THE HARMONOGRAPH.

Illustrated by
Designs actually Drawn by the Machine.

BY

H. IRWINE WHITTY, M.A.

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PREFACE.

This volume does not pretend to be a scientific treatise, though it deals with a subject which has interested and engaged the attention of scientific men for a century past. Nor does it claim any special originality. The circumstances which led to its production are briefly as follows :—

In January, 1892, the Norwich Science Gossip Club, of which I had the honour to be President for that year, held a conversazione to celebrate its coming of age, having just completed its 21st year. It was suggested that the Harmonograph would probably be considered an interesting exhibit; and this suggestion, joined to the fact that I had long been desirous to construct the machine for myself, gave the necessary stimulus. I hastily constructed one, and with the very smallest amount of practical knowledge of its capabilities, exhibited it in action at the conversazione. So many visitors took interest in its performances, crude and rough as they then were, that I conceived the idea that something of the kind I now offer to them might be acceptable. A very short experience had determined me to make an exhaustive examination of this curious machine, with which, though it was familiar enough to me theoretically, I had absolutely no practical acquaintance—in fact, I had never seen one at work.

My readers will, I trust, bear in mind that every one of the curious and beautiful figures which are presented has been separately drawn by the machine itself. Under these circumstances absolute accuracy of every figure contained in the whole fifty volumes, of which the issue consists, is unattainable, and, if two copies are compared, small differences in corresponding figures will be seen. These deviations, however, are slight and of little importance. If anyone of my readers is induced by the book to possess himself of a machine and experiment with it, he will soon be in a position to appreciate the minuteness of the causes which can produce them.

Furthermore, he will fall under the influence of a rare fascination. I have drawn several thousands of figures already, but still with unabated interest do I watch the pen making its intricate and mysterious rounds, passing through cycle after cycle, and laying down curve within curve, with such beautiful precision as to render almost impossible the conception that the whole complicated operation has for its inspiring cause the regular monotonous swing of two great lumps of lead.

The issue of this book is in no way a commercial speculation; part of my reward I have already had in the pleasure experienced by myself in the course of the work—if to this I can add the happiness of being able to communicate some of the same to my readers, my remuneration is complete.

H. IRWINE WHITTY.

Norwich, March, 1893.

THE HARMONOGRAPH.

THE facts that musical notes are due to regular air-pulses, and that the pitch of the note depends on the frequency with which these pulses succeed each other, are too well known to require any extended notice. But although these phenomena and their laws have been known for a very long time, Chladni, late in the last century, was the first who discovered that there was any connection between sound and form. His beautiful and classical experiments may be found fully described in any text-book on sound, and it forms no part of the design of this volume to enter into them. It is with a much later series of experiments by M. Lissajous that we are more immediately concerned. To adequately appreciate them we must dwell for a short space on vibrating movements.

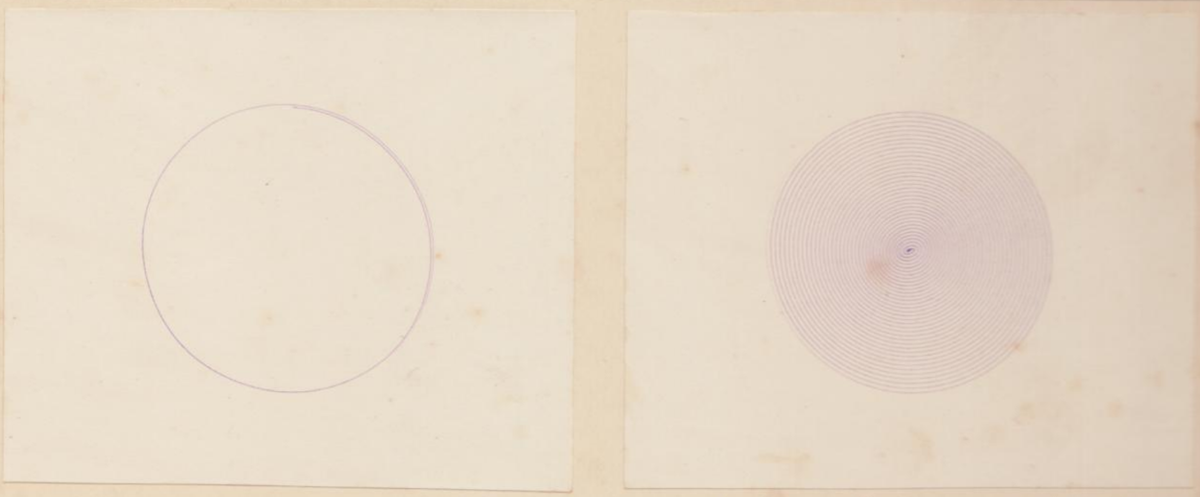
When a body is in such a state of motion that it makes forward and backward movements, returning at the end of each double movement to the position it started from, or nearly so, it is said to *vibrate*. Such a movement is that of the pendulum of a clock, which is slow enough to enable the eye easily to follow the whole motion. Such is also the movement of a tuning fork when sounding, though in this case the motion is so rapid that the eye, although able to appreciate the fact that there is motion, wholly fails to follow each individual swing. Such also is the motion of every sounding body, be it bell, piano string, the sonorous column of air in an organ pipe, or the speaking disc of the telephone.

The mechanical means by which these movements of the sounding body are transmitted to the membrane of the ear, and from thence to the auditory nerve, are of course fully understood; but there our knowledge stops. Why some sounds should give such exquisite pleasure and others such excruciating torture is a problem yet unsolved. We fully understand the nature of both classes of sounds, thanks to the labours of Helmholtz, and the many eminent scientists who have devoted themselves to this study; and if we know the component vibrations of any sound we can easily prophesy whether it will be pleasant or not to the ear. Whether the sound sensation is due to an actual movement communicated to the brain or not we do not know.

