Experimental Studies on the Sound of A Japanese Hanging Fire-Bell

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Experimental Studies on the Sound of A Japanese Hanging Fire-Bell

By

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Abstract

The present paper describes the experimental investigation of the tone colour of a small Japanese hanging bell. The sounds were recorded by a Low-Hilger audiometer, and the curves obtained were analysed by the method of periodogram-analysis. Generally speaking, the sound of the bell used in the experiment contains about five partial tones, and the ratios of their amplitudes change as the time passes after it is struck.

§ 1. Introduction.

The nature of the sound of European church-bells has been studied by many physicists[1]. But so far as the writer knows that of Japanese bells has not yet been studied. The temple-bells in Japan and China are somewhat different from those in Europe in their form and material. Also the method of striking is different. In order to study the nature of the sound of Japanese bells, the writer took a miniature temple-bell, which is now used for the announcement of the opening of temple ceremonies and formerly was used as a fire-alarm too, as the object of his preliminary investigation.

§ 2. The structure of the bell.

A photograph of the bell used in this experiment and its vertical

1. J. Biehle: Archiv f. Musikwiss., 1ster Jahrg., 289 (1919)
J. Biehle: Die Bewertung der Bronze und Gussstahlglocken (1918)
J. Biehle: Phys. Zeits., **22**, 337 (1921)
A. T. Johnes: Phys. Rev., **16**, 247 (1920)
A. T. Johnes: Phys. Rev., **31**, 1092 (1928)
F. G. Tyzzer: Journal of Franklin Institute, **210**, 55 (1930)

cross-section with dimensions are shown in Fig. 1 and Fig. 2.

Fig. 1

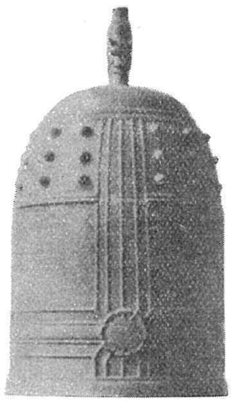
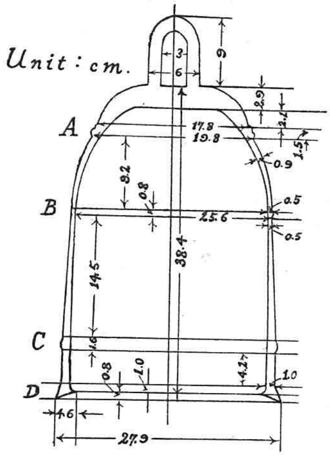


Fig. 2



The upper part AB of the bell is usually called "Ibonomachi (studded portion)", as it has many studs on its outer side for ornamentation. The meridian section of this part, as seen in Fig. 1, consists of two circular arcs. But as their centres are not on the axis of the bell, its surface is not spherical.

The middle part BC of the bell is called "Ikenomachi (pond portion)". This part is rather thin and its surface is nearly vertical, the thickness decreasing gradually from the mouth to this point. It is said that this part must be made as thin as possible, but not so much so that the bell will break when it is struck.

The lowest part CD is called "Kusanomachi (grass portion)", and is also nearly vertical and cylindrical like the middle part. But this portion is made thicker and its lowest edge particularly is made very thick. In the case of a large temple-bell, the centre of mass is situated a little above the dividing line between Ikenomachi and Kusanomachi.

There is a belt-shaped thick part between Ikenomachi and Kusanomachi on the outside, having two small circular flat projections on its opposite sides, which are called "Tsukiza (striking seat)". Either of these flat projections is struck with a heavy wooden clapper from the outside to ring the bell.

The total weight of the bell examined is 19 kg., the calibre is 28 cm., and its height is nearly 40 cm. The bell is composed of copper and zinc in the ratio Cu 10 : Zn 1.5.

§ 3. Apparatus.

We used for this experiment a Low-Hilger audiometer. This instrument is often said to have the fault that there is a resonance effect in its diaphragm. We examined it with tuning forks, however, and found that this effect was tolerably small in the frequencies under this investigation.

§ 4. Experimental data.

