's organ, I thought the intervals were what tuners would call too "keen." I was accustomed to the universal dulling, dumbing of the scale which one hears from an equally tempered instrument, all the notes being thrown a little out of tune; but if you go and sit beside this harmonium, after a little while, when the first effect of novelty is worn off, you will come to like it very much indeed. Our senses are more or less injured by long practice with the other system, and therefore Mr. Bosanquet, I believe, wishes it to be employed by composers to get combinations, to see what they can use in proper intonation, and afterwards arrange for instrumental performance of them by other means. It is intended more to manufacture music upon than for performance.[1]

Mr. Colin Brown is here himself, and he will correct me if he wishes, but I hope he will not disagree with what I say, that he aims at a slightly different object; namely, at getting just intonation in the simplest fashion, and with the least complicated keyboard by which it can be obtained.[2] His keyboard is by no means so elaborate as Mr. Bosanquet's, and is therefore more suitable for accompanying purposes. This it seems to me is a very excellent direction to take. We must make a compromise. Absolute truth is not to be had here; we shall never be able to obtain elaborate execution on instruments like Mr. Bosanquet's or Perronet Thompson's, but here is a harmonium which I believe can be learned in a short time, and which is in some respects even easier to learn than the ordinary keyboard; yet you can produce upon it just intonation to a very considerable if not to the last possible degree. Mr. Brown has in this particular harmonium twenty-nine sounds to the octave; some which are now making (for this is only an experimental instrument, intended to try the arrangement), but which have been delayed by the illness of the workman, will have thirty-two sounds to the octave, and the whole scale can be completed if

[1] For a more detailed account of this instrument, with a diagram of the keyboard, see Appendix I., kindly contributed by Mr. Bosanquet himself.

[2] See Appendix II.

necessary by putting in forty-four sounds to the octave. I shall ask you to listen to it presently, but I am anxious to conclude first my own task as to the application of true temperament to other than keyboard-instruments.

I have spoken hitherto entirely about organs, and harmoniums; with organs not much has been done; whilst harmoniums have occupied most inventors; because they are instruments which show dissonance more than any others owing to the peculiar quality of tone they give out. They are liable to painful interference and harshness of tone. For these reasons they are not liked by many persons. They are, however, very convenient instruments, not at all expensive, nor liable to get out of tune; therefore they are seen in many places where you do not find a piano.

If we can get this true intonation by a moderate amount of mechanism, and at a moderate price, we shall have a harmonium which will play as sweetly as an organ or a piano. For the piano true intonation does not appear to be so necessary, because it has only an evanescent sound, the note being produced by a blow. It hardly causes continuous beats; at any rate they are not so audible; indeed the ear requires to be practised, to have learned the unpleasant art of detecting the beats; when you have once acquired it, you become terribly sensitive to ordinary music; for with the equal temperament, and with the errors which I have pointed out in it, we never get an instrument perfectly in tune. Now for the application of this method to orchestral instruments. We have made a beginning. There is in the Exhibition a trumpet invented by a friend of mine in which the valves are three, but the third valve instead of altering the pitch by a tone and a half, as it usually does, alters it by a comma; therefore Mr. Bassett calls it the "comma trumpet." Whether that particular instrument is or is not successful, I need not here mention, but the idea carried further may be fruitful in good results, because if you can alter any dissonant note a comma up or down, you can produce much more perfect harmony in the orchestra. I am doing the same thing with the clarionet and oboe. Here is a clarionet, only an ordinary one, as I am anxious not to complicate the mechanism more than necessary; but by means of double keys it will produce a great many accurrate intervals. For instance, I can take the E flat in two forms, and the F in three differen ways. Several other notes have alternative fingerings, so that I hope to manufacture reed instruments with which we can get, in many keys if not in all, true intonation. We do not require it in all keys with the clarionet, because as you are aware, players use different instruments for different keys. There is the B flat clarionet which is useful for the flat keys; to play in sharp keys there is the A; and there is also a C clarionet, though it is less used. In this way by having just intonation for one or two keys on either side of the natural key, I believe we shall arrive at more perfect results. It is very desirable it should be so, and I hope we shall be able to carry it out. I will here conclude the talking part of the lecture, but the most important part you will all agree with me will be the description of his new harmonium which Mr. Colin Brown has so kindly undertaken to give us. Before playing he wishes to explain the system on which the keyboard is arranged.