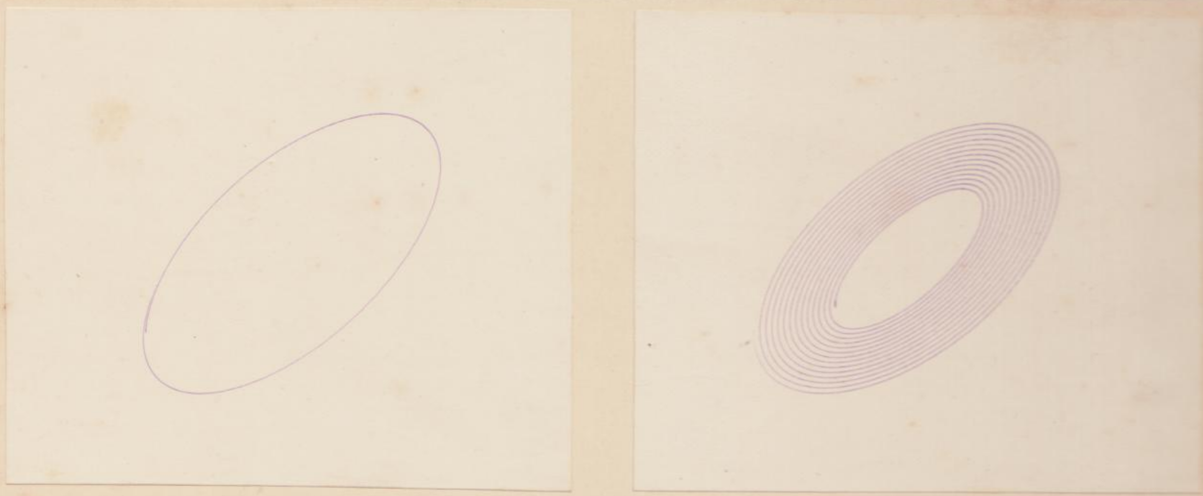
But this ignorance does not prevent our seeing some reason why certain sounds should be pleasant and others displeasing. A smooth rhythmical movement is pleasant to any

UNISON: CC

VIBRATION FRACTION $\frac{1}{1}$



Phase Difference $\frac{1}{4}$



Phase Difference $\frac{1}{8}$

Phase Difference 0 A.

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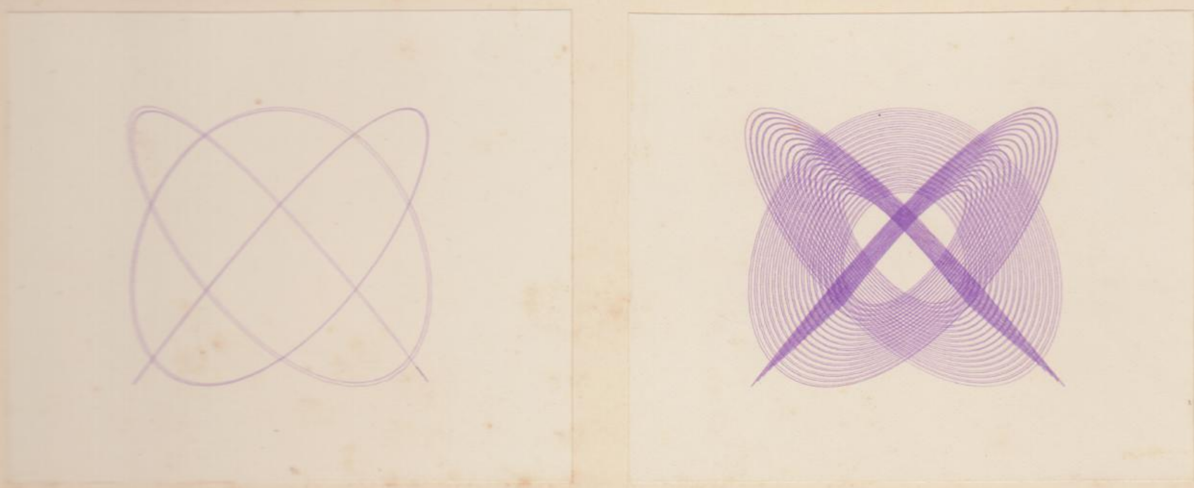
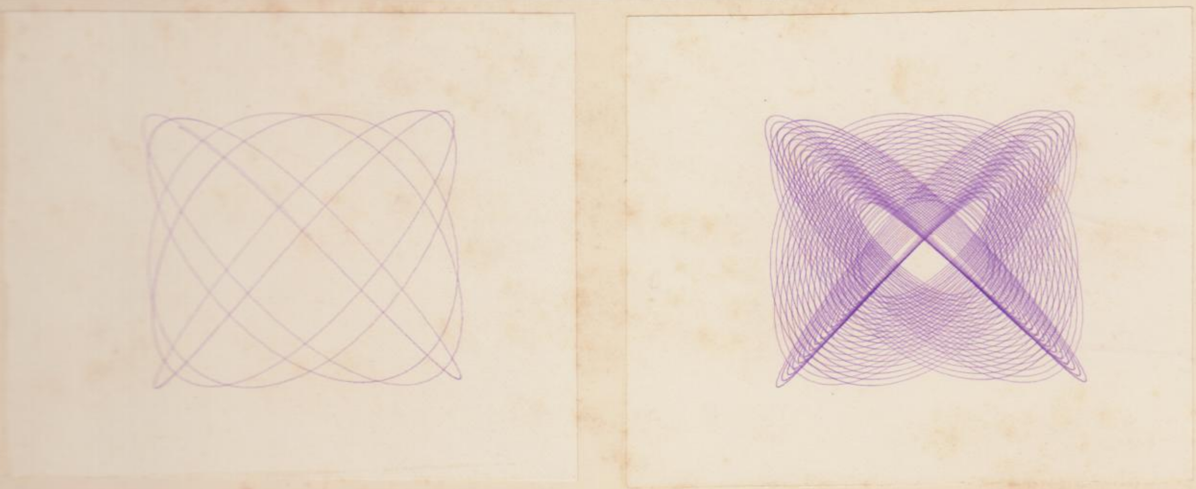
Pl. II. MINOR THIRD: C E♭

