Experiments on the Least Number of Vibrations Necessary to Determine Pitch.

Arthur Farwell.

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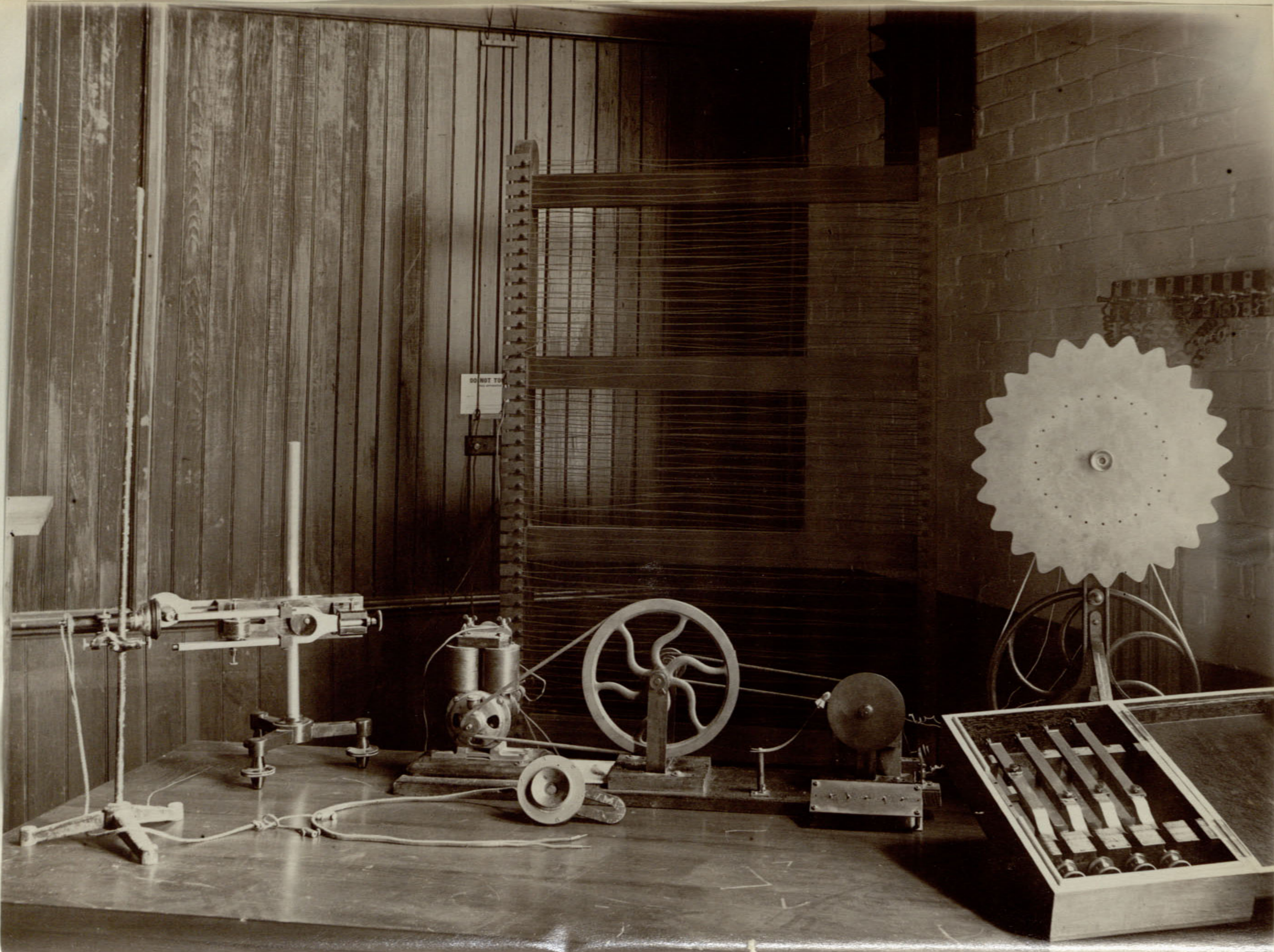
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The earliest investigations upon this subject appear to have been made by Savart and Kohlrausch, whose results, owing to a defect in their method of proceedure, are practically valueless, but of considerable interest from an historic standpoint. To obtain the sounds employed, Savart made use of a toothed wheel, rotating at a known speed and whose teeth were made to impinge upon a card. It was found with a given speed of the wheel, that the impulses due to only two teeth produced a pitch which could be distinguished as different from others which were near it in the scale, and this pitch was identical with that due to a greater number of teeth when the speed was the same. One tooth alone allowed to act gave a lower pitch corresponding in vibration number to the number of revolutions of the wheel per second. Hence it was inferred that two complete impulses or vibrations were necessary for the recognition of a pitch. The chief error in this assumption is due to the fact that the sound waves obtained by this process are far from pure in their character. That is to say, instead of a uniform flow of sinusoidal sound waves, Savart obtained a succession of impulses which were impure and obscured by coalescence with each other. Kohlrausch employed a pendulum carrying a segment of a wheel upon which he could fix any desired number of teeth. His experiments were based upon the same principle as were Savarts thus being open to the same criticism.

Since the performance of these experiments it has been suggested that it is reasonable to suppose that if a single sinusoidal vibration or even a small fraction of such a vibration could be made to fall upon the ear, it would produce a definite pitch. Possibly the mind, aided by the sense of hearing would be, by some natural process, enabled to supply the remainder of the wave in a manner analogous to that of the mathematician who by his equations is enabled artificially to complete a curve of which he has only a portion given.

Accordingly an instrument was devised at the Massachusetts Institute of Technology in 1884 whereby such vibrations or fractions thereof could be caused to fall upon the ear. This apparatus, as modified in 1891, consisted of a telephone circuit comprising two magneto telephones and a circuit-breaking wheel whose speed was controlled by a small electric motor. The wheel was made of brass and had a diameter of 12.51 cm. In the periphery was inserted a small piece of vulcanite which formed an insulating sector .275 cm in length. A spring with its point of contact platinized, pressed against the circumference of the wheel thus securing the passage of the current, which then traversed the shaft and was led off through a second wheel which dipped at all times into a mercury cup. The circuits were so arranged that when the contact spring pressed against the brass portion of the wheel, the current from the transmitting telephone, which was placed in a distant room, was short circuited on itself through the wheel, this being of lower resistance than the receiving telephone, which was placed in a shunt circuit around the wheel; but when the vulcanite sector passed beneath the spring, the current was shunted off through the receiving telephone this being momentarily the circuit of lower resistance. Thus on each revolution of the circuit-breaking wheel a short pulse of sound could be heard at the receiving telephone and its duration was easily calculated, knowing the speed of revolution and the dimensions of the wheel. Transmission was accomplished by striking a tuning fork and placing its foot upon the diaphragm of the transmitting telephone. A bit of wax upon this portion of the fork served to prevent chattering.