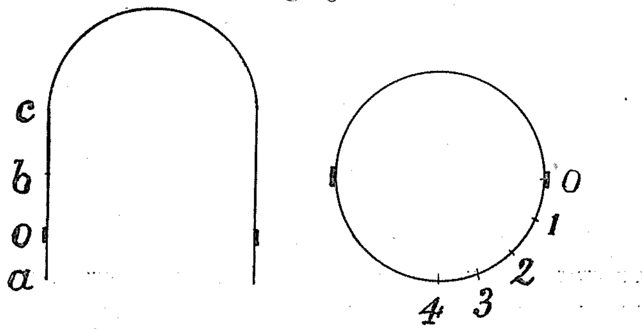
By striking one of the Tsukiza marked o in Fig. 3, we obtained the photograph shown in Pl. I. This plate shows the variation of the wave-form as the time passed after the striking.

Pl. II, Fig. 1—Fig. 6 show the wave-forms obtained by striking different positions on the belt-shaped part $(90/4)^{\circ}$ from each other, marked 2, 3 and 4 in Fig. 3. The number of plates and figures, the points struck and the lapse of time between the beginning of the curves and the striking of the bell are shown in the annexed table and Fig. 3.

	Point struck	Time elapsed	
Plate I, Fig. 1	o	o sec.	not analysed
" Fig. 2	o	0.3 sec.	analysed
" Fig. 3	o	0.5 sec.	"
" Fig. 4	o	1.0 sec.	"
" Fig. 5	o	1.5 sec.	"
" Fig. 6	o	3.0 sec.	"
Plate II, Fig. 1	1	1.0 sec.	analysed at two parts
" Fig. 2	1	1.5 sec.	not analysed
" Fig. 3	1	3.0 sec.	"
" Fig. 4	2	1.5 sec.	analysed
" Fig. 5	3	1.5 sec.	analysed at two parts
" Fig. 6	4	0.5 sec.	analysed
" Fig. 7	*a*	1.0 sec.	analysed
" Fig. 8	*a*	1.5 sec.	not analysed
" Fig. 9	*b*	1.0 sec.	analysed
" Fig. 10	*b*	1.5 sec.	not analysed
" Fig. 11	*c*	1.0 sec.	analysed
" Fig. 12	*c*	1.5 sec.	not analysed

In some of these photographs, we find beats. It can easily be supposed that these beats are caused by the existence of the two "Tsukiza", which act as additional masses to the body.

Fig. 3



Pl. II, Fig. 7—Fig. 8 were obtained by striking different parts along the meridian which contains the "Tsukiza". The centre of mass of the bell is situated on the horizontal line passing through *B* in Fig. 2.

Fig. 1—Fig. 6 in Pl. I were obtained by changing the interval between the striking of the "Tsukiza" and the opening of the shutter. In these plates, we see that the frequencies of the partial tones do not change, but only the ratios of their amplitudes change, and the same wave-form is repeated every 39 fundamental waves, as shown by *a*, *b*, *c* in the plates.

§ 5. Method of analysing.