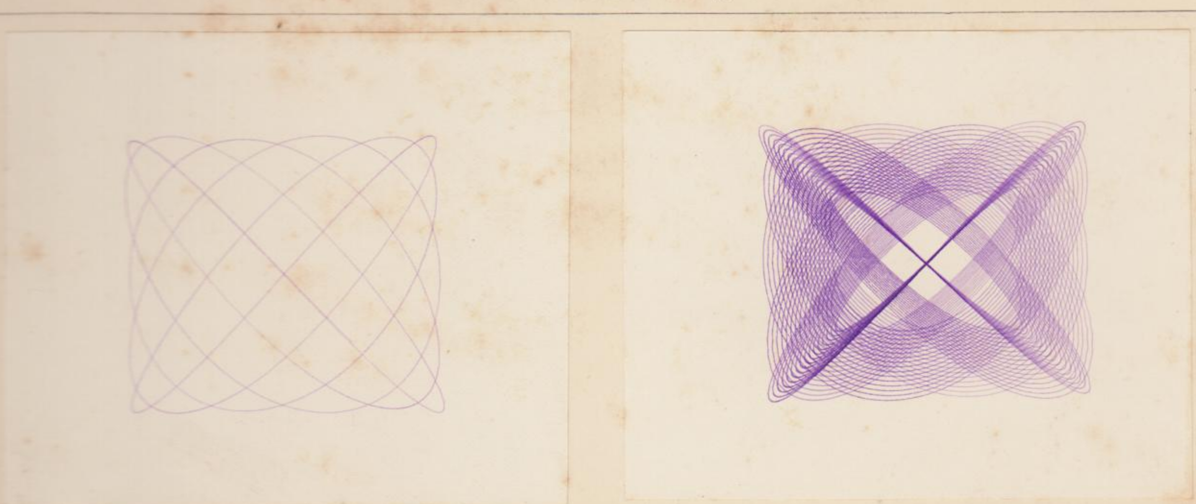
VIBRATION FRACTION $\frac{6}{5}$



Phase Difference $\frac{1}{20}$



Phase Difference $\frac{1}{40}$



Phase Difference 0

portion of the body, and so we should be led to expect that a smooth rhythmical movement of the membrane of the ear should transmit a pleasurable sensation to the brain, while an irregular jerking motion would be likely to prove as irritating to the delicate auditory apparatus as it is to any other part of the body.

When two notes of different pitch are sounded together, each communicates its own particular vibration to the ear drum, and the two produce a pleasant or harsh sound, according as the resulting vibration is smooth or irregular. In the former case the two notes are said to be in *harmony;* the latter combination is called a *discord.*

On such an instrument as the violin, there is, between the lowest note which it can produce and the highest, an infinite number of intermediate tones—a gradual and imperceptible shading, so to speak, of one tone into another. On other instruments, such as the piano, this is not so. A piano can produce a certain limited number of tones, each sharply marked off from its neighbours, above and below. This arrangement forms a *musical scale,* and the principles on which these fixed notes have been selected from the infinite variety of tones available, cannot be better described than by quoting from Prof. Sedley Taylor's beautiful work, "Sound and Music."

"We shall be well within the mark, if we assume that an ordinary ear can recognize on the average between one and two hundred sounds in an octave, or fully one thousand in the whole scale. There is nothing in the continuously shading off gradations of pitch to indicate what sounds should be picked out to form agreeable sequences, or combinations, with each other. Nevertheless, the human mind, working on this seeming chaos from the earliest dawn of musical art, has reduced it to order by discovering the following principle.

"When one sound has been arbitrarily selected as the starting-point, there is a certain number of other sounds, having fixed relations of pitch to that previously chosen, which are capable of forming with it and with each other, melodic and harmonic effects especially pleasing to the ear. These are the notes of the ordinary major and minor scales, the original sound of reference being the common *tonic,* or *keynote,* of those scales. In saying that these sounds have fixed mutual relations of pitch, we merely state formally an obvious fact. A familiar melody is recognised equally well, whether heard in the deep tones of a man's, or in the shrill notes of a child's voice. Whether the singer pitches it on a low or on a high note of his voice makes no difference in the melody itself. In fact, the correctness with which a melody is sung no more depends on the exact pitch of the note on which the singer started it, than does the faithfulness of a plan on the precise *scale* which the draughtsman has adopted. It is sufficient that the constituent notes of the melody should have fixed mutual *relations* of pitch, just as in the plan, the several objects represented need only be drawn *in proportion* to their actual dimensions.

"The difference in pitch of any two notes is called the *interval* between them ; it is on accuracy of intervals that music essentially depends.

"The most important interval in the scale is the *octave*. It is that which separates the highest note of a peal of eight bells from the lowest. The octave has this peculiarity, shared by no other interval, that, if starting from any note we choose, we ascend to that an octave above it, then to that an octave above the last, and so on, we get a number of notes which sound perfectly smooth and agreeable when heard all together. The same thing holds good if we descend by a succession of octaves from the note fixed on as our starting point. Hence we may conveniently regard the whole scale of pitch as divided into a series of octaves taken upwards and downwards from some one sound arbitrarily selected. Narrower intervals situated in any one octave are repeated in all the other octaves, so that, when we have settled these intervals for a single octave, we have settled them for all the rest. Within the limits of the octave the common major scale presents us with *seven notes*, or if we include that which forms the starting point of the next octave, with *eight*. The fact that the eighth note is the octave of the first explains the meaning of the word 'octave,' *i.e.*, 'eighth' (*Latin : 'octavus'*).

"The eight notes are those of an ordinary peal of the same number of bells, or of the white keys of a piano between two adjacent C's. We may for convenience of reference, number them 1, 2, 3, 4, . . . 8, beginning with the lowest note or tonic. The following nomenclature is used to describe the intervals formed by the several notes *with the tonic*.

Notes forming interval.	Name of interval.
1 and 2	Second.
1 " 3	Major Third.
1 " 4	Fourth.
1 " 5	Fifth.
1 " 6	Major Sixth.
1 " 7	Major Seventh.
1 " 8	Octave or Eighth.