Upon the instrument thus constructed, a series of experiments were performed by Charles R. Cross and Margaret E. Maltby, the results of which will be briefly stated. The first of these experiments consisted in attempting to distinguish a C_3 fork (256 vib.) from a C_4 fork (512 vib.) having given but a small number or fraction of their respective vibrations. At the speed at which the circuit-breaking wheel was first run, the listener at the receiving telephone heard .88 of a complete vibration of the lower fork at each revolution of the wheel, and 1.76 vibrations of the higher fork. With this limited number of vibrations, the forks were quite readily distinguishable. The speed was then increased and .80 and 1.60 vibrations of the two forks respectively were transmitted. Here again the forks were readily distinguishable. Several increases in the speed were made and at .42 and .84 vibrations a marked falling off in the percentage of correct estimations was observed, but in general, even with this number, more than one half of the estimations were correct. Almost similar results were obtained with forks C_3 and G_3 (384 vib.). About three fourths of the estimations were correct when the listener heard .41 vibrations of the C_3 and .62 of the G_3 fork. In distinguishing the C_3 fork from the E_3 (320 vib) greater difficulty was noted, and with forks making 256 and 260 vibrations per second respectively, distinction became almost impossible. Thus although in all cases each pulse suggested to the listener a distinct pitch, yet as the interval between the two notes became less, it became more and more difficult to tell which was the higher and which the lower fork.

Several series of observations were now made upon a number of forks, struck irregularly. The listener here attempted to state which of the forks was heard, knowing what forks composed the set. Those used were the C_3, E_3, G_3 and C_4 and the complete vibrations transmitted varied from 4.8 (C_4 fork) and 2.4 (C_3 fork) to 1.8 (C_4 fork) and .9 (C_3 fork) during the course of the series of observations which were made, while the number of correct estimations averaged about 75%. A number of sets of observations were also made upon various combinations of forks with very similar results. Distinction between a C_3 fork and a D_3 (288 vib) was accomplished with the aid of only .25 and .28 vibrations respectively. One curious effect in particular was observed, that occasionally in distinguishing between two pitches a continued misjudgment as to which was the higher and which the lower sound, occurred. This will be spoken of again.

These experiments thus briefly described cover nearly all the work that has been done previously upon the subject, and those experiments described in the remainder of this paper, are in part a continuation of the former, the others being the results of investigations heretofore merely suggested. Throughout the following work, the apparatus used was that which has been described, without modification, except during its use in a certain series of experiments, which which will be noted here after.

The transmitter employed was a loud speaking bipolar magneto instrument having a large diaphragm. The forks were the same as those used in 1891 and were selected from a set composing a Valentine and Carr tonometer. The receiver was also of the same kind before used, being a very sensitive form of magneto instrument manufactured in Sweeden. Care had to be taken to keep both the rim of the circuit-breaking wheel and the contact point of the spring smooth and clean, and even with these precautions, at high speeds, it was impossible to preserve a noiseless contact, so that the pulses were somewhat blurred and run together.

The instrument was adjusted so that during transmission no sound was heard in the receiver as long as the spring pressed against the brass portion of the wheel. When, on the contrary, the spring rested upon the insulating sector the sound from the transmitting fork could be distinctly heard. In making the observations, the wheel was run at a moderate speed, and the time of one hundred revolutions noted. From this, knowing the pitch of the fork, the number of complete vibrations sent through the receiver at each revolution could be readily calculated. The speed at first was such that there was little or no difficulty in distinguishing the forks used, one from the other. These forks were in the first series of observations, the c_3 and the c_4.

Table I shows in detail the results obtained. In the first column the sets of observations are numbered for reference, this column being continued through all the Tables, though not necessarily representing the chronological order in which the series were made. The second ~~and~~ third columns headed c_3 and c_4, give the number of complete vibrations of each fork respectively, that were transmitted at each revolution of the wheel. Then follow the series of observations as made, the erroneous estimations having a line drawn

Table I.

No.	C_3	C_4	Records	P.
1.	0.68	1.36	$C_3\ C_4\ \underline{C_4}\ C_4\ C_4\ C_4\ C_3\ C_4\ C_3\ \underline{C_4}$	80
2.	"	"	$C_4\ C_3\ C_4\ C_3\ C_3\ C_3\ C_4\ C_4\ C_4\ \underline{C_4}$	90
3.	"	"	$C_3\ C_4\ C_3\ C_4\ C_4\ C_4\ C_4\ C_3\ C_3\ C_3$	100
4.	0.52	1.04	$C_3\ C_4\ C_3\ C_4\ C_4\ C_4\ \underline{C_3}\ C_3\ C_4\ C_3$	90
5.	"	"	$C_3\ C_4\ C_3\ C_4\ C_4\ C_3\ C_3\ C_4\ C_3\ C_4$	100
6.	"	"	$C_4\ C_3\ C_4\ C_3\ C_4\ C_4\ C_3\ C_3\ C_3\ C_4$	100
7.	0.42	0.84	$C_3\ C_4\ C_3\ C_3\ C_4\ C_4\ C_4\ C_3\ C_4\ C_3$	100
8.	"	"	$C_4\ C_3\ C_4\ C_3\ C_3\ C_4\ C_4\ C_3\ C_4\ C_3$	100
9.	"	"	$C_4\ C_3\ C_3\ C_3\ C_4\ C_4\ \underline{C_4}\ C_4\ C_3\ C_4$	90
10.	0.41	0.82	$C_3\ C_4\ C_3\ C_4\ C_4\ C_4\ C_4\ C_3\ C_3\ C_4$	100
11.	"	"	$C_4\ C_3\ C_4\ C_3\ C_3\ C_3\ C_4\ C_3\ C_4\ \underline{C_3}$	90
12.	"	"	$\underline{C_4}\ C_3\ C_3\ C_4\ C_4\ C_3\ C_4\ C_3\ C_4\ C_3$	90
13.	0.37	0.74	$C_3\ C_4\ C_3\ C_4\ C_3\ C_4\ C_4\ C_3\ \underline{C_4}\ C_3$	90
14.	"	"	$C_4\ C_3\ \underline{C_3}\ C_4\ C_4\ C_4\ C_4\ C_3\ C_4\ C_4$	90
15.	"	"	$C_4\ C_4\ C_3\ C_4\ C_3\ C_3\ C_3\ C_4\ C_3\ \underline{C_3}$	90
16.	0.33	0.66	$C_3\ C_4\ \underline{C_4}\ C_4\ C_3\ C_3\ C_3\ C_4\ C_4\ C_3$	90
17.	"	"	$\underline{C_3}\ C_3\ \underline{C_3}\ C_3\ C_4\ \underline{C_3}\ C_4\ C_3\ C_3\ \underline{C_3}$	60
18.	"	"	$C_3\ C_3\ \underline{C_4}\ \underline{C_4}\ \underline{C_3}\ \underline{C_3}\ C_3\ C_4\ C_4\ C_3$	60
19.	"	"	$C_3\ C_4\ C_3\ \underline{C_3}\ \underline{C_3}\ C_4\ C_3\ \underline{C_4}\ \underline{C_3}\ \underline{C_3}$	50