Mr. Brown.—The construction of this instrument arose from a series of experiments in analysing a musical sound. It is mathematically and musically correct, and contains neither compromise nor approximation of any kind from beginning to end of the fingerboard. The octave consists of seven digitals, with one added for the minor scale. It involves no complicated calculations, for there are only seven musical relations or differences on the keyboard, and these require neither decimals, nor logarithms, nor equations to express them.

The scales run horizontally along the instrument, the keys across it, scales and keys being at right angles. The progression of fingering the scale in all keys is the same, and as no extra digitals, such as the five black upon the common keyboard, are required to play chromatic tones, this fingerboard is called the 'natural fingerboard.'[1]

Instead of beginning where, as Dr. Stone pointed out, is usual, with the larger intervals of the scale, as the octave and fifth, I have begun at the other end of the scale with the first elements—8 : 9—9 : 10—15 : 16.

Though the larger intervals of the scale are relatively incommensurable, by starting with these primary relations we find that every interval is accurately produced from them;

[1] See Appendix II. kindly contributed by Mr. Colin Brown.

thus $\frac{9}{8}$ added to $\frac{10}{9}$ give $\frac{5}{4}$, the major third; and these, added to $\frac{16}{15}$, give $\frac{4}{3}$ the perfect fourth; and so on—$\frac{9}{8}$, $\frac{10}{9}$, $\frac{16}{15}$, $\frac{9}{8}$, $\frac{10}{9}$, $\frac{9}{8}$, $\frac{16}{15}$ added together give $\frac{2}{1}$ or the octave.

In addition to these three relations, $\frac{9}{8}$ less $\frac{16}{15}$ gives 128 : 135, or the chromatic semitone; thus there are in the scale two tones, $\frac{9}{8}$ large and $\frac{10}{9}$ less, and two semitones, $\frac{16}{15}$ diatonic and $\frac{135}{128}$ chromatic.

Besides these four relations, the three musical differences of the scale are also to be found on this instrument, viz., $\frac{10}{9}$ less $\frac{16}{15} = 24 : 25$, the imperfect chromatic semitone—$\frac{9}{8}$ less $\frac{10}{9} = 80 : 81$, the comma—and the schisma 32,768 : 32,805, which is also deduced from these relations.

The comma is the difference between the large and less tones or steps of the scale.

The schisma is the difference between a sharp tone and a flat one, say between D♯ and E♭.

The round added digital in each octave does not belong to the series of the major scale; it produces the major seventh and sixth in the minor scale, and also introduces the imperfect chromatic semitone of 24 : 25, being $\frac{10}{9}$ less $\frac{16}{15}$. The effect of this additional digital is very peculiar; the tone seems to be too flat till it is heard in the chord.

These seven are all the primary musical relations and differences to be found on the natural fingerboard; there are many secondary keys to which I have paid no attention, —they may be very beautiful, but I do not enter into that question—for I have yet to learn, first, if they are true, and, secondly, if they are necessary or useful. The introduction of a round digital, placed upon the white as well as on the coloured digitals, would supply every secondary key that the most exacting musician can demand; but I was anxious to avoid anything that would complicate or confuse the fingerboard.

Music has greatly to complain of mathematicians for carrying their formulæ beyond their legitimate sphere into the domain of music; and mathematicians, on the other hand, have to complain of musicians for demanding a number of secondary keys which are not mathematically or musically in true key relationship. It would be quite easy to make an instrument with them all, and at no great cost of money; but what would be the advantage?

In constructing this instrument the principles I had to consider were: a mathematical series of sounds on the one hand and a musical series on the other; I had to reconcile and adjust their differences, and mark their coincidences. These coincidences are represented by the digitals on my fingerboard. I began with the simplest elements of the scale; and had to feel for and find my way at every step. This instrument is limited in its range, embracing only eight major keys with relative minors. It has only one keyboard of three levels, the addition of another level would complete the cycle of thirteen keys; it may, however, be extended to any range, C being always the central key—from C♭ grave to C♯ acute are given in the plan lodged in the Patent Office.