"When two notes of the same pitch are sounded together, *e.g.*, by two instruments or by two voices, the notes are said to be in *unison*. Though there is here no difference of pitch whatever, it is convenient to rank the unison as an interval. With this explanation we may add to the above table that 1 and 1 form the interval of an unison.

"The several pairs of notes forming the intervals laid down in our table do not all produce smooth and agreeable effects when sounded together. The following pairs blend pleasantly

1—3, 1—4, 1—5, 1—6, 1—8 ;

the remaining two, 1—2 and 1—7, give rise to decidedly harsh effects. The intervals in the first line are therefore classed as concords, those in the second as discords."—*(Taylor, "Sound and Music," pp.* 59, *sqq.)*

There are two other intervals which rank as concords occurring in the Minor Scale, which will be referred to later in discussing the figures corresponding to them.

Having thus settled the various intervals with which we are concerned and their names, we must now return to M. Lissajous' experiment, already alluded to, by which he shewed a connection between sound and form. Two tuning forks were taken, tuned to give out exactly the same note, forming, therefore, an interval of an unison when sounded together. Each had fixed to the extremity of one prong a very small light mirror. They were arranged, one vertical, the other horizontal, with the mirrors facing each other, in such a manner that a ray of light from a powerful lamp fell, first on one mirror, was from it reflected on to the second mirror, and thence on to a screen, where it formed a small brilliant spot of light as long as the tuning forks were at rest.

Now, suppose the horizontal fork alone is set vibrating, a little consideration will shew that the spot of light reflected from it will execute backward and forward movements on the screen; but as the movement of the fork is very rapid the effect produced on the eye will, from the persistence of effect on the retina, be that of a horizontal line of light on the screen. Similarly, if the vertical fork is set vibrating, the other having been brought to rest, the effect will be that of a vertical line of light on the screen. Now, let both forks be set in vibration simultaneously, and there is no longer seen either a vertical or horizontal straight line, but one or other of the figures represented in the left-hand column of outline figures on Plate I., that is, the varying forms of the ellipse, having the straight line and circle as particular cases. Why we get sometimes one, sometimes the other, of these forms, will be explained later on, when treating of the same figures as produced by the Harmonograph.

If for one of the forks we substitute another, whose note forms with the remaining one the interval of an octave, we get on the screen the outline figures represented on the left-hand column of Plate VIII. If the interval be that of a Fourth or a Fifth, we get the figures represented on Plates IV. and V. respectively.

These figures thus produced are evanescent. The vibrations of the forks rapidly grow less and less, and accordingly the size of the figures gradually diminishes, until at the expiration of a few seconds the forks have come to rest, and the original spot of light is all that remains on the screen. To render them permanent, and at the same time to reduce the rapidity of the vibrations, so that the movements can be followed throughout by the eye, is the object of the Harmonograph.

This instrument was first constructed by Mr. Tisley, of the firm of Tisley and Spiller, the well-known opticians. In principle it is extremely simple. It consists of two heavy pendulums, each of which swings in a plane at right angles to that of the other. In the machine as originally produced, a plan followed by the author in constructing his, the pendulum rods are prolonged above the pivots on which they swing, and on the top of one is fixed a small cylindrical table, the axis of the cylinder coinciding with the centres on which the pendulum swings. To the top of the other, by means of a pivot moving freely, but without shake, is attached an arm, the free end of which carries a pen made out of a glass tube drawn out till the bore at the point is of microscopic dimensions, and ground down till the point is barely larger than the orifice. The length of the arm is so adjusted that, when both pendulums are at rest, the point of the pen rests exactly in the centre of the little table carried by the other pendulum. From this arrangement it will be seen that if one pendulum is set swinging while the other is at rest, the pen will mark a straight line on the paper carried on the table. If that pendulum be stopped, and the other put in motion, a straight line will again be traced, but this time at right angles to the other. Here we have a result in every way similar to that produced by Lissajous' arrangement, with the double advantage that the trace is permanent, and is performed so slowly that the eye can follow every part of the movement. In Lissajous' experiments the figure obtained depended on the *interval* between the notes produced by the forks, that is, on the *proportion* between their respective vibrations per second, and not in any way on the actual note, or rate of vibration of either. The lower note or tonic might be of any pitch, provided that the other was higher by the proper interval without any change taking place in the figure produced. In this regard also the Harmonograph fulfils the conditions of the experiment. The rate at which a pendulum swings depends on its length, and as the pendulums of the Harmonograph are so constructed that the bobs can be slid up and down the rods, we can by adjusting the bobs to the proper distance from the pivots, obtain any proportion we please in the rates of vibration of the two pendulums.

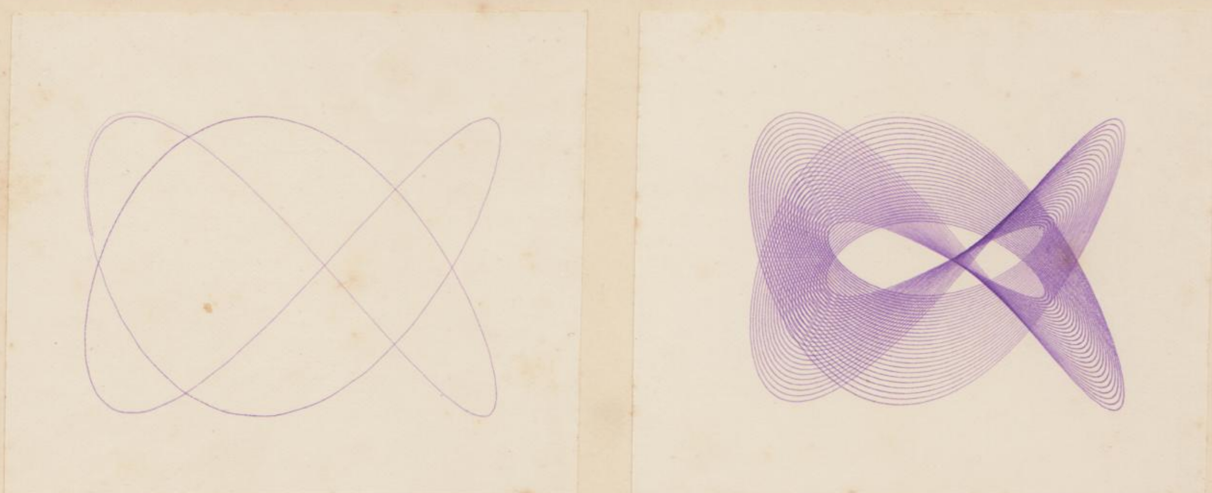
This description of the machine, though necessarily slight, will be sufficient to enable the reader to follow the process of obtaining successively the figures on the Plates. To get those on Plate I., the pendulums are adjusted to the same length as nearly as may be. One is then set swinging, preferably the one carrying the paper, the pen being supported so that it may not touch the paper, by means of a thread ; then the second is started, and when both are steadily swinging the pen is gently lowered on to the paper. The ellipse in some one of the forms depicted on Plate I. will be traced. But it will be found almost impossible to produce two consecutive ones exactly alike, and even a cursory examination will shew on what the difference between the various forms depends. It will be found that if the second pendulum