No.	C_3	C_4	Records.	P
20.	0.33	0.66	$\underline{C_3}\ \underline{C_4}\ C_3\ C_4\ \underline{C_3}\ \underline{C_3}\ \underline{C_4}\ \underline{C_4}\ \underline{C_3}\ \underline{C_4}$	20
21.	"	"	$C_3\ \underline{C_3}\ C_3\ C_3\ C_3\ \underline{C_4}\ \underline{C_3}\ \underline{C_3}\ \underline{C_3}\ C_4$	50
22.	"	"	$C_3\ C_4\ C_3\ \underline{C_3}\ C_3\ \underline{C_4}\ C_3\ \underline{C_3}\ C_3\ C_4$	70
23.	"	"	$C_3\ C_4\ \underline{C_3}\ C_3\ C_3\ C_3\ C_4\ C_4\ C_4\ \underline{C_3}$	80
24.	"	"	$C_3\ C_4\ C_3\ C_4\ C_4\ C_4\ C_3\ C_3\ \underline{C_3}\ C_3$	90
25.	"	"	$\underline{C_3}\ C_4\ \underline{C_3}\ C_3\ C_3\ C_4\ C_3\ C_4\ C_4\ \underline{C_3}$	70
26.	"	"	$C_3\ C_3\ C_4\ C_4\ C_4\ \underline{C_4}\ C_3\ C_4\ C_4\ C_4$	90
27.	"	"	$C_3\ C_3\ C_4\ C_4\ C_4\ C_4\ C_3\ C_4\ \underline{C_4}\ C_4$	90
28.	0.31	0.62	$C_3\ C_4\ \underline{C_4}\ C_3\ C_3\ C_3\ C_4\ C_4\ C_4\ C_4$	90
29.	"	"	$\underline{C_4}\ C_4\ C_3\ C_4\ C_3\ C_3\ \underline{C_4}\ \underline{C_3}\ C_3\ \underline{C_3}$	60
30.	"	"	$C_3\ C_4\ C_3\ C_4\ C_4\ C_4\ C_3\ C_3\ \underline{C_3}\ C_3$	90
31.	"	"	$C_4\ C_4\ C_4\ C_4\ C_3\ C_4\ C_3\ C_4\ C_4\ C_4$	100
32.	0.29	0.58	$C_3\ C_4\ C_3\ \underline{C_3}\ \underline{C_4}\ \underline{C_4}\ C_3\ C_4\ \underline{C_3}\ C_3$	60
33.	"	"	$\underline{C_3}\ \underline{C_4}\ C_3\ C_4\ C_4\ \underline{C_4}\ \underline{C_3}\ C_3\ C_4\ C_4$	60
34.	"	"	$C_4\ C_3\ \underline{C_4}\ C_4\ C_4\ C_4\ C_3\ C_4\ C_3\ C_3$	90
35.	"	"	$C_3\ C_4\ C_3\ C_4\ C_4\ C_4\ C_4\ C_3\ C_3\ C_3$	100
36.	0.28	0.56	$C_3\ C_4\ C_4\ C_3\ \underline{C_4}\ C_3\ C_4\ C_3\ \underline{C_3}\ C_3$	80
37.	"	"	$C_4\ \underline{C_3}\ C_3\ C_4\ C_3\ C_4\ C_4\ C_3\ \underline{C_4}\ C_4$	80
38.	"	"	$\underline{C_4}\ C_3\ C_4\ C_3\ C_4\ C_4\ C_3\ C_4\ \underline{C_4}\ C_4$	80
39.	"	"	$C_3\ C_3\ C_3\ C_4\ C_4\ C_4\ C_4\ C_3\ C_4\ C_3$	100

beneath them. The last column headed P. shows the percentage of correct estimations.

In making these observations the experimenter at the transmitter sent to the listener four preliminary signals thus - 256 - 512 - 256 - 512 - before beginning the set, in order that the two tones should if possible fix themselves in the mind of the listener; in the tables no note is made of these preliminary signals. A set of ten observations was then made, each observation consisting of an estimation whether the fork heard was the higher or the lower one, this being noted down as C_3 or C_4. The fork was usually held in place during several revolutions of the wheel, the listener hearing four or five

pulses of each pitch transmitted
As is seen from the table, the sets of experiments 1, 2 and 3 were made with .68 and 1.36 vibrations from the two forks, just twice as many vibrations from the c_4 fork passing, at a given speed of the wheel. Before making any observations whatever, the ear was given a little preliminary training, so that when the first recorded series were made, little difficulty was found in distinguishing between the two forks. Sets 4, 7, 10, 13, and 16 marked an increase in speed and hence a less number of complete vibrations transmitted. In the falling off from .68 and 1.36 vibrations, in the first sets to .33 and .66 in the sixteenth, no increased difficulty was found

in obtaining a large percentage of correct estimations. In sets 17 to 22 inclusive, the spring failed to preserve a noiseless contact and the tones were sometimes clear and sometimes confused so that no reliance could be placed upon the results. In sets 23 and following, the speed was successively raised so that in the final series, the vibrations transmitted were reduced to .28 for the C_3 and .56 for the C_4 fork. In all sets where the operation of the apparatus was satisfactory, will be observed a large preponderance of correct over incorrect estimations. At speeds higher than those tabulated, good spring contact could not be secured, but the experiments performed would indicate that could this difficulty be obviated, the results could be carried satisfactorily to a point considerably beyond that actually reached. Although in the foregoing sets, each pulse seemed to have a distinct pitch of its own, yet this pitch was not, at least at high speeds of the wheel, the true pitch of the fork, for while the interval in reality was an octave, in some of the sets it appeared to the listener to be a distinct minor third, while at the same time the fork which was in reality higher, sounded lower in pitch than the other. Even in these sets, the greater part of the estimations were correct for the ear was familiarized by virtue of the preliminary signals, with these peculiarities. As nearly as could be judged by the listener, the higher fork appeared to be lower than the other by a minor third while the lower fork seemed to retain its normal pitch. Whether this effect was due to inductance, to the spring contact, or to interference due to the natural rate of vibration of either diaphragm can be determined only by further experiment.

Table II shows a similar series of experiments, but instead of octave forks, the c_3 and G_3 were used. These forks were found distinguishable with .74 and 1.11 vibrations from each respectively. When the speed was raised, much difficulty was found in preserving a good contact at the spring, which persisted in scratching, even

Table II.