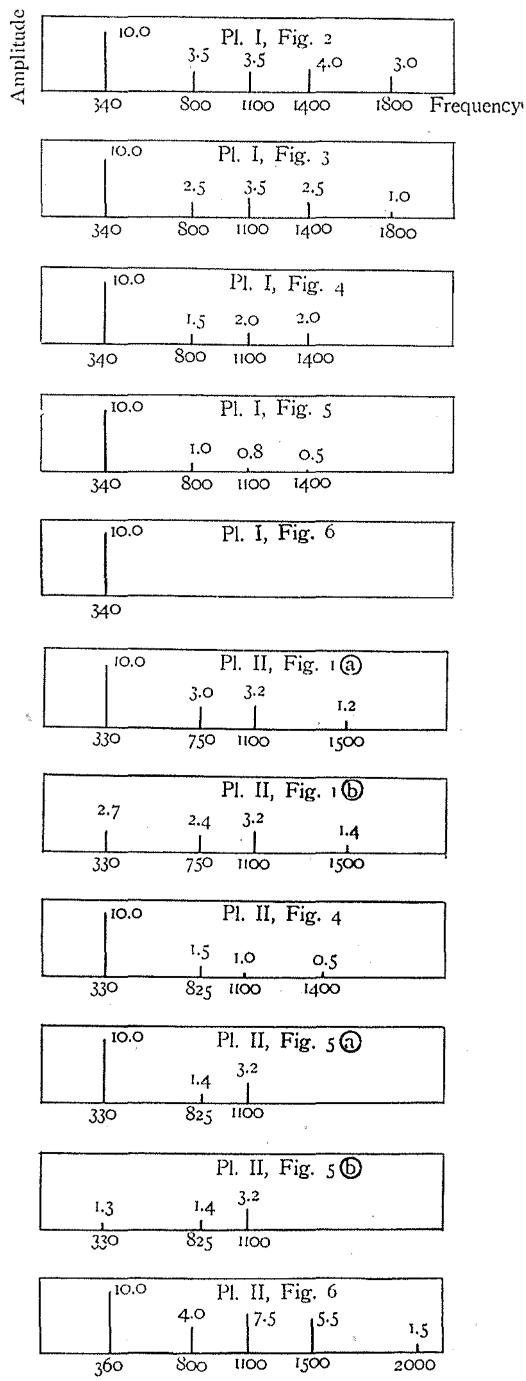
Since, as is well known, the component-frequencies of the vibrations of a bell are not harmonic, we can not apply the ordinary method of Fourier's analysis to our curves to get their component sine-curves. Therefore we used the periodogram analysis[1]. Having found one period and its amplitude, we can draw a sine-curve with the period and amplitude found. Then subtracting this curve from the original one, we get a new curve. With this new curve we find another period and its frequency. Continuing this process, we can find the remaining components. This method is very tedious and the result thus obtained is naturally not so accurate as those that can be obtained by the ordinary Fourier method.

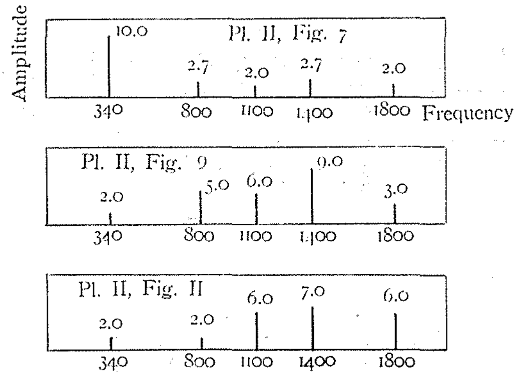
§ 6. Results.

The results of the periodogram analysis are shown in the following diagram.

The conclusions obtained from these results are as follows:

1. Whittaker and Robinson: "The calculus of observations". pp. 343-360.
Carse and Shearer: Edinburgh Mathematical Tracts. No. 4.


Amplitude
Frequency
Pl. I, Fig. 2
10.0 3.5 3.5 4.0 3.0
340 800 1100 1400 1800
Pl. I, Fig. 3
10.0 2.5 3.5 2.5 1.0
340 800 1100 1400 1800
Pl. I, Fig. 4
10.0 1.5 2.0 2.0
340 800 1100 1400
Pl. I, Fig. 5
10.0 1.0 0.8 0.5
340 800 1100 1400
Pl. I, Fig. 6
10.0
340
Pl. II, Fig. 1ⓐ
10.0 3.0 3.2 1.2
330 750 1100 1500
Pl. II, Fig. 1ⓑ
2.7 2.4 3.2 1.4
330 750 1100 1500
Pl. II, Fig. 4
10.0 1.5 1.0 0.5
330 825 1100 1400
Pl. II, Fig. 5ⓐ
10.0 1.4 3.2
330 825 1100
Pl. II, Fig. 5ⓑ
1.3 1.4 3.2
330 825 1100
Pl. II, Fig. 6
10.0 4.0 7.5 5.5 1.5
360 800 1100 1500 2000



(i) From Pl. I, we see that the fundamental tone (frequency = 340) always has the greatest amplitude. In Fig. 2, the 4th partial (frequency ≒ 1400) has the 2nd greatest amplitude. In Fig. 3 and Fig. 4, the 3rd partial, and in Fig. 5 the 2nd partial has the 2nd greatest amplitude. This shows that among the overtones the highest one predominates immediately after the bell is struck, but it quickly damps away and the next highest one takes its place and so on. And after 3sec., the overtones entirely vanish, and the fundamental tone only continues to exist.