FIFTH

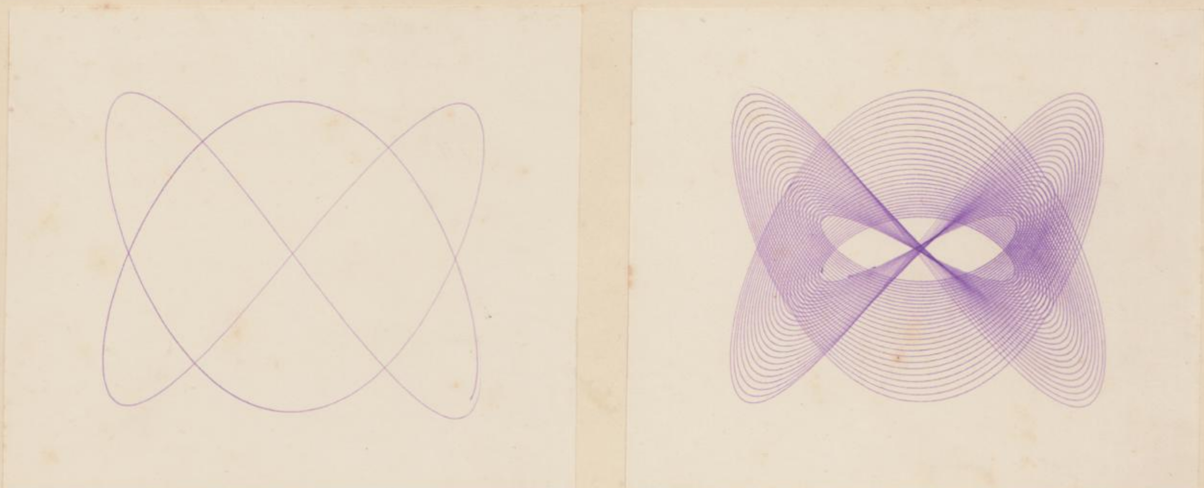
Pl. V.

VIBRATION FRACTION $\frac{3}{2}$

Phase Difference $\frac{1}{8}$



Phase Difference $\frac{1}{16}$



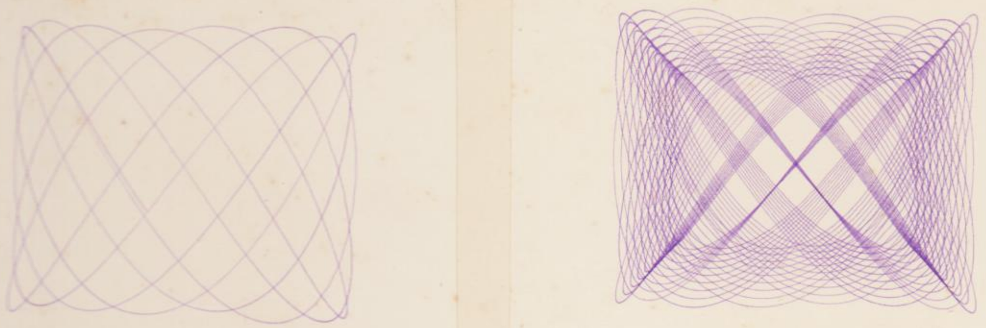
Phase Difference 0

PL. VI. MINOR SIXTH: C A♭

VIBRATION FRACTION $\frac{8}{5}$

PHASE DIFFERENCE $\frac{3}{20}$

PHASE DIFFERENCE $\frac{3}{40}$



PHASE DIFFERENCE 0

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be let go at the moment the other is passing the centre of its swing, an ellipse with its longer axis in the direction of the swing of one of the pendulums will be formed. If the extent of swing of the two be exactly equal this will give the circle. If one be swinging more widely than the other, the greater axis of the ellipse will be in the direction of the greater swing. If on the other hand the second pendulum be let go at any other period of the oscillation, the axis of the ellipse will be inclined, and the figure will be narrower the nearer the starting point approaches the extremity of the oscillation of the first pendulum. If the start is effected in such a manner that both reach the extremity of a swing at the same moment, the trace will be a straight line. To render possible the production of any given figure at will, an accessary piece of apparatus is necessary. This is a small trigger arrangement which holds the end of the rod of the second pendulum, and which is liberated, in the author's machine, by means of a small electromagnet. In connection with this is a contact key worked by the first pendulum. This contact key is adjustable, and can be so arranged that the first pendulum completes the electric circuit, and liberates the second automatically at any desired point on its swing. Thus armed, the machine can repeat the desired form at will, and it was only by this device that the author was enabled to produce the fifty copies of each figure necessary for illustration.