No.	C_3	G_3	Records	P.
40.	0.74	1.11	G G C G G C C C G G	50
41.	"	"	G C G G G C C C C G	60
42.	"	"	G C G C C C G C G G	100
43.	"	"	C C C G C C C G C G	80
44.	0.41	0.61	C G C G C G C C G C	50
45.	"	"	C C G C C G C G C C	50
46.	"	"	C C G C G C C G C C	40
47.	"	"	C G G G C C G C C G	10
48.	"	"	C G C G C G C C G C	80
49.	"	"	C G C G C G G G G C	10
50.	"	"	G C G G C C G G G G	50
51.	"	"	C G C C G C C G C G	80
52.	"	"	G C G C C C G G C C	10
53.	"	"	C G G C C C G G C C	70
54.	"	"	C G C C G C C G C G	60
55.	"	"	C G C C G G G C C C	70
56.			C C G C C C G G C C	70
57.			G G C G C C G C G G	70

when polished with emery. Thus distinction was rendered almost impossible in sets 44 to 52 inclusive with the exception of sets 48 and 51 where there was little or no scratching at the spring. From the curious results of sets 47, 49 and 52 can scarcely any deduction be made since on account of the failure of the spring to operate well, these sets were not made under normal conditions. In sets 53 to 57 inclusive, the apparatus again worked satisfactorily, and correspondingly better results were obtained. Attempts to extend the results of this series were baffled only by the failure of the spring to perform its function satisfactorily.

It was now attempted to determine the pitch of the tones transmitted, by comparison with forks of similar pitch struck by the listener, no preliminary signals being given. Table III gives the results of the first trials of this kind, which although they failed to bring about any satisfactory conclusions are interesting from another stand point. As stated, no preliminary signals were sent, but each set consisting of the C_3 and C_4 forks struck irregularly, was begun immediately, the listener attempting to distinguish which was which by comparing the sound heard, with two forks known to be of the same vibration rate as those used at the transmitter. Sets 58 and 59 gave a large percentage of correct estimates but

Table III

No.	C_3	C_4	Records	P.
58.	0.69	1.38	C_3 C_4 C_3 C_3 C_4 — — —	100
59.	"	"	C_4 $\underline{C_3}$ C_3 C_4 C_3 C_3 C_4 C_3	87.5
60.	0.54	1.08	C_3 $\underline{C_4}$ $\underline{C_3}$ $\underline{C_4}$ $\underline{C_3}$ $\underline{C_3}$ C_4 C_3	37.5
61.	"	"	$\underline{C_4}$ $\underline{C_3}$ $\underline{C_3}$ $\underline{C_3}$ $\underline{C_4}$ $\underline{C_4}$ $\underline{C_3}$ $\underline{C_4}$	0
62.	"	"	$\underline{C_4}$ $\underline{C_3}$ C_4 $\underline{C_4}$ $\underline{C_4}$ C_4 $\underline{C_4}$ C_4	37.5
63.	"	"	$\underline{C_4}$ $\underline{C_3}$ $\underline{C_3}$ $\underline{C_3}$ C_3 C_4 C_3 C_3	50

were of no value as far as the point in question was concerned for the comparison forks proved entirely useless, it being merely a matter of memory to tell which was the higher and which the lower fork. That is, the preliminary signals being already dispensed with, the results would have been equally good whether the listener had forks for comparison or not. When the speed was raised in set 60, giving .54 and 1.08 vibrations of the two forks the percentage of correct estimations almost invariably fell below 50% thus demonstrating that after the vibrations sent, had been cut down to a certain amount, an apparent reversal of pitch took place, which caused the higher fork to sound lower than the other. Thus in sets 60, 61, 62 and 63, had preliminary signals been given, this reversal would have been appreciated and in all probability the percentages would have been above 50. Set 61 is a striking example of this curious illusion. Whatever else it may or may not show, Table III at least shows that with the speeds of wheel employed, it was impossible to determine the actual pitch of the notes sent, by comparison with similar forks.

An attempt was then made to devise a series of observations by which more conclusive results could be reached. The transmittor now took five forks making 256, 320, 384, 424 and 512 vibrations per second. These were struck irregularly and the listener attempted to select from among the sounds transmitted, the c_4 pitch, having that fork alone for comparison. Eight observations constituted a set and in sets 64, 65, 66 and 78 of Table IV which follows, the sign o signifies ~~that~~ the listener estimated the corresponding pitch to be the c_4 and the dash (—) signifies an estimation that it was not c_4, but some one of the other forks, no attempt being made to tell which one. The estimations were made by comparing each sound transmitted with the c_4 fork, then recording the result. The subscript x signifies an

Table IV

No.	C_4	Records.	P_1	P_2
64.	2.64	— —x — — O — — O	$66\frac{2}{3}$	100
65.	"	O —x — — — — O —	$66\frac{2}{3}$	100
66.	"	— O — O — O —x —x	60	100
	C_3			
67.	1.32	O — —x — O — O —	75	100
68.	"	O —x — — — —x Ox —	$33\frac{1}{3}$	80
69.	"	O — — —x Ox — —x —x	25	75
70.	1.10	O — — Ox O — O —	100	80
71.	"	— —x Ox — Ox O —x —x	25	50
72.	"	O Ox — O —x — Ox O	75	50
73.	"	O —x — Ox Ox —x —x O	40	$33\frac{1}{3}$
74.	"	—x Ox O — — O O Ox	75	50
75.	"	O — Ox —x O —x Ox O	60	$33\frac{1}{3}$
76.	"	—x O O —x O —x O —	$57\frac{1}{7}$	100
77.	1.08	O — — O —x Ox — O	75	75
	C_4			
78	2.16	—x — — — Ox O O —	$66\frac{2}{3}$	80

incorrect estimation. The second column in the table gives the number of complete vibrations of the C_4 fork transmitted. In sets 67 to 77 inclusive, an attempt is made to select the 256 fork (C_3) in a similar manner, and in these sets, the second column gives the vibrations in terms of the C_3 fork as indicated in the table. The selection was not always made from five forks, thus in set 73 the only forks employed at the transmitter were the 256 and 320, and in sets 74, 75, and 76, only the 256 and 384, which fact was previously made known to the listener. Likewise in set 77 only the 256, 320, 384 and 427 forks were used, and in set 78 only the 384, 424 and 512.

The first of the percentage columns headed P_1 gives the per cent of correct estimations upon those pitches transmitted in each set which actually were the 512 or 256 as the case might be: the column P_2 gives the percentage of correct estimations upon those forks in each set which were other than the fork which was being selected. For satisfactory indications it will be seen that both these percentages must be high, for if either falls off it shows at once that the listener is unable to distinguish clearly whether he hears the fork he is endeavoring to select, or some other one of the set. Thus sets 64, 65, 66, and 78 show that the C_4 fork is quite readily distinguished from among a number of others when we receive from it as low as 26.4 or 21.6 vibrations. In the eleven sets, 67 to 77 inclusive, made upon the 256 fork, six gave results in which the percentages of correct estimations in both columns were high enough to permit us to infer that the C_3 fork was distinguishable, while five gave the opposite result. But in no case was a note mistaken for a C_3 which was in reality distant from it on the scale. Thus the C_3 and E_3 forks were those most often mistaken for each other. This leads us to believe that with an ear slightly more trained than was the observers, at the time no difficulty would arise in clearly distinguishing the C_3 fork. This however is a matter for further experiment.