(ii) Pl. II. Fig. 7—Fig. 12 show that higher overtones become intensified as the point struck changes from the lower to the upper part.

(iii) Pl. II. Fig. 1—Fig. 6 show that the beat appears in the fundamental tone as we strike 1 or 3 in Fig. 3. This fact coincides with the classical theory of Helmholtz and Rayleigh.

In conclusion the writer wishes to express his great obligation to Professor Tamaki for his valuable instruction and guidance in this experiment.

Plate I

Fig. 1

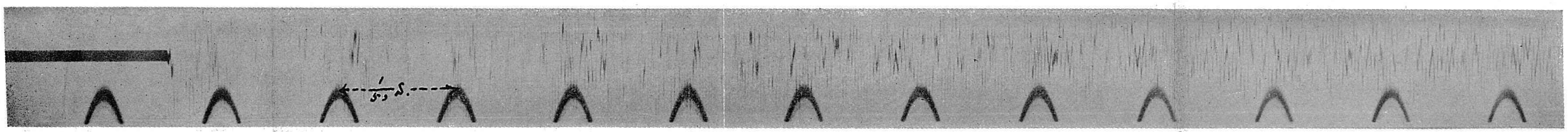


Fig. 2

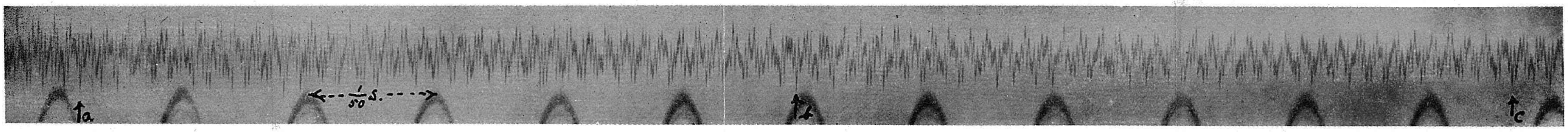


Fig. 3

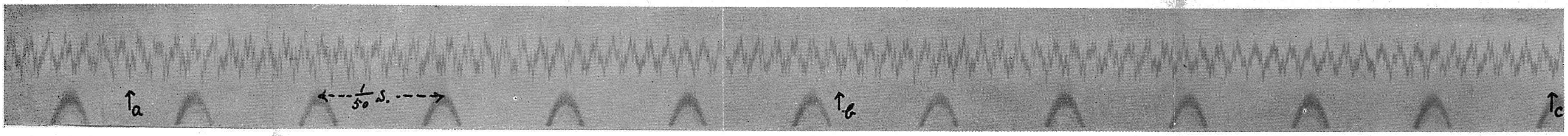


Fig. 4

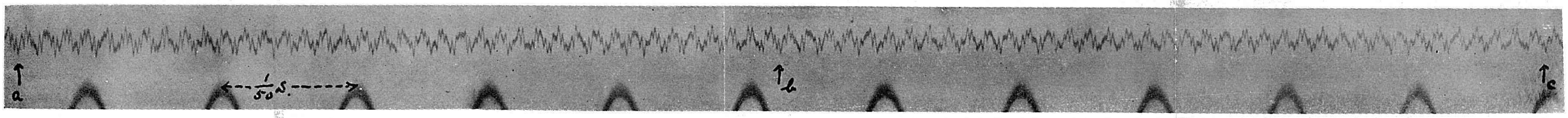


Fig. 5

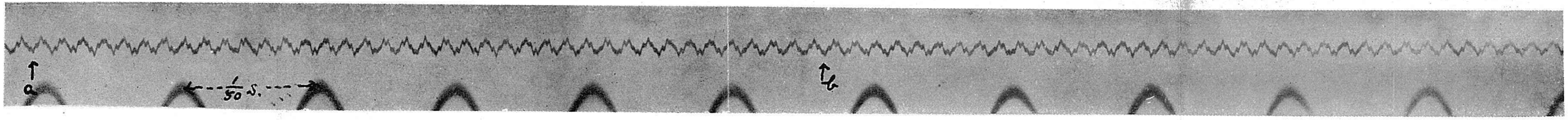


Fig. 6

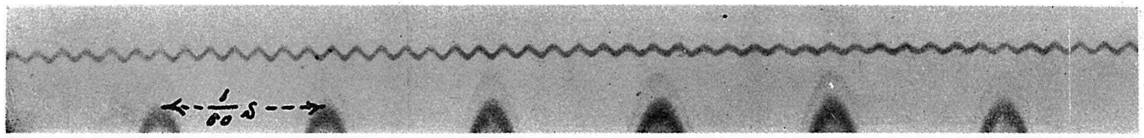


Plate II

Fig. 1

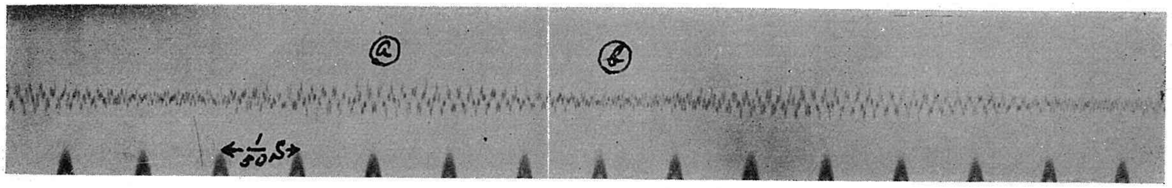


Fig. 2

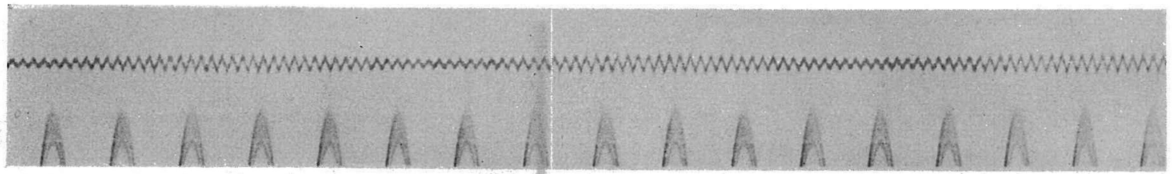


Fig. 3