The question is often asked, How can such an instrument be played upon? No musical instrument can be of any real practical value unless it can be easily played. I shall not offer my own opinion upon this point, but that of a gentleman who has studied the subject thoroughly and whose opinion may be relied upon. After examining the fingerboard carefully he remarked,—first, that any person understanding the relation of keys in music will comprehend the principle of this keyboard in a few minutes; secondly, that any person who can play upon an ordinary harmonium will play just as well upon this fingerboard by two or three weeks' practice.

These two statements have been already amply verified, for everyone who has tried to play upon this instrument half-a-dozen times has done so readily. The third statement made by my friend was that any person learning to play will save from two to three years usually spent in practising keys, because the scale in every key is played upon the natural fingerboard by the same progression of fingering.

Some time must elapse before this last can be verified—but there can be little question as to its correctness.

APPENDIX I.

BOSANQUET'S GENERALISED KEYBOARD.

In the enharmonic harmonium exhibited at the Loan Collection of Scientific Instruments, South Kensington, 1876, there is a keyboard which can be employed with all systems of tuning reducible to successions of uniform fifths; from this property it has been called the generalized keyboard. It will be convenient to consider it first with reference to perfect fifths; it is actually applied in the instrument in question to the division of the octave into fifty-three equal intervals, the fifths of which system differ from perfect fifths by less than the thousandth part of an equal temperament semitone.

It will be remembered that the equal temperament semitone is the twelfth part of an octave. In the present notice the letters E. T. are used as an abbreviation for the words "equal temperament."

The arrangement of the keyboard is based upon E. T. positions taken from left to right, and deviations or departures from those positions taken up and down. Thus the notes nearly on any level are near in pitch to the notes of an E. T. series; notes higher up are higher in pitch; notes lower down lower in pitch.

The octave is divided from left to right into the twelve E. T. divisions, in the same way, and with the same colours, as if the broad fronts of the keys of an ordinary keyboard were removed, and the backs left.

The deviations from the same level follow the series of fifths in their steps of increase. Thus G is placed $\frac{1}{4}$ of an inch further back, and $\frac{1}{12}$ of an inch higher than C; D twice as much; A three times, and so on, till we come to C′, the note to which we return after twelve fifths up; this note is placed three inches further back, and one inch higher than the C from which we started.