Table V is similar to table III in that it represents the attempt made distinguish between two forks by comparison with two of similar vibration rate. The radical difference between this and the former experiment is that here considerable time was allowed to elapse between the successive observations so that the element of memory should not enter as so large a factor in influencing the results. Columns C_3, G_3 and C_4 show the number of complete vibrations of the respective forks heard by the observer at the receiving instrument. Erroneous

Table V.

No.	C_3	G_3	C_4	Records.	P.
79.	0.68	1.02	—	$\underline{G}$ C G C $\underline{C}$ C G $\underline{C}$ G G	
				C $\underline{G}$ G C C G C G G $\underline{G}$	75
80.	—	1.02	1.36	G G G C C $\underline{G}$ G C G $\underline{G}$	
				G $\underline{C}$ $\underline{G}$ $\underline{G}$ $\underline{C}$ G $\underline{C}$ $\underline{G}$ C G	60
81.	0.69	—	1.38	$\underline{C_4}$ C_4 $\underline{C_3}$ C_4 C_3 C_4 C_3 C_3 C_3 C_4	
				$\underline{C_4}$ C_3 $\underline{C_3}$ $\underline{C_3}$ $\underline{C_3}$ C_3 C_4 C_3 $\underline{C_3}$ C_3	65

estimations are underlined. From the manner in which these experiments were conducted, it is thought that the effect of memory was largely if not wholly eliminated and that the forks were recognized only by the similarity of the sounds heard, to the duplicate comparison forks. This table needs no further explanation.

Table VI is a similar series with three forks instead of two. From the low number of correct estimations it will be seen that these sets were not successful, therefore it was decided to begin at a much slower rate of speed and increase by steps carrying the process as far as possible. The table is similar in form

Table VI

No.	C_3	G_3	C_4	Records.	P.
82.	0.68	1.02	1.36	$\underline{G}$ $\underline{C_4}$ $\underline{G}$ $\underline{C_3}$ $\underline{C_4}$ $\underline{G}$ $\underline{C_4}$ $\underline{G}$ $\underline{C_3}$ G	
				G $\underline{G}$ C_3 $\underline{G}$ G $\underline{C_3}$ C_4 $\underline{G}$ G $\underline{C_3}$	30
83.	"	"	"	$\underline{G}$ $\underline{C_3}$ $\underline{C_4}$ $\underline{C_3}$ C_3 G $\underline{C_4}$ $\underline{G}$ $\underline{G}$ $\underline{C_3}$	
				$\underline{C_3}$ C_3 $\underline{G}$ $\underline{C_4}$ C_4 $\underline{G}$ $\underline{C_4}$ C_3 $\underline{C_3}$ $\underline{C_4}$	25
84.	"	"	"	C_4 $\underline{G}$ $\underline{C_3}$ $\underline{C_3}$ C_3 $\underline{G}$ C_4 $\underline{C_3}$ $\underline{G}$ $\underline{C_3}$	30

to table V and will explain itself.

In table VII the speed was lowered and a new series begun with the same three forks, the rate of speed being such as to give 1.32, 1.98, and 2.64 vibrations of the forks C_3, G_3, and C_4. These values were cut down by successive steps until in sets 91 and 92 the vibrations transmitted were .97, 1.45 and 1.94 for the C_3 C_3 and C_4 forks respectively, during which there was a marked preponderance of correct over incorrect estimations. Considering the estimations as a matter of chance, since there are three forks, the probility is that $33\frac{1}{3}$% of them would be correct, so that if in estimating the percentage falls

Table VII.

No.	C_3	G_3	C_4	Records	P.
85.	1.32	1.98	2.64	$\underline{C_3}\ C_4\ \underline{G}\ \underline{C_4}\ C_4\ C_4\ \underline{C_3}\ C_3\ C_3\ G$	
				$C_4\ C_4\ \underline{G}\ \underline{C_4}\ \underline{C_3}\ \underline{G}\ C_4\ \underline{C_3}\ C_4\ C_3$	55
86.	1.31	1.96	2.62	$C_3\ \underline{G}\ C_4\ G\ C_4\ \underline{G}\ \underline{C_3}\ G\ C_3\ \underline{C_4}$	
				$C_4\ C_3\ G\ C_4\ C_4\ C_3\ G\ \underline{C_3}\ C_3\ C_4$	75
87.	1.06	1.59	2.12	$C_4\ \underline{G}\ G\ G\ C_3\ \underline{G}\ \underline{G}\ \underline{C_3}\ \underline{G}\ C_4$	
				$G\ C_3\ G\ \underline{C_3}\ C_4\ C_4\ \underline{C_3}\ C_4\ \underline{G}\ C_3$	60
88.	1.04	1.56	2.08	$\underline{G}\ C_3\ C_4\ C_4\ \underline{C_3}\ \underline{C_3}\ \underline{G}\ \underline{C_4}\ C_3\ C_4$	
				$G\ \underline{G}\ G\ \underline{C_3}\ G\ C_3\ \underline{C_3}\ C_3\ C_4\ \underline{C_3}$	55
89.	"	"	"	$C_3\ C_4\ \underline{G}\ \underline{C_3}\ \underline{G}\ C_3\ \underline{G}\ C_3\ \underline{G}\ \underline{C_3}$	
				$C_3\ G\ G\ C_3\ \underline{C_3}\ G\ C_4\ \underline{G}\ C_3\ G$	60
90.	"	"	"	$C_4\ C_3\ C_4\ G\ G\ C_4\ C_3\ C_3\ C_4\ G$	100
91.	0.97	1.45	1.94	$C_3\ C_3\ \underline{G}\ C_4\ \underline{C_3}\ G\ C_3\ \underline{C_3}\ \underline{G}\ G$	
				$G\ C_4\ C_4\ \underline{G}\ C_4\ C_3\ \underline{G}\ G\ C_4\ C_3$	70
92.	"	"	"	$C_3\ C_3\ G\ C_4\ \underline{G}\ C_4\ G\ \underline{C_3}\ \underline{C_3}\ C_3$	
				$\underline{G}\ C_3\ C_3\ C_4\ \underline{G}\ C_4\ \underline{G}\ C_4\ \underline{C_3}\ G$	65
93.	0.89	1.33	1.78	$\underline{C_4}\ \underline{G}\ \underline{G}\ \underline{C_3}\ \underline{C_3}\ C_3\ \underline{C_4}\ \underline{C_4}\ \underline{G}\ \underline{C_4}$	
				$\underline{C_3}\ \underline{G}\ \underline{G}\ \underline{G}\ \underline{C_4}\ \underline{C_3}\ \underline{C_3}\ \underline{C_4}\ C_3\ C_3$	15
94.	"	"	"	$C_4\ \underline{C_3}\ G\ \underline{C_3}\ \underline{C_4}\ C_4\ C_3\ \underline{G}\ C_4\ \underline{C_4}$	
				$C_3\ \underline{C_4}\ \underline{G}\ \underline{G}\ \underline{C_4}\ C_4\ \underline{G}\ G\ \underline{C_4}\ C_4$	45