This clears the way for a few words on a matter of the greatest importance in connection with vibrating movements, namely, what is termed the *phase.* When, in the case of the instrument which we have before us, the two pendulums pass, at the same moment, through the position which they would occupy when at rest, they are said to be in the same *phase of vibration.* If when one is at its central point the other is at the extremity of its swing, the *difference of phase* is a quarter of a vibration (*note:* that a vibration consists of a double swing, ending when the pendulum returns to the point from which it started). It is on difference of phase, then, that the difference of form of the ellipses got by pendulums in unison depend ; and underneath each figure is marked on the plate the difference of phase necessary to produce it. The same holds good of the figures on all the other plates, the forms due to three differences of phase being given in each case.

Whether difference of phase has any effect in altering the quality of a sound is a matter in dispute. Helmholtz thinks not. Sir Wm. Thomson (Lord Kelvin) thinks it has. Where such giants differ, the author has no intention of throwing his pigmy weight into either scale.

If when the pen has described a complete ellipse the drawing is allowed to proceed, it will be found that owing to the friction of the pivots, and more especially of the pen on the paper, the pen will not have arrived exactly at the point it started from, but will proceed to describe a second ellipse slightly smaller than the first. A third, smaller still, will follow, and this gradual diminution in size will continue until the friction has finally brought the pen to rest in the centre of the figure. In this manner the beautiful spirals represented in the first two figures in the right-hand column are produced: of the third we will speak presently. So on all the other plates the right-hand figures are produced by repetition of the corresponding left-hand outline, each rendered smaller than the preceding, by the falling off of the amplitude of swing owing to friction. If the pendulums were kept up by clockwork, they would continue simply to trace the outline over and over again.

All the right-hand figures correspond to the outline adjacent with the exception of the last one (marked A) on Plate I. It will be seen at a glance that having started with a straight line the complete figure must also be a straight line, as the pen would simply trace the same over and over again, the falling off in amplitude merely producing a shortening of the line which would not be perceptible on the paper. Therefore, instead of an uninteresting repetition of the line, the very interesting figure at the bottom of the column was selected to fill the space. It shews at a glance the variation of figure produced by change of phase difference. To obtain it the pendulums are thrown slightly out of unison by sliding one of the weights up a little higher on the rod. The effect of this is to make the shorter gain slightly on the longer pendulum, so as to alter the initial difference of phase and consequently the form of the ellipse traced by the pen. We have already seen that, with equal amplitude of swing, the circle is the figure given when the difference of phase is $\frac{1}{4}$, that is when one pendulum is one quarter of a complete vibration behind the other, and that when the difference is 0, a straight line is described. Consequently, supposing the difference at starting to be arranged at a quarter, the effect of the gain of one pendulum will be to gradually diminish this difference, ultimately effacing it altogether. This effect may be clearly seen in the figure. Starting by tracing the circle which bounds the figure, a succession of gradually narrowing ellipses are seen, due to the diminishing difference of phase, until the second pendulum has at last overtaken the slower and arrived at the same phase, with the effect that the ellipse has now become a straight line. The original circle is slightly distorted by the first few ellipses projecting a little at either end.

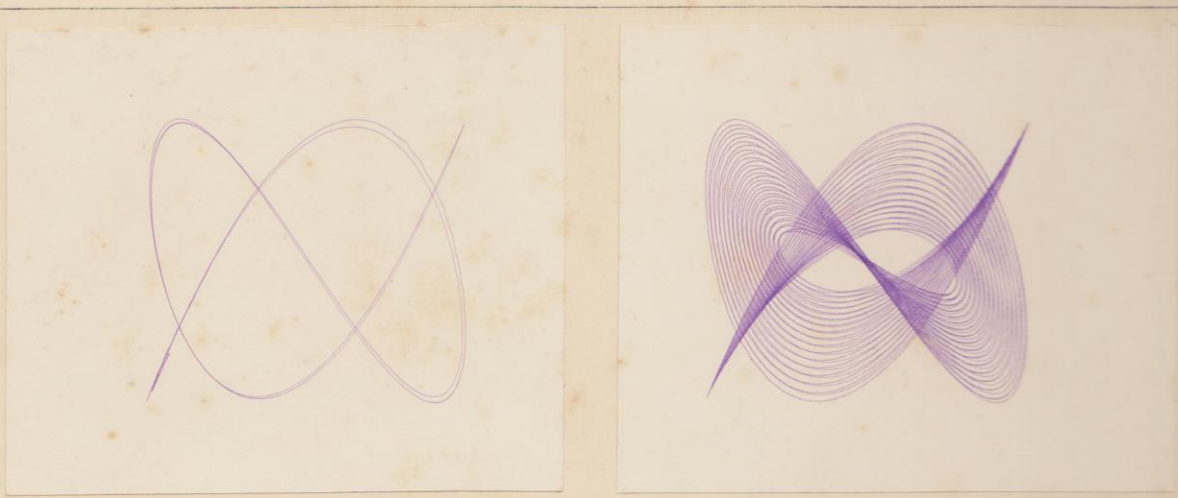
These unison figures are best obtained by using very light weights on the pendulums, in order that the size of successive curves may be diminished by the friction rapidly enough to keep the lines from cutting into each other, and producing a uniform coloured figure.

Now putting on heavy weights—in the author's machine nearly five pounds—and sliding one up the rod, until it is found by trial that one makes six vibrations to the other's five, we get the figure corresponding to the MINOR THIRD. By this is meant the figure described when the number of swings of one pendulum bears to the other the same proportion which exists between the vibration of two forks or two strings which give this interval when