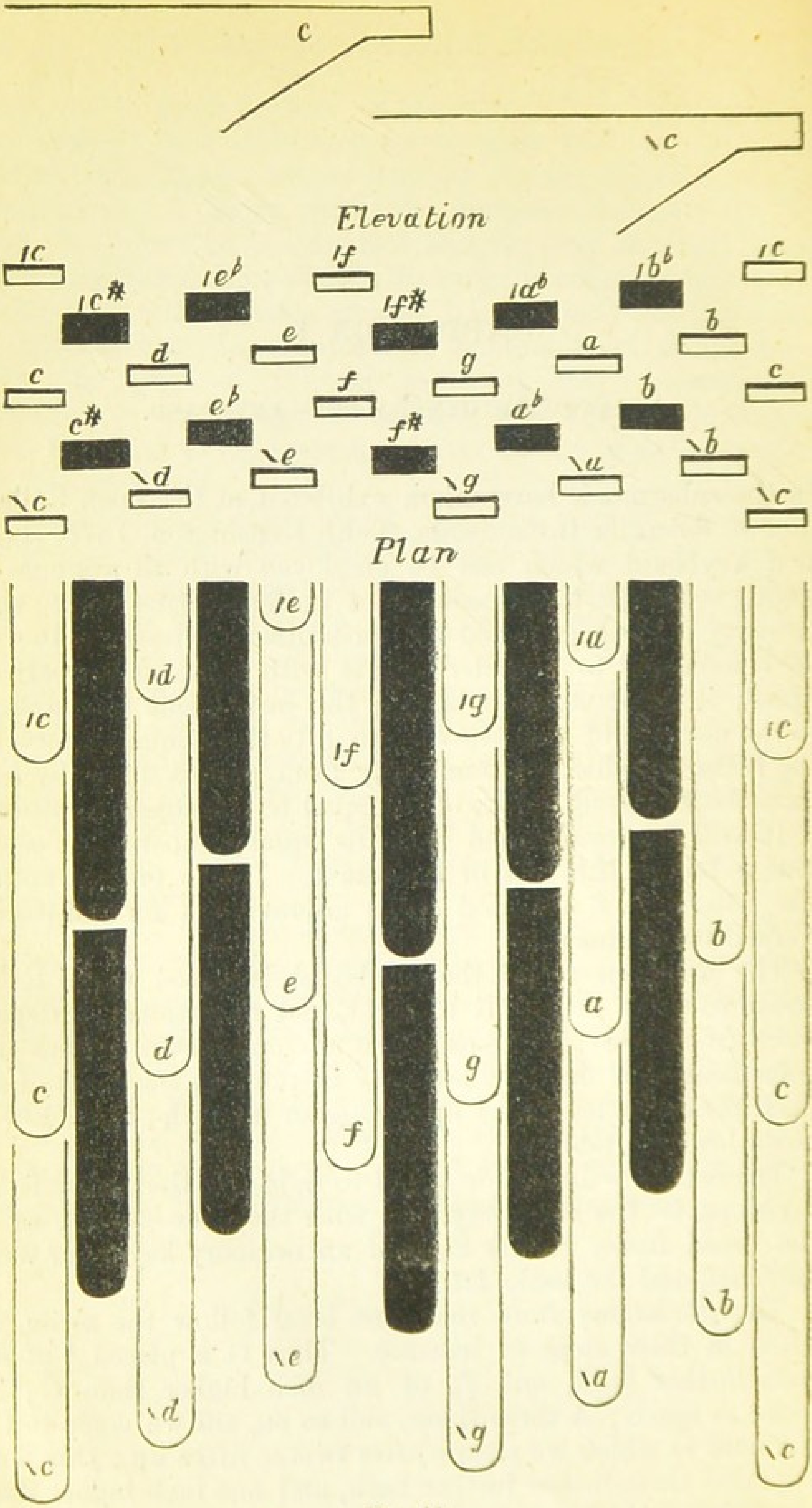

Fig. 10.

With the system of perfect fifths the interval, C—C′, is a Pythagorean comma.

With the same system, the third determined by two notes eight steps apart in the series of fifths (C—C′), is an approximately perfect third.

With the system of fifty-three the state of things is very nearly the same as with the system of perfect fifths.

The principal practical simplification which exists in this keyboard, arises from its arrangement being strictly according to intervals. From this it follows that the position relation of any two notes forming a given interval is always exactly the same; it does not matter what the key-relationship is, or what the names of the notes are. Consequently, a chord of given arrangement has always the same form under the finger; and as particular cases, scale-passages as well as chords have the same form to the hand in whatever key they are played. A simplification which gives the beginner one thing to learn, whereas there are twelve on the ordinary keyboard.

The keyboard has been explained above with reference to the system of perfect fifths and allied systems; but there is another class of systems to which it has special applicability —the mean-tone and its kindred systems. In these the third, made by tuning four fifths up, is perfect or approximately perfect. The mean-tone system is the old unequal temperament. The defects of that arrangement are got rid of by the new keyboard, and the fingering is remarkably easy. The unmarked naturals in the diagram present the scale of C when the mean-tone system is placed on the keys.[1]

[1] For further details on this important subject readers are referred to the forthcoming work *An Elementary Treatise on Musical Intervals and Temperament*, with an account of an enharmonic harmonium exhibited in the Loan Collection of Scientific Instruments, South Kensington, 1876; also of an enharmonic organ exhibited to the Musical Association of London, May, 1875, by R. H. M. Bosanquet, Fellow of St. John's College, Oxford. London: Macmillan and Co., 1876.

APPENDIX II.

THE NATURAL FINGERBOARD WITH PERFECT INTONATION.

The digitals consist of three separate sets, of which those belonging to four related keys, representing the notes 2, 5, 1, 4, are white; those belonging to three related keys, and representing 7, 3, 6, are coloured—the small round digitals represent 7 *minor*, or the major seventh of the minor scale. These are the same in all keys.

This fingerboard can be made to consist of any number of keys.

The scales run in the usual order in direct line, horizontally, from left to right *along* the fingerboard.

The keys are at right angles to the scales, and run vertically *across* the keyboard, from 'C♭♭ in the front to C'♯♯ at the back, C being the central key.

The scale to be played is always found in direct line, horizontally between the key-notes marked on the fingerboard, but the digitals may be touched at any point.

The order of succession is always the same, and consequently the progression of fingering the scale is identical in every key.