No.	C_3	G_3	C_4	Records.	P.
95.	0.93	1.39	1.86	$\underline{C_3}$ $\underline{C_3}$ G C_4 C_3 C_3 $\underline{G}$ G $\underline{C_3}$ C_3	
				G C_4 C_4 $\underline{C_3}$ C_3 $\underline{G}$ $\underline{C_4}$ $\underline{G}$ $\underline{C_3}$ C_4	55
96.	"	"	"	$\underline{G}$ G C_3 $\underline{C_3}$ C_4 $\underline{G}$ $\underline{C_3}$ C_4 C_4 G	
				$\underline{C_4}$ C_3 $\underline{C_4}$ $\underline{C_4}$ $\underline{C_4}$ $\underline{C_4}$ C_4 C_4 G C_4	55
97.	0.94	1.41	1.88	$\underline{C_3}$ G C_4 $\underline{G}$ C_4 G $\underline{C_3}$ $\underline{G}$ C_3 C_4	
				C_4 $\underline{C_3}$ C_4 $\underline{C_3}$ $\underline{G}$ G C_4 C_3 C_3 G	65
98.	"	"	"	C_3 C_4 G $\underline{G}$ C_3 $\underline{C_3}$ $\underline{G}$ G C_3 C_4	
				G C_4 C_4 $\underline{G}$ C_3 $\underline{C_3}$ C_4 G C_3 C_4	75
99.	0.84	1.26	1.68	$\underline{G}$ C_3 $\underline{C_4}$ G $\underline{G}$ $\underline{G}$ C_3 $\underline{C_4}$ $\underline{C_4}$ $\underline{G}$	
				C_3 $\underline{C_3}$ $\underline{C_4}$ C_3 $\underline{G}$ $\underline{G}$ $\underline{C_3}$ C_4 $\underline{C_3}$ G	35
100.	"	"	"	$\underline{C_3}$ $\underline{C_4}$ $\underline{C_3}$ C_3 $\underline{G}$ $\underline{C_4}$ $\underline{C_4}$ C_3 C_3 $\underline{G}$	
				$\underline{C_3}$ $\underline{C_3}$ $\underline{G}$ $\underline{C_4}$ $\underline{C_4}$ $\underline{C_4}$ C_3 C_3 $\underline{C_4}$ $\underline{C_3}$	25
101.	0.86	1.29	1.72	C_3 $\underline{G}$ $\underline{G}$ $\underline{C_4}$ C_4 C_3 C_4 C_4 G $\underline{C_4}$	
				$\underline{C_3}$ $\underline{G}$ G $\underline{C_3}$ C_4 $\underline{G}$ $\underline{C_3}$ C_3 $\underline{G}$ G	50
102.	"	"	"	$\underline{C_3}$ $\underline{C_3}$ $\underline{G}$ $\underline{C_3}$ $\underline{C_3}$ $\underline{C_3}$ $\underline{G}$ $\underline{G}$ C_4 $\underline{C_3}$	
				$\underline{C_3}$ $\underline{G}$ $\underline{C_3}$ $\underline{C_3}$ $\underline{G}$ C_4 $\underline{C_3}$ $\underline{C_3}$ $\underline{G}$ C_3	15
103.	0.89	1.33	1.78	$\underline{G}$ $\underline{C_3}$ C_4 C_3 $\underline{C_3}$ $\underline{G}$ C_4 G G $\underline{G}$	
				C_3 C_3 $\underline{C_3}$ $\underline{C_4}$ G $\underline{C_3}$ $\underline{C_3}$ C_4 $\underline{C_3}$ G	50

in a marked degree higher than that amount, we should accept the set as evidence that the brief pulses of sound were actually distinguishable by comparison. In the drop from set 92 to set 93, we find the ear was not sufficiently sensitive to distinguish satisfactorily between the different forks. The speed was lowered again in sets 95 and 97 when the forks again became distinguishable. In set 99 the speed was again raised to a greater amount than in set 93 when the identity of the pitches again became lost. A slight increase in the number of vibrations transmitted served to nearly restore this identity but sets 101, 102 and 103 are by no means conclusive since the great falling off in percentage of set 102 demonstrates that the recognition of the tones was established on no firm basis. There is one factor influencing the results which has not been mentioned but which unavoidably modifies them in a large degree. This is the natural fatigue of the ear, which, after the effort engendered by the continual strain of several successive series of observation, becomes insensible to the refinements of hearing necessitated by the experiment. Thus sets 99 and 100 were made at the end of several hours of similar work, so that had the ear not been overtaxed, better results might reasonably have been expected. Table VII certainly shows that with considerably less than two complete vibrations, pitches such as those employed may be termed recognizable by comparison.

The following table, VIII was made with three forks not bearing to each other such simple ratios as those previously used. It was thought that this element might introduce a new difficulty in distinguishing the pitches, but this was evidently not the case if this conclusion may be drawn from the only set which was made. The forks used were the c_3, the $G\flat_3$ (372 vib) and the A_3 (432 vib.) Since it was found that it involved no more difficulty than in distinguishing between the c_3, G_3 and c_4

Table VIII.

No.	C_3	$F_3^\#$	A_3	Records.	P.
104.	0.97	1.41	1.64	$\underline{C_3}$ $F^\#$ $\underline{F^\#}$ A A $\underline{F^\#}$ $\underline{A}$ $F^\#$ C_3 A	
				C_3 C_3 A $F^\#$ $F^\#$ $\underline{C_3}$ $\underline{F^\#}$ A C $F^\#$	170

forks, it was not thought necessary to extend the table.

From an examination of Table IX it might appear to be a step backwards from table V since the sets are of the same nature but with a greater number of vibrations transmitted. These sets, which are made upon two forks only, were carried along parallel to those of table VII, and were taken whenever the observer in making table VII became confused as to the identity of two particular forks, while taking a set on three. Thus in set 95 of table VII some confusion existed between the forks c_3 and c_4 so a set on these two was taken, this being set 110 of table IX. The series in this table then may be

Table IX.