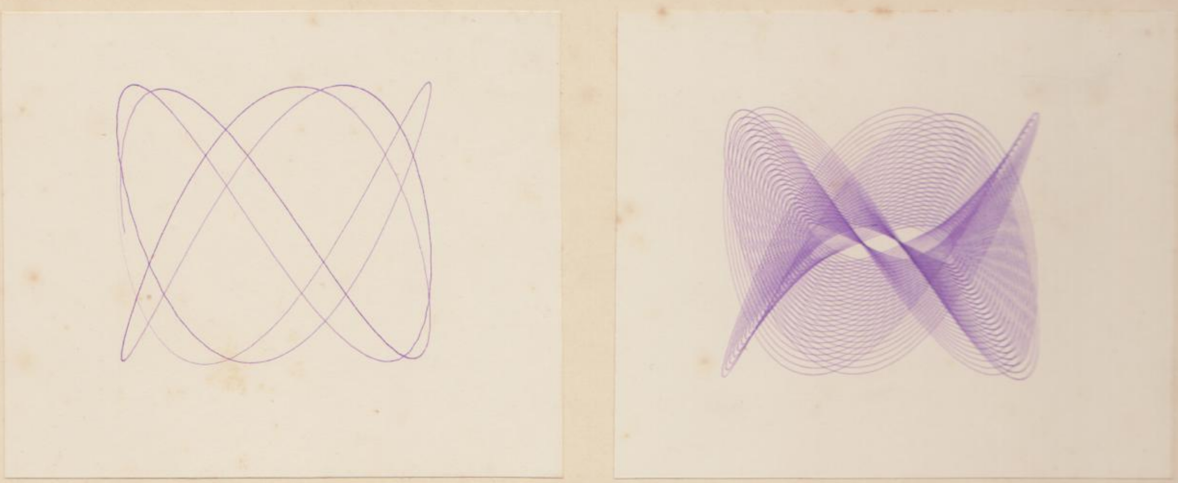
MAJOR SIXTH: CA

Pl. VII.

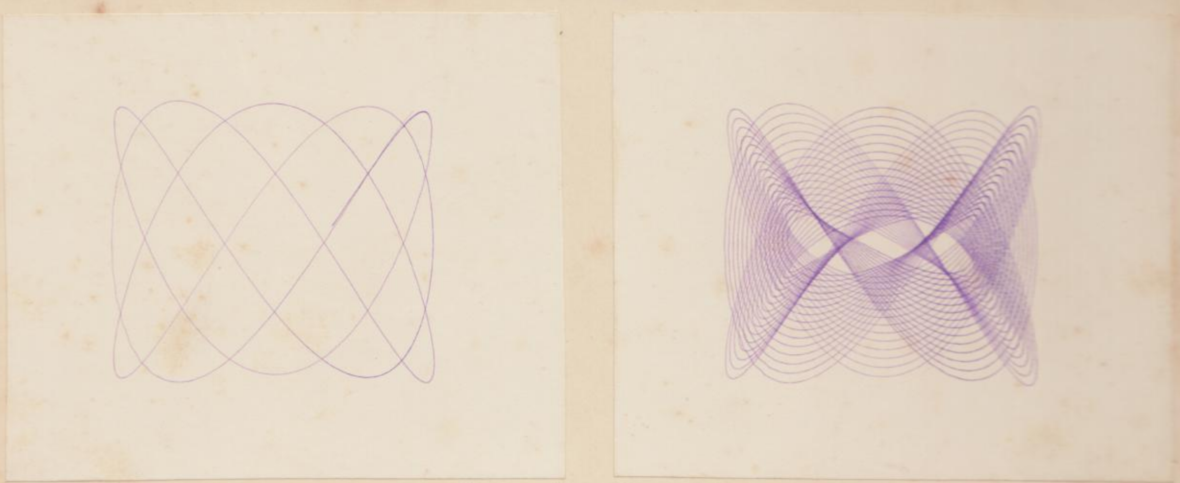
VIBRATION FRACTION $\frac{5}{3}$



Phase Difference 0



Phase Difference $\frac{1}{16}$



Phase Difference $\frac{1}{8}$

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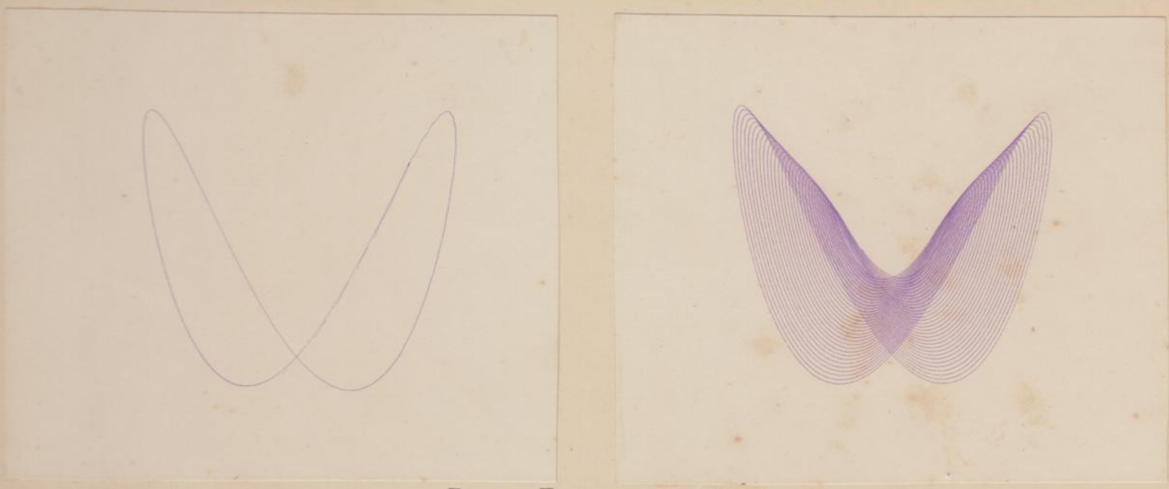
Pl. VIII.