The 1st, 2nd, 4th, and 5th tones of the scale, are played by the white digitals, the 3rd, 6th, and 7th, by the coloured.

The sharpened 6th and 7th of the modern minor scale are played by the round digitals. The round digital, two removes to the left as in the key of B flat, is related to that in the Key of C as 8 : 9, and supplies the sharpened sixth in the relative minor of C; so in all keys similarly related.

Playing the scale in each key the following relations appear—

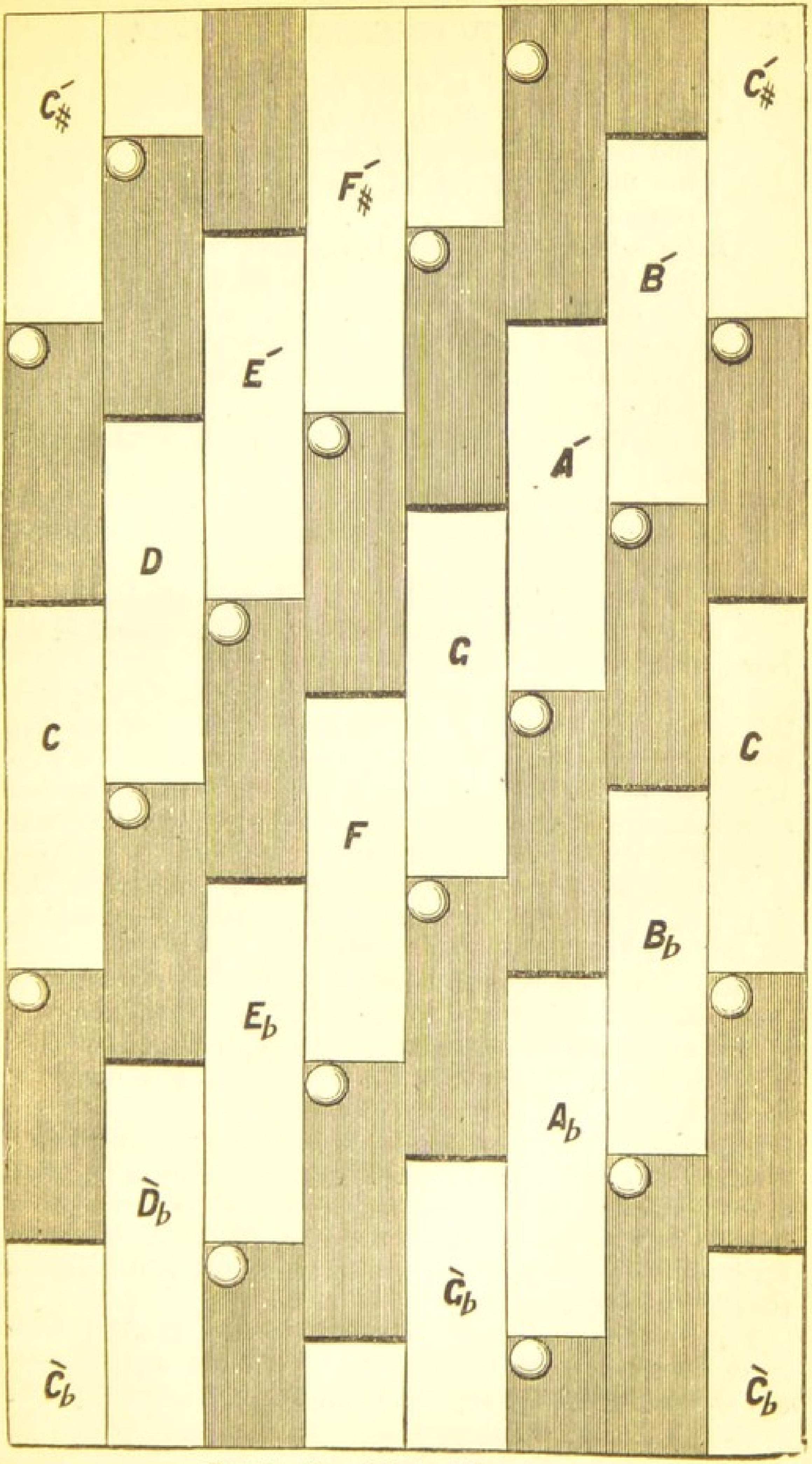

Fig. 11.—Plan of Natural Fingerboard.