No.	C_3	G	C_4	Records	P.
105.	1.31	1.96	—	$C_3\ C_3\ \underline{G}\ G\ G\ \underline{G}\ G\ G\ C_3\ G$	80
106.	1.04	1.56	—	$C_3\ C_3\ G\ G\ C_3\ G\ C_3\ C_3\ C_3\ G$	
				$C_3\ G\ G\ C_3\ C_3\ C_3\ G\ G\ C_3\ G$	85
107.	—	1.56	2.08	$G\ G\ G\ C_4\ C_4\ G\ C_4\ C_4\ \underline{G}\ G$	90
108.	0.97	1.45	—	$\underline{C_3}\ C_3\ G\ \underline{C_3}\ C_3\ G\ C_3\ \underline{G}\ \underline{G}\ \underline{C_3}$	50
109.	0.97	1.45	—	$\underline{C_3}\ \underline{C_3}\ \underline{C_3}\ G\ C_3\ \underline{C_3}\ C_3\ C_3\ \underline{G}\ \underline{G}$	40
110.	0.93	—	1.86	$C_4\ C_4\ C_3\ C_4\ C_3\ C_3\ \underline{C_4}\ C_3\ C_4\ C_4$	90
111.	—	1.39	1.86	$\underline{G}\ C_4\ G\ C_4\ G\ \underline{G}\ G\ C_4\ C_4\ G$	80
112.	0.93	1.39	—	$\underline{G}\ C_3\ G\ C_3\ \underline{C_3}\ G\ \underline{C_3}\ C_3\ \underline{G}\ G$	60
113.	0.93	1.39	—	$C_3\ C_3\ \underline{G}\ G\ \underline{C_3}\ \underline{G}\ G\ C_3\ \underline{C_3}\ G$	60
114.	0.89	1.33	—	$C_3\ \underline{G}\ \underline{G}\ \underline{C_3}\ \underline{G}\ G\ G\ \underline{C_3}\ G\ \underline{G}$	40
115.	0.89	1.33	—	$\underline{G}\ \underline{C_3}\ \underline{C_3}\ G\ C_3\ \underline{G}\ C_3\ G\ G\ C_3$	60
116.	0.72	1.08	—	$C_3\ C_3\ \underline{G}\ \underline{C_3}\ C_3\ G\ G\ \underline{C_3}\ \underline{C_3}\ C_3$	60
117.	0.72	1.08	—	$G\ \underline{C_3}\ C_3\ G\ \underline{G}\ \underline{C_3}\ \underline{G}\ C_3\ C_3\ G$	60

regarded in the light of practice sets, as no striking features or new results are brought forward. The poor results of sets 108, 109 and 114 may be ascribed to fatigue of the ear.

A new method of study was now pursued. This consisted in naming or endeavoring to name, with a limited number of vibrations, the actual interval between various forks, in the following manner. The transmittor took six forks, C_3 (256 vib.), D_3 (288 vib.), E_3 (320 vib.), $F_3^{\#}$ (364 vib.), G_3 (384 vib.) and C_4 (512 vib.) with which it was possible to form ten intervals, these being the minor second, major second, minor and major third, perfect fourth, diminished and perfect fifth, minor sixth and seventh, and the octave. The abbreviations for these intervals as used in Table X are as follows:- min 2, maj 2, min 3, maj 3, perf 4, dim 5, perf 5, min 6, min 7, oct. The sets were made as follows,- no preliminary signals were given and the listener had no forks for comparison. Each interval was transmitted by striking first one of the forks composing it, then the other. This operation was then repeated and the next interval given twice in a like manner. This was continued until the set was complete. Each set consisted in all of ten intervals sent in any order or with any duplications the transmitter might see fit. In exceptional cases, longer or shorter

Table X.

No.	C_3	D_3	E_3	$F^{\#}_3$	G_3	C_4	Records.	P.
118.	4.33	4.87	5.41	6.15	6.49	8.66	Oct - dim 5 - min 3 - min 6 - min 6	
							min 3 - perf 5 - min 3 - maj 3 - dim 5	70
119.	"	"	"	"	"	"	min 3 - dim 5 - min 7 - oct - perf 5	
							perf 4 - min 6 - min 3 - perf 4 - perf 4	90
120.	"	"	"	"	"	"	perf 4 - maj 3 - dim 5 - perf 5 - min 6	
							perf 4 - min 7 - min 3 - min 7 - perf 4	90
121.	4.00	4.50	5.00	5.68	6.00	8.00	Oct - min 3 - min 7 - maj 3 - perf 4	
							perf 4 - perf 5 - min 6 - min 7 - perf 4	90
122.	"	"	"	"	"	"	perf 5 - dim 5 - min 7 - maj 3 - perf 4	
							min 6 - min 3 - oct - perf 4 - min 7	100
123.	"	"	—	—	—	"	min 7 - min 7 - oct - min 7 - oct	
							oct - oct - oct - min 7 min 7	100
124.	3.72	4.18	4.65	5.29	5.58	7.44	maj 2 - min 7 - oct - maj 3 - dim 5	
							perf 5 - perf 4 - dim 5 - maj 2 - min 3	50
125.	"	"	"	"	"	"	min 7 - min 3 - oct - min 6 - dim 5	
							maj 2 - min 2 - min 6 - perf 5 - dim 5	40
126.	"	"	"	"	"	"	min 3 - perf 5 - min 7 - oct - min 2	
							oct - maj 3 - dim 5 - perf 4 - maj 2	80

No.	C_3	D_3	E_3	$F^{\#}_3$	G_3	C_4	Records	P.
127.	3.72	4.18	4.65	5.29	5.58	7.44	min 3 - maj 2 - perf 5 - dim 5 - min 7	
							oct - min 7 - maj 3 - maj 2 - dim 5	60
128.	3.52	3.96	4.40	5.00	5.28	7.04	maj 2 - min 7 - min 3 - min 6 - dim 5	
							min 2 - dim 5 - min 7 - oct - maj 2	60
129.	"	"	"	"	"	"	perf 4 - dim 5 - oct - min 7 - min 3	
							maj 3 - min 7 - perf 5 - maj 3 - maj 2	40
130.	"	"	"	"	"	"	perf 4 - min 7 - min 7 - min 3 - min 6	
							dim 5 - oct - perf 5 - min 7 - maj 2	60
131.	"	"	"	"	"	"	maj 3 - dim 5 - perf 4 - perf 5 - min 2	
							dim 5 - maj 2 - maj 2 - min 6 - min 7	70
132.	"	"	"	"	"	"	maj 2 - maj 2 - maj 3 - maj 2 - min 3	
							min 2 - maj 2 - min 2 - perf 4 - min 6	70
133.	3.39	3.81	4.24	4.82	5.08	6.78	dim 5 - perf 4 - oct - min 7 - min 3	
							min 2 - min 7 - dim 5 - maj 3 - maj 2	60
134.	"	"	"	"	"	"	maj 2 - dim 5 - min 3 - min 6 - dim 5	
							min 7 - min 6 - min 2 - oct - maj 2	60
135.	3.19	3.57	3.98	4.53	4.78	6.38	maj 2 - perf 5 - min 6 - min 7 - maj 3	
							dim 5 - min 3 - oct - perf 4 - min 2	100
136.	"	"	"	"	"	"	min 7 - oct - maj 3 - min 2 - maj 2	
							maj 2 - min 6 - perf 5 - dim 5 - oct	50