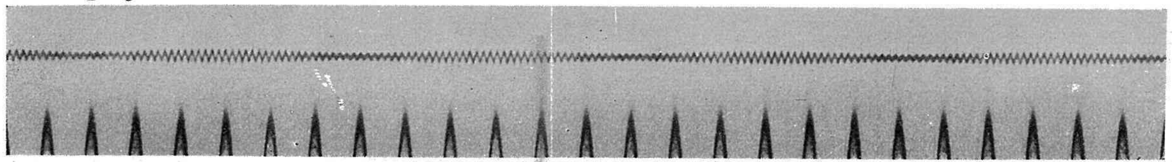


Fig. 4

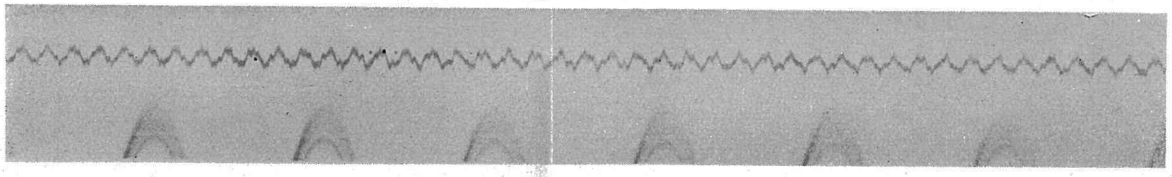


Fig. 5

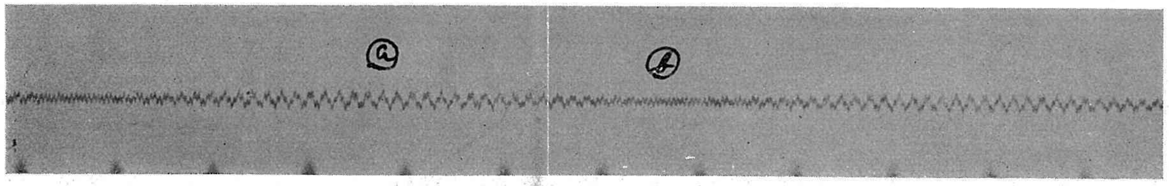


Fig. 6

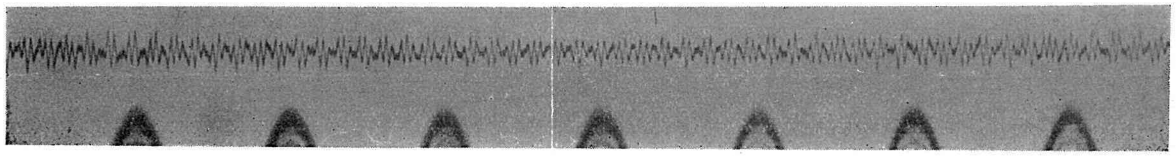


Fig. 7

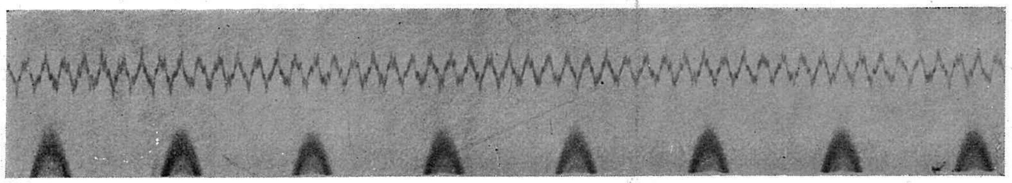


Fig. 8

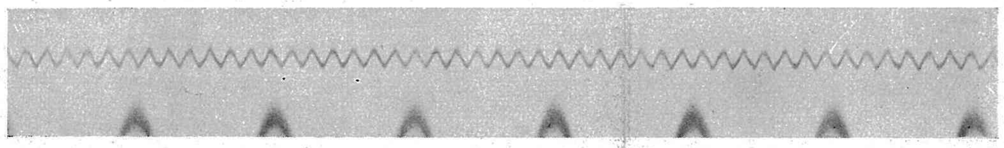


Fig. 9

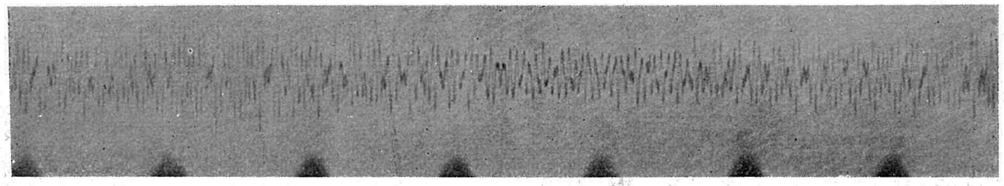


Fig. 10

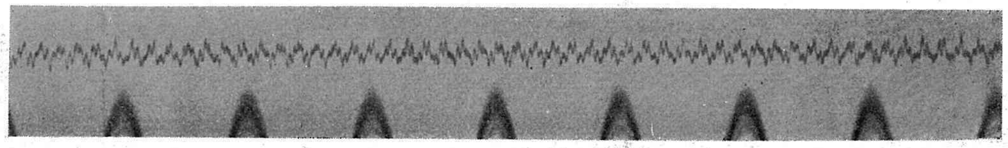


Fig. 11

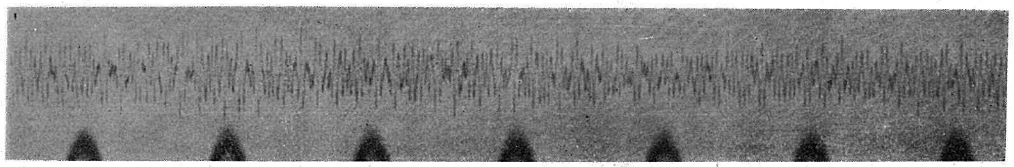


Fig. 12