From white digital to white, say from the 1st to 2nd, and 4th to 5th of the scale, and from coloured to coloured, or from the 6th to the 7th of the scale, the relation is always	8 : 9
From white to coloured, being from the 2nd to 3rd, and from the 5th to the 6th of the scale	9 : 10
From coloured to white, being from the 3rd to the 4th, and from the 7th to the 8th of the scale	15 : 16

From *white* to *white*, or *coloured* to *coloured*, is always the large step.

From *white* to *coloured* is always the less step.

From *coloured* to *white*, the diatonic semitone or the small step.

The round digital is related to the coloured which succeeds it as 15 : 16, and to the white which precedes it as 25 : 24, being the imperfect chromatic semitone.

Looking *across* the fingerboard at the digitals *endwise*, from the end of each white digital to the end of each coloured immediately above it, in direct line, the relation is always 128 : 135, or the chromatic semitone; and from the end of each coloured digital to the white immediately above it, in direct line, the comma is found 80 : 81.

Between all enharmonic changes, such as between A♭ 404$\frac{44}{81}$ to G♯ 405, the interval of the schisma always occurs, 32,768 : 32,805, the difference being 37.

These simple intervals and differences, 8 : 9—9 : 10—15 : 16—24 : 25—80 : 81—128 : 135—and 32,768 :32,805, comprise all the mathematical and musical relations of the scale. The larger intervals of the scale are composed of so many of 8 : 9—9 : 10—and 15 : 16—added together.

The digitals rise to higher levels at each end, differing by chroma and comma, or comma and chroma alternately; this causes separate levels on the fingerboard at each change of colour; though these are not essential, they will be found very useful in manipulation, and serve readily to distinguish the different keys.

The two long digitals in each key are touched with great convenience by the thumb. The lower end of each coloured digital always represents the 7th in its own key, and the borrowed, or chromatic sharp tone, in every other, thus, the 7th in the key of G is the sharpened fourth, or F sharp, in the key of C,—and so in relation to every other chromatic sharp tone.

The white digital is to every coloured digital as its chromatic flat tone, thus, the fourth in the key of F is B ♭, or the flat seventh, in the key of C,—so in relation to every other chromatic flat tone. In this way all chromatic sharp and flat tones are perfectly and conveniently supplied without encumbering the fingerboard with any extra digitals, such as the black digitals on the ordinary keyboard, the scale in each key borrowing from those related to it every possible chromatic tone in its own place, and in perfect intonation.

The tuning is remarkably easy, and as simple as it is perfect.

While all the major keys upon the fingerboard, according to its range, have relative minors, the following, 'B ♭, 'F, 'C, 'G, 'D, A, E, B, F ♯, C ♯, G ♯, and D ♯, can all be played both as major and as perfect tonic minors.

These secondary keys are more than appear at the first inspection of the fingerboard. A series of round digitals placed upon the white, and a comma higher, additional to those placed upon the coloured digitals, would supply the scale in every form the most exacting musician could desire, but it is a question if such extreme extensions are either necessary or in true key-relationship—and whether simplicity in the fingerboard is not more to be desired than any multiplication of keys which involve complexity and confusion.

NOTE.—A full description of the voice harmonium may be found in the specification for patent. The principles upon which it is constructed and tuned will be found fully stated in *Music in Common Things*, Parts I. and II., published by Messrs. William Collins, Sons, and Co., Glasgow and Bridewell Place, New Bridge Street, London, and the Tonic Sol Fa Agency, 8 Warwick Lane, London, E.C.

APPENDIX III.

Since the delivery of the above lectures, another harmonium has been sent to the Loan Collection by Herr Appunn, of Hanover, on the system of true temperament. The detailed account of its mechanical appliances has not as yet arrived; but it may be briefly described as having thirty-six keys, playing thirty-five perfect fifths; the major thirds being tuned by eight fifths downwards, that is, a *schisma* too flat. These are arranged in one row of keys, with two rows of buttons or studs. The keyboard is double, with an extra row of twenty-four tones arranged on the ratio 16 : 19 with respect to the two bottom rows, so as to compare the effect of the minor chord, using 16 : 19 with the usual 5 : 6.

London: R. Clay, Sons, and Taylor, Printers.