No.	C_3	D_3	E_3	$F^{\#}_3$	G_3	C_4	Records.	
137.	3.19	3.59	3.98	4.53	4.78	6.38	dim 5 - maj 2 - min 3 - maj 2 - maj 2	
							dim 5 - oct - perf 4 - min 7 - oct	50
138.	2.97	3.34	3.71	4.22	4.45	5.94	min 2 - min 7 - dim 5 - perf 5 - maj 2	
							min 7 - oct - maj 2 - maj 3 - perf 4	
							maj 3 - min 6 - maj 3 - min 7 - maj 2	
							oct - maj 3 - oct - min 2 - perf 4	60
139.	"	"	"	"	"	"	min 3 - perf 5 - dim 5 - oct - min 2	
							min 7 - oct - maj 2 - perf 5 - perf 4	60
140.	2.74	3.08	3.42	3.89	4.11	5.48	maj 2 - maj 2 - min 7 - oct - min 2	
							perf 4 - min 7 - dim 5 - min 7 - maj 3	
							min 3 - maj 2 - perf 4 - perf 5 - oct	
							maj 3 - min 7 - oct - min 3 - maj 2	60
141.	2.53	2.85	3.16	3.59	3.79	5.06	perf 4 - min 7 - maj 3 - min 6 - min 2	
							oct - dim 5 - maj 2 - oct - min 3	60
142.	"	"	"	"	"	"	maj 2 - dim 5 - maj 2 - perf 5 - oct	
							oct - min 7 - min 2 - perf 4 - min 3	80
143.	2.21	2.48	2.76	3.14	3.31	4.42	min 3 - oct - maj 2 - perf 4 - min 6	
							min 2 - dim 5 - perf 5 - min 6 - perf 5	60
144.	"	"	"	"	"	"	min 2 - dim 5 - perf 5 - min 7 - oct	
							maj 3 - maj 2 - min 7 - min 3 - min 6	50

No.	C_3	D_3	E_3	$F^{\#}_3$	G_3	C_4	Record	P.
145.	1.85	2.08	2.31	2.63	2.77	3.70	maj 3 - maj 2 - perf 4 - min 7 - maj 3	
							min 6 - oct - min 3 - min 3 - min 7	20
146.	"	"	"	"	"	"	oct - min 6 - maj 3 - min 7 - perf 4	
	"	"	"	"	"	"	min 7 - perf 5 - dim 5 - min 3 - perf 5	30
147.	"	"	"	"	"	"	min 6 - min 7 - oct - min 3 - maj 3	
							perf 5 - oct - dim 5 - maj 2 - maj 2	30
148.	2.09	2.35	2.61	2.97	3.13	4.18	oct - min 2 - maj 3 - maj 2 - min 7	
							maj 2 - min 7 - dim 5 - perf 4 - perf 5	60
149.	"	"	"	"	"	"	min 7 - maj 2 - min 7 - min 3 - maj 2	
							oct - perf 4 - min 7 - maj 3 - perf 5	30
150.	"	"	"	"	"	"	min 6 - oct - oct - perf 5 - oct	
							min 6 - maj 3 - maj 2 - min 3 - min 2	40

sets were made. In table X which gives the results of these experiments, the columns headed C_3, D_3, E_3 $F^{\#}_3$ G_3 and C_4 give for the fork corresponding, the number of complete vibrations transmitted, during the particular set opposite which these values are found. Erroneous estimations as in previous sets, are underlined. The last column, P. gives the percentage of correct estimations. In order to transmit the requisite number of vibrations for these expiriments, at a convenient speed of the wheel, it was found necessary to construct a second one. In this wheel the radius was 6.26 cm. and the length of the insulating sector 1.10 cm.

It was found that the listener

frequently confused the octave and the minor seventh, so a set was made upon only these two intervals, (set 123) which resulted in a percentage of 100. It is not necessary that the percentage of correct estimations should be largely in excess of 50% as in certain of the previous sets, in order to show that the intervals were actually distinguishable, for had the results been due to chance alone, about 10% correct is all that could be expected, since there are ten intervals employed. While it is true that each interval is transmitted twice, the listener has the privilege of only one estimation upon it. An examination of the table will show however, that until set 145 is reached, in nearly every case was the percentage of correct estimations either 50% or above that amount. The falling off in percentage from set 135 to sets 136 and 137 is due to the fact that during the two latter sets the speed of the motor rose unaccountably to a speed largely in excess of its value during set 135. The amount of this rise was however unknown. Sets 145, 146 and 147 were evidently beyond the power of the listener. Set 148 gave good results, which might have been sustained in sets 149 and 159 but for fatigue.

It is a curious and striking fact that while with less than one vibration, the listener could, by the aid of duplicate forks, distinguish with considerable readiness between several pitches, yet without the aid of such forks he was unable to recognize the true interval between these pitches, even when, in the latter case, two or three whole vibrations were transmitted. This will be seen from an examination of sets 97 and 98 of table VII and sets 145 to 147 table X. The component pitches of the unrecognizable intervals appeared to be clear and distinct in most cases so that well defined intervals were thought to be heard, but from the results of those sets just mentioned, it appears that these are not identical with the intervals really transmitted. It can scarcely be thought that with several whole vibrations, the observed phenomena of reversal of pitch could occur, when with less than one complete vibration as in table VII, those pitches retained their identity. As a matter of fact, the mistakes in recognizing intervals were seldom very great. For example; the minor seventh and the octave were frequently confused, but not when given in a set by themselves. Likewise the major second and minor third could not always be distinguished, or a minor sixth and a diminished fifth, but it was only occasionally that a third would be mistaken for a fifth, or a sixth for an octave, and then the confusion arose in almost all cases among the lower forks, that is, those giving at that particular speed, the least number of vibrations. When the ear was somewhat fatigued the listener found that he could without effort, convince himself that he was hearing any one of the three lower forks used, i.e. the C, D or E provided one of these three was actually being transmitted. Under these conditions it was of course impossible to achieve good results.

Another curious phenomena was observed in the experiments on distinguishing two forks by comparison. It will be seen by comparing tables V and IX that frequently better results were obtained with less than with more vibrations transmitted. There seemed to be no reason for this apparent discrepancy since the ear was as well or better practised in making table IX than when table V was made. To test this matter a repetition of sets 108, and 109 table IX was made the results of which are given in table XI. From the satisfactory results there obtained we think that undoubtedly recognition becomes easier with the transmission of more vibrations, and that sets 108 and 109 were accidental departures from normal results.

In regard to the least number of vibrations necessary to determine pitch, these experiments would indicate that there is no definite limit, that it depends upon the ear of the individual, how far he may carry the recognition of pitch. The phenomena of reversal apparently occurs at no definite point, this

Table XI.

No.	C_3	G_3	Records.	P.
151.	0.97	1.45	$C_3 \underline{C_3} G\ C_3G\ C_3\ \underline{C_3}\ \underline{G}.\ \underline{G}\ \underline{C_3}$	50
152.	"	"	$C_3\ \underline{G}\ G\ \underline{C_3}\ \underline{C_3} G\ C_3G\ C_3\ C_3$	70
153.	"	"	$G\ C_3\ \underline{C_3}\ C_3C_3\ \underline{C_3}\ \underline{C_3}\ \underline{G}\ C_3G.$	60

being but a factor in the personal equation of the experimenter.