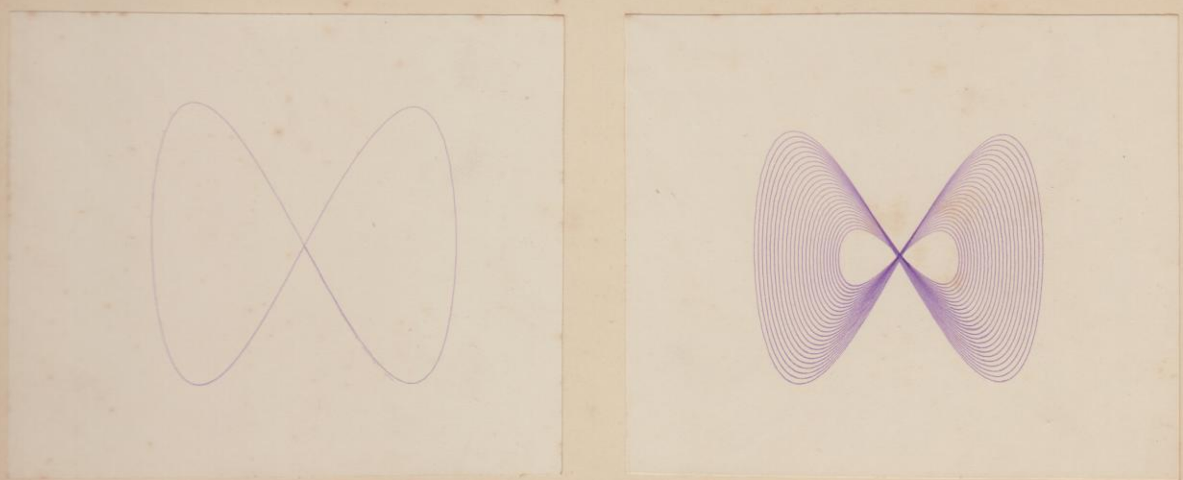
OCTAVE: CC

VIBRATION FRACTION $\frac{2}{1}$

Phase Difference $\frac{1}{4}$



Phase Difference $\frac{1}{8}$



Phase Difference o

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sounded together. To take a numerical example. Suppose the tonic or lower note to be the middle C, on a pianoforte, then the upper note of the minor third will be E♭. The middle C is given by a fork or string which makes 264 vibrations in a second, and the E♭ $316\frac{4}{5}$, and a little arithmetic will shew the first of these numbers is exactly $\frac{5}{6}$ of the other, or that while the higher tuning fork is making 6 vibrations the lower makes 5. This is one of the two concords in the minor scale of which mention has been made. It will be seen that the figure corresponding to it is complicated, owing to the long cycle of movements the pen has to pass through before it arrives again at its starting point. This indicates a correspondingly complicated movement of the drum of the ear, when impressed by two notes separated by this interval, and points to the probability that the corresponding sensation will not be as pleasant as if the resulting movements were simpler. Accordingly we find the Minor Third reckoned as only a moderate harmony. Sedley Taylor says of it that "it possesses strong elements of dissonance."

Space will not permit a lengthened discussion of all the figures selected. What has been already said will be sufficient to show the connection between harmony of sound and symmetry of form which it has been my object to indicate.

Sliding the weight still further up the rod until the swings are in the proportion of 4 to 3, the figure corresponding to the FOURTH is obtained. The simple relation of the vibrations give a simple symmetrical figure, and lead us to expect a result pleasant to the ear; nor are we disappointed. Though far from equal to the next interval, it is superior in its harmonic qualities to the Minor Third.

Still further shortening and therefore quickening the pendulum corresponding to our higher note, until the swings are in the proportion of 3 to 2, we reach the figure corresponding to the extremely perfect concord the FIFTH. The further simplifying of the relation gives a still simpler figure than that of the Fourth, and leads us to anticipate still greater harmony to the ear. As a fact, the only interval which surpasses it in smoothness is the octave, and the latter it must be remembered has already been mentioned as being absolutely perfect.

The next figure which claims attention is that given by the other interval in the minor scale already alluded to—that of the MINOR SIXTH. We get this figure by adjusting the pendulums till the relation of swings is 8 of one to 5 of the other. The magnitude of the numbers involved lead us at once to suspect only a moderate amount of harmony; the complicated nature of the figure strengthens the opinion, and we may again quote Professor Sedley Taylor as to the actual result. "We are here near the boundary line between concord and discord. . . . On the pianoforte and other instruments of fixed tones, *the same notes* (C A♭), *which represent the Minor Sixth, have also to do duty as one of the harshest discords, the Sharp Fifth* (C G♯). The extremely defective consonance of the

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Minor Sixth could hardly be more conclusively shewn than by the fact just mentioned." It may be added that this figure is also far the most difficult to obtain with the Harmonograph with accuracy, owing to the difficulty of seeing in the complicated maze of lines which form the cycle, the precise adjustment required to prevent alteration of the initial difference of phase and consequent distortion of figure.

The next plate represents the figures due to the MAJOR SIXTH. Here the vibration fraction, or relative vibration numbers, becomes again more simple—5 of one pendulum to 3 of the other. The figure is still complicated, but must be reckoned, at least in the author's opinion, one of the most striking and beautiful in the series, particularly the middle one. As a harmony, it is ranked by musicians as about equal to the Major Third.

Last, but not the least curious in the figure to which it gives rise, as supreme among all in the perfection of its harmonic effects, comes the OCTAVE. We have already quoted Professor Taylor's statement as to the musical value of this interval, so on that point need say no more. The vibration proportion is the simplest of all—2 to 1—and the figure as simple as the concord is perfect. It is not a little curious, the coincidence—for of course it is the merest coincidence—that the figure given by the pendulums when vibrating in the same proportion as the strings which form the interval between the first and eighth notes, should be the figure 8, distorted, it is true, when the phases differ, but so singularly accurate when they coincide.

Overtones and beats are out of the sphere of this little work, though they form the principal causes of harmony and discord. For an acquaintance with them and their effects, we must refer the reader to the many able text-books on Sound. Professor Taylor's delightful book, already quoted, and Professor Tyndall's "Sound," will well reward the reader who may desire to become versed in the physical basis of harmony; while any mathematical reader, who may care to investigate the mathematics of the beautiful curves, will find a very simple exposition of them in Jamin's "Cours de Physique de l'Ecole Polytechnique." All the task the author set himself was to lay before a few friends the productions of the fascinating machine which gives its title to this little volume, together with such few remarks as might enable them to understand how they are produced. This latter part has been done "with rough and all unable pen," but if he has succeeded in giving them some little pleasure, he will have succeeded in accomplishing the main object of his work.